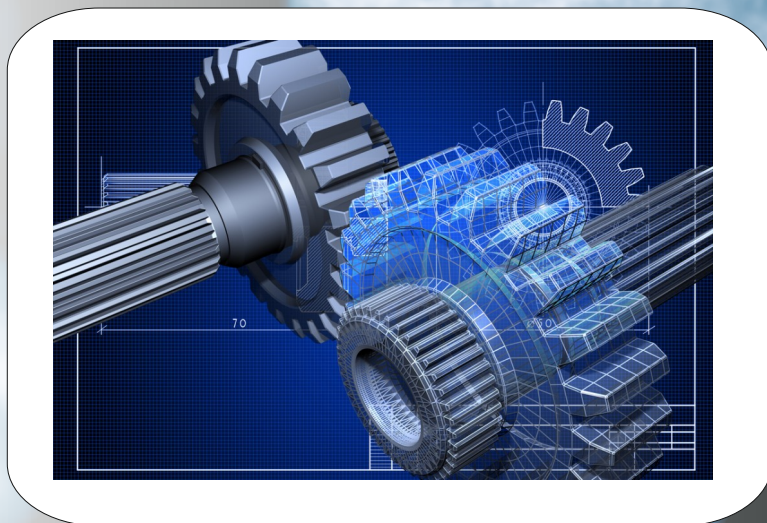


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TEXTURE CONTROL IN PIPELINE STEELS BY THERMO-MECHANICAL CONTROL PROCESSING

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Abstract: The texture evolution in pipeline steel is studied as a function of the thermo-mechanical processing parameters –rolling temperature and cooling rate after the finish rolling stage carried out with equal rolling reduction per pass.. The austenite recrystallization and grain growth during thermo-mechanical control processing (TMCP) of a pipeline steel grade are described and analysed in terms of precipitation state progress. Two stage controlled rolling (roughing and finishing) was carried out on a laboratory rolling mill for a set of completed and interrupted schedules. Subsequent to rolling, two different cooling routes were used water quenching and accelerated water cooling (ACC) together with coiling simulation. From the combination of transmission electron microscopy (TEM) observations, detailed texture analysis and inductively coupled plasma-mass spectroscopy (ICPMS) precipitates quantification, consistent correlations between precipitation state and microstructure at every stage of TMCP can be recognized. The formation of specific transformation textures was explained via appropriate texture models that describe both formation of transformation and recrystallization textures in the austenite.

Keywords: PIPELINE STEEL, PROCESSING, MICROSTRUCTURE, TEXTURE

1. Introduction

Many sources of oil and natural gas are situated in regions with extremes of temperatures varying from -80°C to 20°C. This put severe requirements to the pipeline steels from which pipelines are made. The requirements as high fracture toughness at low temperatures and strength in combination with excellent weldability and high thickness of the plates are only part of them which allow them operating under high pressure at low temperatures [1, 2]. Such desired combination of properties is obtained successfully in high strength low alloy (HSLA) steels by combining of appropriate alloying strategy with thermo-mechanical control processing (TMCP). After TMCP the pipeline steel has microstructures containing ferrite and small fractions of pearlite (for the low strength and toughness grades), various types of bainitic ferrite in combinations with martensite /austenite islands (MA) or low carbon martensite and bainite for very high strength grades. The desired combination of high strength and toughness in these steels is obtained mainly via significant grain refinement and precipitation strengthening. Large deformation imposed to the material on its way from slab to plate provides significant microstructural and crystallographic textures and as a result, anisotropy of the majority of mechanical properties. Relationships between plastic anisotropy and crystallographic texture are well-described [3], but at least they should be combined with microstructure morphology data to give sound results for TMCP steels [4,5,6]. The toughness anisotropy is more difficult to be linked with the texture beyond the dependency of the transition temperature on the fraction of cleavage planes parallel to fracture surface in a certain direction of testing [6]. The current work studies the possibilities for texture control during the TMCP of pipeline steels.

2. Experimental

Blocks of 75 mm thickness, 95 mm length and 160 mm width were cut from cast slabs of HSLA steel whose chemical composition is shown in Table 1. The blocks were hot rolled in 2-high laboratory rolling mill (roll diameter, 400mm) in two steps - rough rolling and finish rolling. All specimens were reheated at 1250 °C for 2h and hot rolled to 12mm thick plates with a final rough rolling temperature 1180 °C above the calculated austenite non-recrystallization temperature (T_{nr}). Different schedules were designed and carried out by maintaining identical roughing conditions

but varying the process parameters of the finish rolling, namely, the temperature of the first rolling denominated as “start finish rolling temperature” (SFRT), end rolling temperature (ERT) and cooling rates. To study the changes in microstructure and texture part of the samples were quenched after the end of the rolling schedule and the other part were accelerated cooled to 560°C and next coiling simulation was made. The rolling schedules are shown schematically in Fig. 1. All final rolling schedules were executed with a constant reduction per pass.

Table1. Chemical composition of the steel, (in mass %)

C	Mn	P	S	Nb+V+Ti	Mo+Ni+Cu+Cr	Fe
0.06	1.6	<0.02	<0.003	<0.1	<0.1	balance

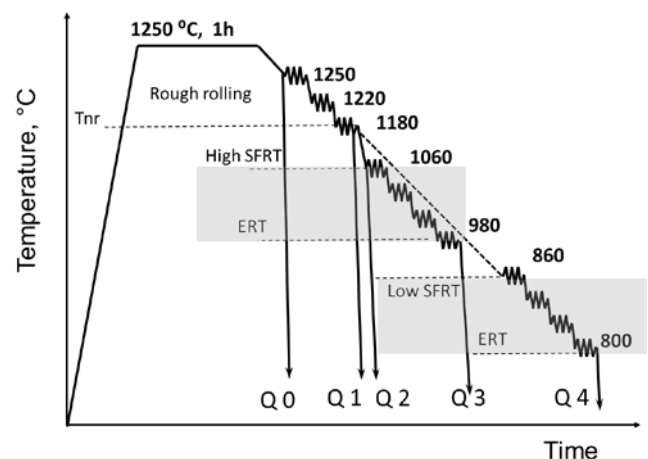


Fig. 1: Scheme of the rolling schedules. The numbers show the rough rolling temperatures and the SFRT and ERT for 2 different schedules.

In order to study the evolution of the precipitation state during TMCP, quenching was done at different moments during processing (cf. Fig. 1): Quench 0 (Q0) after reheating and before the first roughing pass, Quench 1 (Q1) after rough rolling, Quench 2 (Q2) before first rolling pass, Quench 3 (Q3) after finishing at high FRT, Quench 4 (Q4) after finishing at low FRT. For determining the amount of niobium precipitated small specimens underwent a selectively

dissolved process. An amount of 0.8g of material was dissolved and filtered. Precipitates were trapped with an Anopore (0.02 μ m) filter while the dissolved iron matrix and the remaining elements in solid solution were filtrated. The Nb content attached to the filter and those in the residue phase were measured by using Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Transmission electron microscope (TEM) operated at 200 KV equipped with Energy Dispersive X-ray Spectroscopy EDX was used to support the precipitates analysis. Optical microscopy and electron backscatter diffraction (EBSD) were used to characterize the microstructure. Crystallographic texture was measured in the $\frac{1}{2}$ thickness of the plates using X-ray Diffraction (XRD) and processed employing FHM-MTM software developed by Van Houtte [7].

3. Results and Discussion

Fig. 2 shows the microstructure of the steels after reheating at 1250°C 1h (Fig.2a), end of rough rolling at 1180°C (Fig. 2,b) and before the first rolling at 1060°C (Fig. 2c). The shape and size of the prior austenite grains delineated with black lines after Bechet-Beaujard [8] etching show that the austenite recrystallizes completely after rough rolling and in the cooling stage to 1060°C austenite grain growth takes place.

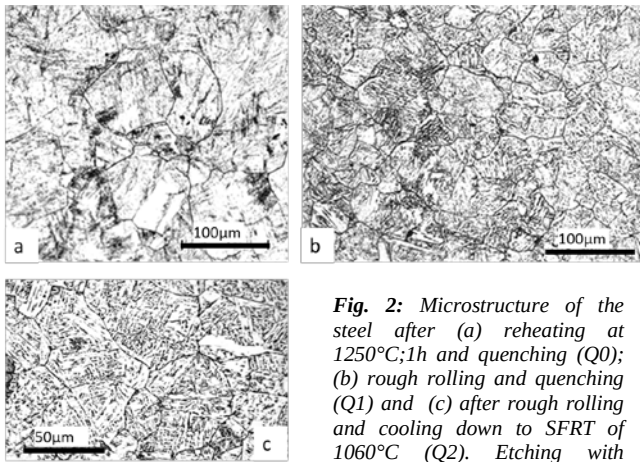


Fig. 2: Microstructure of the steel after (a) reheating at 1250°C/1h and quenching (Q0); (b) rough rolling and quenching (Q1) and (c) after rough rolling and cooling down to SFRT of 1060°C (Q2). Etching with Bechet-Beaujard etchant [8] to reveal the prior austenite grains.

The following rolling passes were carried out below the austenite non-recrystallization temperature (T_{nr}). Rolling below T_{nr} causes formation of pancaked grains and significant grain refinement after accelerated cooling as shown in Fig. 3.

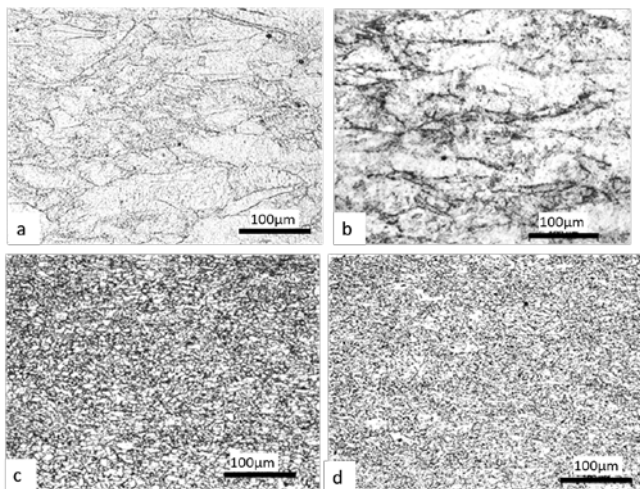


Fig. 3: Microstructure of the steel after: (a) quenching from ERT 980°C (Q3); (b) from ERT 800°C (Q4); (c) after accelerated cooling from 980°C and (d) after accelerated cooling from 800°C.

The microstructures shown in Fig. 3(b, d) show also that after rolling at low start finish rolling temperature and accelerated cooling the microstructure is finer than after rolling at high finish rolling

temperatures, although there is no significant difference in the prior austenite grain size (cf. Fig.3a and b). The average grain size diameter in samples rolled with low SFRT was 8 μ m whereas in the samples rolled at high SFRT it was 12 μ m. Hence the grain refining can be associated to the development of the internal defects in the austenite grain size that play role of potential nuclei for BCC phases.

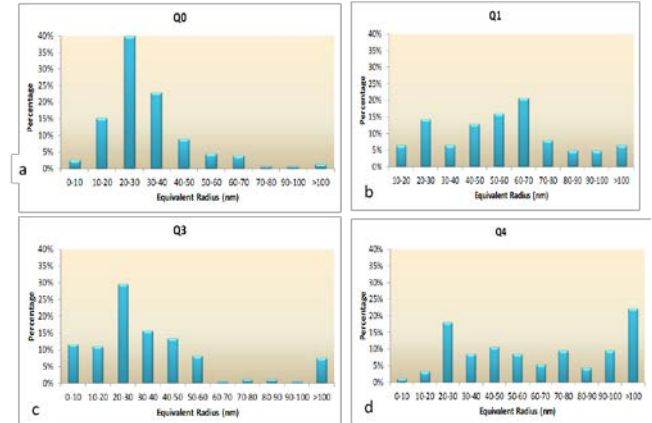


Fig. 4: Experimentally determined precipitate size distribution at various TMCP stages.

The analysis of the Nb precipitates (Fig. 4) shows that the growth of Nb precipitates start already at the rough rolling stage (Fig. 4b) and it does not change significantly during the finish rolling if the SFRT is high (Fig. 4c). However, if the SFRT is as low as 800°C the precipitates grow and the fraction of precipitates larger than 100nm increases significantly.

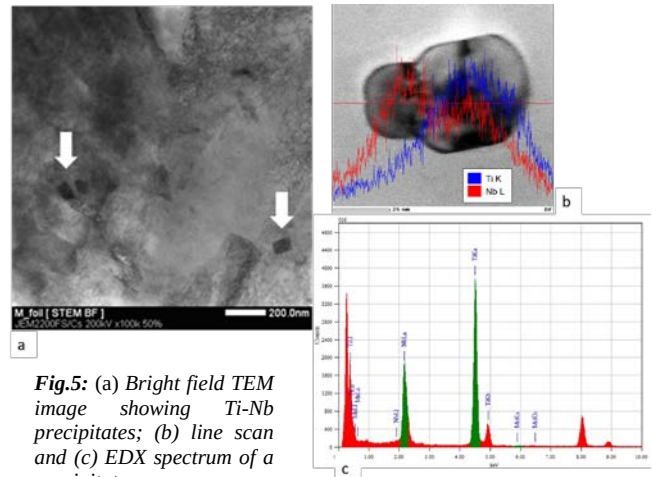


Fig.5: (a) Bright field TEM image showing Ti-Nb precipitates; (b) line scan and (c) EDX spectrum of a precipitate.

Different precipitation activity during controlled rolling has important influence on the crystallographic texture of the plates. The measured transformation textures after different rolling stages are shown in Fig. 6 as orientation distribution functions (ODFs).

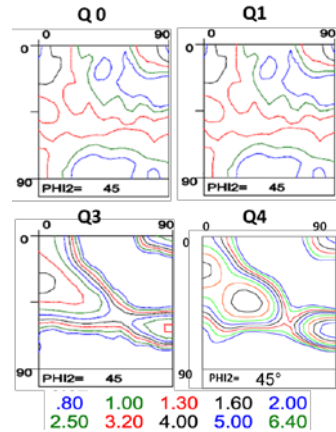


Fig. 6: ODFs of plates rolled and quenched from different temperatures.

Samples after reheating to 1250°C and quenching show typical BCC transformation texture originating from recrystallized austenite with mainly cube $\{001\}<100>$ orientation and a weak brass component $\{110\}<112>$. The transformation textures after high SFRT and low

SFRT are similar and although the maximum intensities on the ODFs change depending on SFRT they remain only on the BCC transformation components originating from deformed austenite with brass and coper{112}<111> orientation.

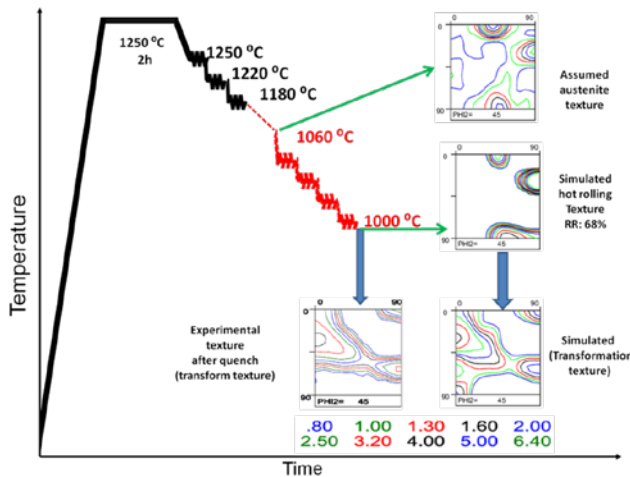


Fig. 7: Modelled (right colon) and experimental textures for material rolled at high SFRT.

Crystal plasticity modelling was used to predict the texture formation (Fig. 7) during controlled rolling and subsequent quenching. Advanced Lamel (ALAMEL) model [9] was used in the calculations of the deformation textures of austenite and the transformation of the austenite to BCC phase was assumed to follow the Kurdjumov-Sachs transformation mechanism. The calculated texture (Fig. 7 bottom right) shows very good agreement with the measured texture (Fig. 7 bottom left). The appearance of the rotated Goss texture component{110}<011> in the modelled texture is due to the fact that the model cannot take into account the valiant selection

i.e. in real case not all texture components appear but only selected ones which are favoured in the current transformation conditions.

The appearance of different type transformation textures can be followed with the help of Fig. 8[10]. The figure shows the position of the ideal texture components in the

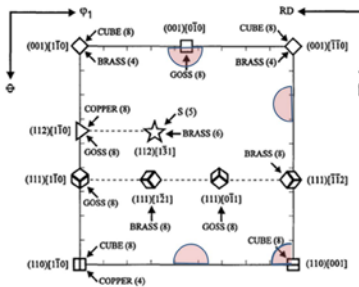


Fig. 8: main BCC and FCC texture components in $\Phi_{12}=45^\circ$

$\Phi_{12}=45^\circ$ section of the Euler space where the most common BCC texture components appear. The main austenite texture components

brass, coper, cube and Goss are plotted in the same section with grey circles. The arrows and the numbers show from which austenite texture component the BCC texture component originates and the number of variants. Austenite with S {123}<634> orientation is not shown because it does not appear in this section of the Euler space.

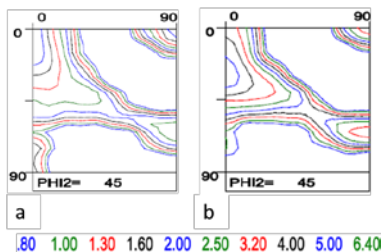


Fig. 9: Transformation textures of austenite after rolling and accelerated cooling. (a) High SFRT; (b) Low SFRT.

In real production conditions the plates follow or accelerated cooling route or air cooling route depending on the ancillary equipment of the rolling mill. This gives additional time of the austenite to recrystallize if the finish rolling temperature is enough high and

the time between start of the accelerated cooling and last rolling pass is too long. The effect of the delayed accelerated cooling is clearly demonstrated on the texture by appearance of texture components which are typical transformation texture components of the recrystallized austenite like rotated cube {001}<110>, rotated Goss {110}<011> or more rare -Goss{110}<001> texture components. The appearance of recrystallization texture components and especially rotated cube could have negative influence on strength and toughness anisotropy of the plates [10]. Hence, to avoid appearance of this texture component the time between the final rolling and accelerated cooling should be reduced. On the other hand lowering the start finish rolling temperature (SFRT) causes significant growth of the precipitation (cf. Fig. 4d) and they cannot suppress effectively the austenite recrystallization.

4. Conclusions

- Significant grain refining effect was observed in the samples rolled at low SFRT in combination with accelerated cooling;
- Increase of the SFRT and delayed accelerated cooling cause strengthening of the texture component originating from recrystallized austenite;
- Precipitation kinetics plays significant role in controlling the recrystallization of the austenite.

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ELECTRODISCHARGE AND ELECTROCHEMICAL DRESSING OF SUPERHARD GRINDING WHEELS

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Abstract: In the paper the electrodischarge and electrochemical dressing method of super hard grinding wheels using segmental tool electrode and low concentration of electrolytes has been presented. Also the investigation stand for dressing has been depicted. The experimental results concerned forming of cutting surface of grinding wheels (CSGW) in two different processes: electrodischarge profiling and electrochemical dressing. The obtained results confirmed usefulness of both of these processes in forming macro- and microgeometry of CSGW, reduction of geometrical deviations and form dressing of super hard grinding wheels with metal bond. Potential application of electrochemical and electrodischarge methods using diluted solutions of electrolytes for dressing of grinding wheels has been presented. The hybrid system of electrodischarge and electrochemical grinding wheels dressing has been proposed.

Keywords: SUPER HARD GRINDING WHEEL, ELECTROCHEMICAL AND ELECTROCHEMICAL DRESSING, CSGW, CD, CBN

1. Introduction

Grinding wheels made of super hard abrasives (such as: natural diamond CD, synthetic diamond SD or cubic boron nitride CBN) bonded are nowadays very modern abrasive tools. They are referred to below as super hard grinding wheels. These super hard grinding wheels have attractive operational properties, especially: a very good cutting abilities, long life, good tear strength, and high quality of grinding [1,2,8,11,12]. Super hard grinding wheels are generally used in the machining of hard – to – grind materials, e.g. cemented carbide, ceramics and glass, high – speed steel, tungsten carbide, titanium alloys. Rational exploiting of their attractive mechanical properties is determined by the accurate formation of working profile and macro- and micro-geometry (topography) of grinding wheel cutting surface CSGW [2,3,8,10].

Dressing of superabrasive grinding wheels comprises 3 principal operations: profiling, sharpening and fining (cleaning). Profiling of grinding wheel aims at formation of the macro-geometry of working profile of grinding wheel, being one of the factors responsible for deviations in shape and size of ground workpieces. Sharpening of grinding wheel consists in formation of micro-geometry of CSGW, comprising among others: the number, shape and distribution of static and kinematic cutting edges on the working surface of CSGW. These cutting edges decide of the cutting performance of grinding wheel and determine the course and results of grinding. The goals of fining of grinding wheel are removal of grinding products, deposited on CSGW, and regeneration of cutting performance of grinding wheel. Realization of these operations, which are crucial for mechanical characteristics of superabrasive grinding wheels is a difficult task both for the manufacturers of grinding wheels and for their users, because of their specific physicochemical properties (e.g. very high hardness of abrasive materials, high durability of metal bond) [3,7,9,13]. Therefore the conventional methods such as dressing by using the single-point diamond dressers, rotating dressers, hard rollers or abrasive whetstones, corundum or soft steel block dressing etc. are neither useful nor effective. The most predisposed for dressing of superabrasive grinding wheels were found to be certain unconventional dressing methods, mainly erosive ones [5-12].

The method of electrochemical super hard grinding wheels dressing using alternating current, referred to as the ECD-AC method, was developed in the Lodz University of Technology [4÷7]. Electroerosion dressing methods EDD are particularly useful for profiling of super hard grinding wheels, especially for multilayer grinding wheels with distinct cutting profile shape CPS. It is to note that the thermal character of CPS formation by using these approaches has a negative impact on cutting performance of the dressed grinding wheels. Therefore in many cases they have to be additionally sharpened on completion of electroerosion dressing [6,10,12]. Hybrid dressing methods rank among the promising and intensively developing techniques of formation of mechanical

properties of superabrasive grinding wheels. They are mainly based on coupled, electro-erosive and electrochemical processes. These systems take advantage of both types of erosive dressing approaches and facilitate simultaneous profiling and sharpening of a grinding wheel within one operation.

Analysis of the usefulness of erosive methods of super hard grinding wheels dressing indicates that electrodischarge and electrochemical methods are the most suitable of them. The first methods are particularly useful for grinding wheels profiling, and the latter ones for their sharpening. These two dressing manners are realized in two separate operations, which require application of different appliances. That considerably limits their use for dressing of multilayer grinding wheels. In the paper, authors propose a electrodischarge and electrochemical dressing system, using segmental tool electrode and diluted solutions of electrolytes. The principle of operation of this system, stand for its realization and experimental results concerning dressing of super hard grinding wheels have been reported.

2. Method of hybrid electrodischarge and electrochemical dressing system

Analysis of the usefulness of erosive methods of super hard grinding wheels dressing indicates that electrodischarge and electrochemical methods are most predisposed of them [4,6]. The first electrodischarge methods are particularly useful for grinding wheels forming, and the latter ones electrochemical methods for their sharpening.

The scheme of this hybrid dressing process is presented in Fig. 1, however the scheme of a stand for hybrid electrodischarge and electrochemical form dressing system of super hard grinding wheels is shown in Fig. 2 .

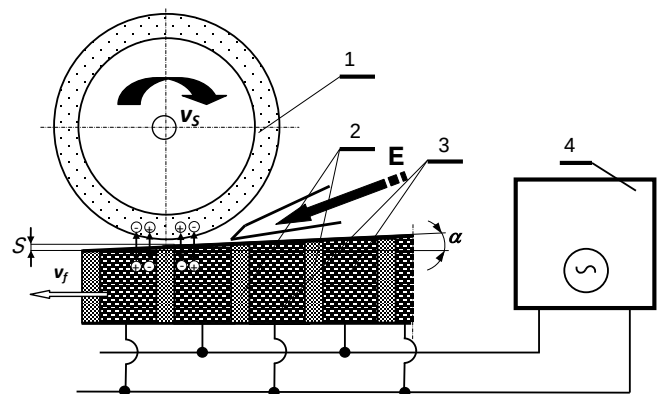


Fig.1. Schematic diagram of hybrid electrodischarge and electrochemical dressing system: 1 – grinding wheel, 2 – diluted solutions of electrolytes supply, 3 – slat electrode, 4 – impulse generator, 5 – AC power unit, S – inter electrode gap, α – angle of working tool electrode inclination.

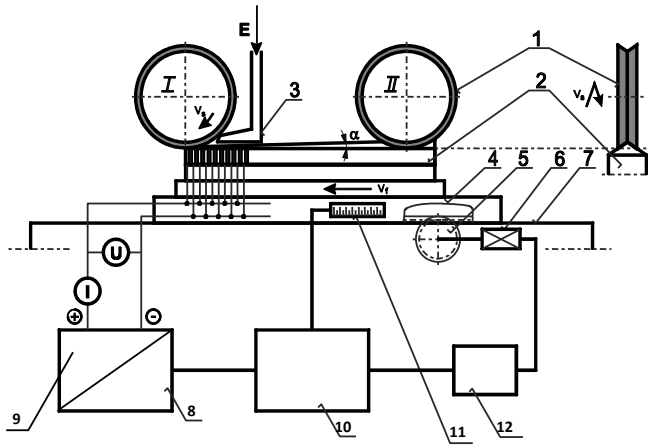


Fig. 2: The scheme of a stand for hybrid electrodischarge and electrochemical form dressing system of super hard grinding wheels: 1 – grinding wheel, 2 – working tool electrode, 3 – electrolyte supply jet, 4 – grinder table, 5 – toothed gear for transmission of the grinder table feed, 6 – electric motor, 7 – grinder body, 8 – impulse generator, 9 – AC power unit, 10 – control system, 11 – optical device, 12 – motor programmer, v_s – grinding wheel speed, α – angle of working tool- electrode inclination, E – electrolyte solution, I and II – initial and final position of the grinding wheel during CSGW forming.

These two dressing manners are realized in two separate operations, which require application of different appliances. The view of working zone and segmental tool-electrode is presented in Fig. 3. That considerably limits their use for form dressing of multilayer grinding wheels. Our investigations point at the possibility of combining the advantages of both the dressing methods, and their realization in a single dressing operation, by means of a hybrid system of grinding wheels dressing. The proposed dressing system is based on application of coupled electrodischarge and electrochemical processes. The first of these processes has substantial effect on the grinding wheel profile forming, and the second on the CSGW sharpening. The system principle is based on application of both a segment tool-electrode (Fig. 3b), providing non-contact voltage supply to a grinding wheel, and specially selected, diluted solutions of electrolytes.

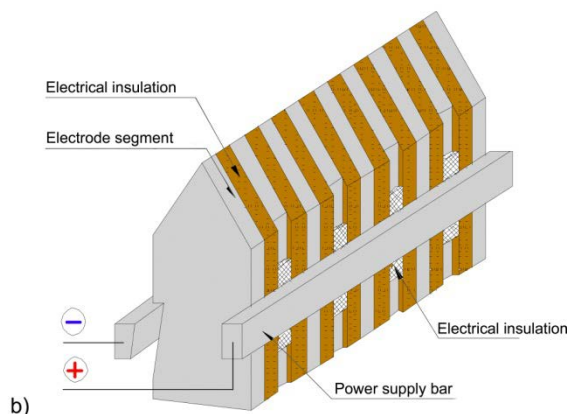


Fig. 3. The view of working zone (a) and segmental tool-electrode (b).

Dressing process (Fig. 2) of grinding wheels using this system proceeds in two permanents. First of them realizes electrodischarge forming of the grinding wheel, second realizes electrochemical dressing of it with ECD-AC method. During electrodischarge dressing of grinding wheel the segment tool electrode is connected with impulse generator – 8, which initiates spark discharge between the metal bond and segments of tool-electrode. During electrochemical dressing process the tool-electrode is connected with AC power unit – 9. The feed of tool-electrode to grinding wheel is realized by its inclination – α and low longitudinal feed of table of the grinder. To realization of presented dressing system of grinding wheels, the test stand which base is the proper adapted electrochemical grinding machine type ECTB-8 was constructed.

3. Results and discussion

The tests of the stand including among other things: control of proper function of its assembles, measurement of electric parameters of impulse generator and recording of courses of impulses of voltage and intensity of electric current during electrodischarge dressing process were performed. Electrical parameters of electro-erosive grinding wheels dressing were determined on the basis of results of preliminary experiments of dressing of diamond and CBN grinding wheels. To determine the suitable electrical parameters of the pulse generator, the voltage and current intensity of spark discharges occurring in an inter-electrode gap (between grinding wheel and working electrode) were recorded, and the basic parameters characterizing the effectiveness of grinding wheel dressing process were estimated. They were as follows: the volume of abrasive material removed through erosive process and the relative wear of working electrode [6]. Representative records of effective passes of spark discharges during electro-erosive dressing of (D125/100 M75) grinding wheel are displayed in Fig. 3. Presented variations in voltage and intensity of electric current in the inter-electrode gap provide evidence of generation of the plasma channel and spark discharges, which are essential for effective removal of metal bonds of grinding wheels subjected to this treatment. Analyze of courses of impulses (Fig. 4) indicates that there are conditions for come into being plasma channel and spark discharge which is necessary for removal of metal bond of grinding wheel during dressing process. It confirms that impulses in this process are the spark machining with relatively uniformly energy of discharge. The investigations connected settlement of electric parameters of generator providing obtaining the best indexes of effectiveness of electrodischarge dressing process of grinding wheels have been continued.

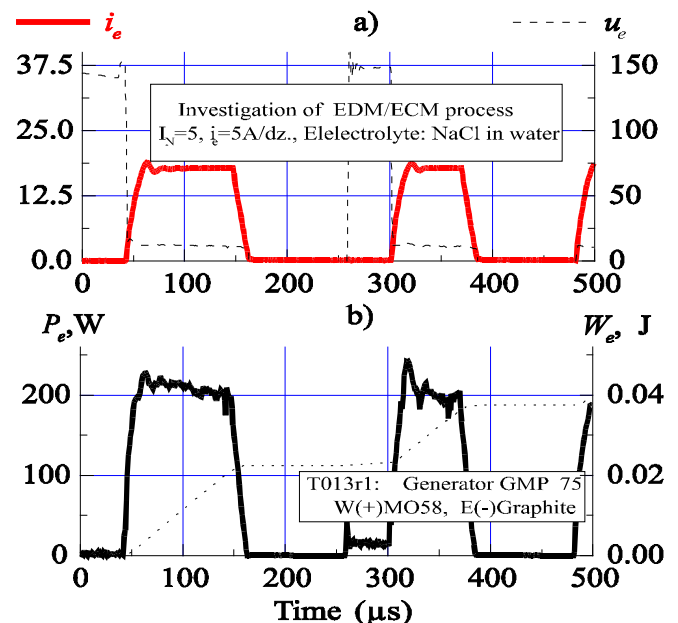


Fig. 4. Example courses of impulses of electric current: a) intensity of electric current – i_e , and decrease in voltage – U_e , b) course of power – P_e and energy of impulses of electric current – W_e .

Effects of electrical parameters of pulse generator on effectiveness of electrodischarge dressing of grinding wheels are shown in Table 1. These results were achieved during relatively long (approximately 180-200 min) electrodischarge dressing of grinding wheels, carried out for 3 different ranges of electrical parameters of pulse generator (referred to as: P1, P2, and P3 in Table 1).

Table 1: Effect of electrical parameters of electric pulse generator on results of dressing of grinding wheels.

Type of dressing	Type of grinding wheel	Type of electrode material	Electrical parameters	Capacity of grinding wheel ΔV_s [mm ³]	Relative wear of tool electrode $v = \frac{\Delta V_e}{\Delta V_s} \times 100\%$
Transverse pass	SD 125/100 M75	Cu/C	P ₁	162,5	59,8
			P ₂	270,3	39,7
			P ₃	Z	Z
		Ti/Ti	P ₁	153,4	65,5
			P ₂	279,8	41,5
			P ₃	290,4	55,4
		Ti/C	P ₁	127,4	75,3
			P ₂	205,2	62,3
			P ₃	240,8	72,5
Longitudinal pass	SD 125/100 M75	Cu/C	P ₁	78,4	45,3
			P ₂	140,4	33,2
			P ₃	Z	Z
		Ti/Ti	P ₁	88,0	53,2
			P ₂	166,7	31,1
			P ₃	170,3	51,1
		Ti/C	P ₁	73,4	69,2
			P ₂	122,3	68,5
			P ₃	Z	Z
	RBN 125/100 M75	Cu/C	P ₁	84,1	52,3
			P ₂	145,8	35,0
			P ₃	154,3	62,1
		Ti/Ti	P ₁	79,9	45,6
			P ₂	136,7	44,6
			P ₃	138,5	51,2
		Ti/C	P ₁	58,5	45,1
			P ₂	108,3	44,0
			P ₃	Z	Z

P₁: U=100V, I=25A, t_i=16μs, t_p=125μs
P₂: U=250V, I=50A, t_i=125μs, t_p=320μs
P₃: U=300V, I=75A, t_i=250μs, t_p=1000μs
Z – short circuit of electrode

Analysis of these results indicates that increments in power supplied by pulse generator resulted in larger volumes of removed abrasive material and the greater relative wear of working electrode. It is to note that for the maximum power of the pulse generator (referred to as P3) the negative phenomenon, termed “the short circuit of electrode” occurred in many experimental trials. Due to this phenomenon the continuation of EDD process was impossible. Results of these experiments indicate that the spark channel, which provides the relatively uniform energy of spark discharges, was generated over the following ranges of pulse generator parameters: working voltage 250 V, current intensity 25-50 A, pulse duration 125-250 μs, pulse pause 250-500 μs.

Profiling of grinding wheel by electrodischarge dressing of grinding wheels using a slat-tool electrode with an apical angle of 90°, and the α angle of inclination with respect to its longitudinal feed (Figure 1). The following quantities were determined: the accuracy of CSGW patterning after the profile of tool electrode and the relative wear of tool electrode. Representative results of studies are shown in Fig. 5. The applied electrical parameters of pulse generator were determined earlier and are referred to as P2 in Table 1. Results of these studies proved that CSGW could be patterned after the profile of tool electrode. However, the accuracy of this

operation depends on the relative wear of working electrode. This dependence indicates that the wear of tool electrode should be taken into consideration within the step of its designing because approaching the target depth of the CSGW profile requires application of the electrode with a significantly larger working cutting length.

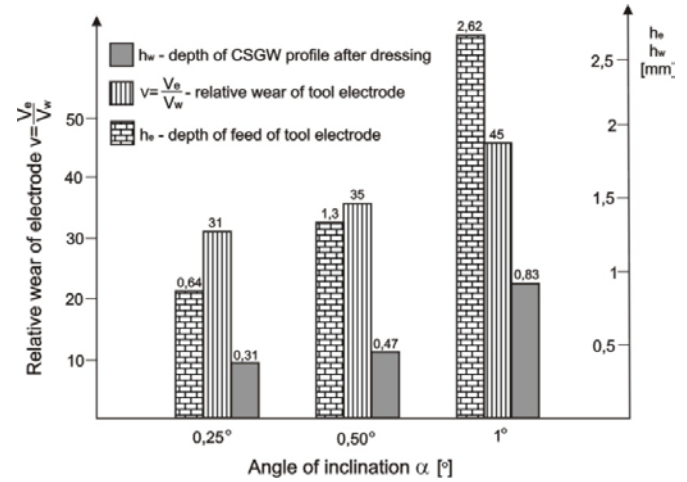


Fig. 5. The influence of the angle of the working tool electrode inclination on the relative efficiency of dressing and the wear of electrode; grinding wheel D125/100 M75, feed of electrode - 0.4 mm/min.

Example investigation results concerned the assessment of effectiveness of electrodischarge and electrochemical dressing process on the shaping of micro- and macrogeometry of the CSGW are presented in Fig. 6-8. Comparative studies on macro- and microgeometry (topography) of CSGW formed through electroabrasive and electrochemical processes were conducted.

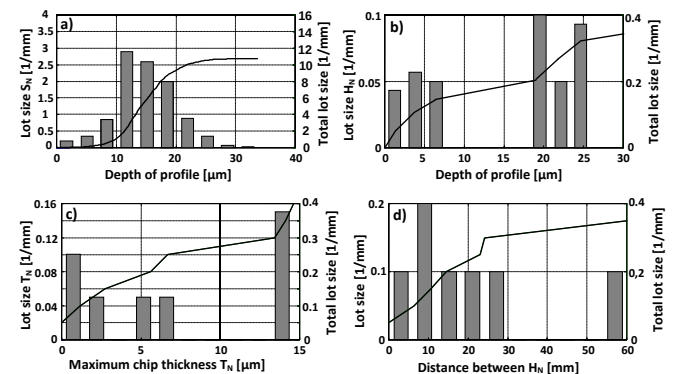


Fig. 6. Streometrical parameters of the CSGW after electrodischarge dressing of the grinding wheel D125/100 M75: (a) S_N – static cutting edges, (b) H_N – kinematics cutting edges, (c) T_N – maximum chip thickness, (d) L_N – distance between kinematics cutting edges; grinding wheel D125/100 M75, wheel speed = 25m/s, table speed = 5m/min, depth of cut = 0,02 mm

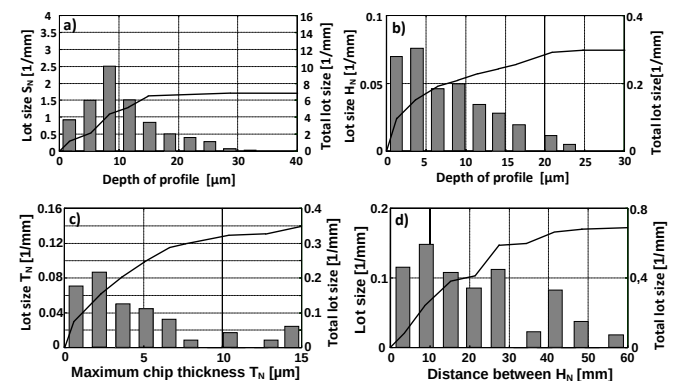


Fig. 7. Streometrical parameters of the CSGW after electrochemical dressing of the grinding wheel D125/100 M75: (a) S_N – static cutting edges, (b) H_N – kinematics cutting edges, (c) T_N – maximum chip thickness, (d) L_N – distance between kinematics cutting edges; grinding wheel D125/100 M75, wheel speed = 25m/s, table speed = 5m/min, dept of cut = 0,02 mm.

The effectiveness of electrodischarge and electrochemical dressing processes in the forming of the CSGW macro- and microgeometry was assessed on the basis of the stereometric parameters, such as numbers of static cutting edges (S_N) and kinematic cutting edges (H_N), and the average maximum thickness of a chip (T_N). They were determined using the computer analysis of circumferential representation of the CSGW profile and simulation of the grinding process [1,5,7].

In Fig. 6-7 the comparison of stereometrical parameters of the CSGW (static cutting edges, kinematical cutting edges, maximum chip thickness and distance between kinematical cutting edges after electrodischarge dressing process and electrochemical dressing has been depicted. Application of electrodischarge dressing process causes approximately a 100% increase of number of static edges (S_N), almost 70% increase of depth of deposition of the static edges, 40% decrease of number of kinematic edges (H_N), about 60% increase of depth of deposition of the kinematic edges, approximately 65% increase of number of average thickness of chips (T_N) and about a 100% increase of distance between cutting edges (L_N).

The differences in CSGW morphology correspond with results obtained using SEM method. The SEM pictures of CSGW are presented in Fig. 8.

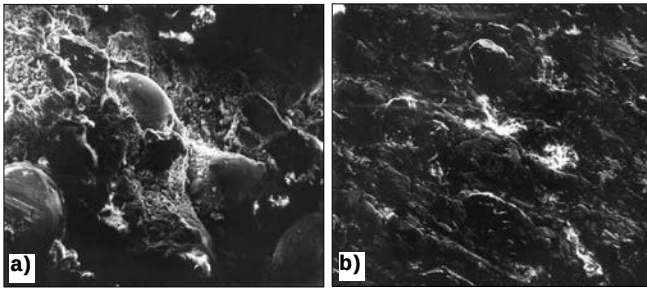


Fig. 8. SEM images of the grinding wheel D125/100 M75 after dressing: (a) electrodischarge dressing, (b) electrochemical dressing.

The comparison of the CSGW images (Fig. 8 a) confirms that a result of the thermal effect of spark discharges on the CSGW is a curvature of grinding grain edges brought about by their partial graphitization. These unfavorable processes are not observed after electrochemical dressing (Fig. 8b). This phenomenon indicates that electrodischarge dressing process has to be followed by electrochemical sharpening dressing operation.

Analysis of stereometrical parameters of the CSGW after electrodischarge (Fig. 6) and electrochemical dressing process (Fig. 7) indicates essential differences in forming of macro- and microgeometry. The electrochemical dressing process causes a decrease of number of static edges (S_N) and kinematic edges (H_N), their proper concentration in the nominal surface of CSGW and increase in the average thickness of chips (T_N) and in the distance between cutting edges (L_N). These favorable changes of stereometrical parameters of CSGW improve cutting ability of the grinding wheel.

4. Conclusion

Presented studies confirmed the usefulness of the coupled, electrodischarge and electrochemical system of grinding wheels dressing for forming the functional qualities of metal-bonded superabrasive grinding wheels. This two-step system is particularly suitable for: correction of geometrical deviations of grinding wheels, CSGW patterning after the profile of tool electrode, and formation of the required macro- and microgeometry (topography) of CSGW. The principal advantage of this system is simultaneous realization of two operations, i.e. electrodischarge profiling and electrochemical sharpening of superabrasive grinding wheels.

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NICKEL FERRITE-ACTIVATED CARBON MATERIALS – PREPARATION AND PHOTOCATALYTIC EFFICIENCY FOR CLEANING OF MALACHITE GREEN AND REACTIVE BLACK 5 DYES UNDER UV-ILLUMINATION

НИКЕЛОВ ФЕРИТ-АКТИВЕН ВЪГЛЕН МАТЕРИАЛИ – ПОЛУЧАВАНЕ И ФОТОКАТАЛИТИЧНА ЕФЕКТИВНОСТ ЗА ОЧИСТВАНЕ НА МАЛАХИТОВО ЗЕЛЕНО И РЕАКТИВНО ЧЕРНО 5 БАГРИЛА ПОД УВ ОБЛЪЧВАНЕ

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Abstract: Nickel ferrites having different stoichiometry supported on activated carbon ($\text{Ni}_{0.25}\text{Fe}_{2.75}\text{O}_4\text{-AC}$, $\text{Ni}_{0.5}\text{Fe}_{2.5}\text{O}_4\text{-AC}$, $\text{NiFe}_2\text{O}_4\text{-AC}$) were prepared by co-precipitation using nitrate precursors and activated carbon from peach stones and calcination procedure in nitrogen atmosphere. The physicochemical properties of these materials were studied by powder X-ray diffraction analysis (PXRD) and Mössbauer spectroscopy. The presence of spinel ferrite and additional hematite phases was established by PXRD. The photocatalytic properties of the so synthesized nickel ferrite-AC materials were tested and compared in oxidative degradation of Malachite Green (MG) and Reactive Black 5 (RB5) dyes under UV-light irradiation. The photocatalytic tests show that investigated samples lead to much higher degree of degradation of MG (86%-92%) compared with that of RB5 (17%-35%) due to their structure. The results proved that nickel ferrite-AC materials are more efficient photocatalysts for removal of MG as model contaminant from aqueous solution under UV light than RB5.

Keywords: NICKEL FERRITES-AC, MALACHITE GREEN, REACTIVE BLACK 5, PHOTOCATALYTIC DEGRADATION

1. Introduction

The development of efficient methods to reduce environmental contamination is of great practical importance. The heterogeneous photocatalysis is an outstanding method for purification of polluted waters [1]. Hazardous organic compounds are among the major factors of environmental pollution, especially in water media [2]. Synthetic dyes find wide application for coloring purposes in leather, textile, printing, food, cosmetic and plastic industries [3]. The water contamination caused by dyes is posing a problem throughout the world. Colour is the first aspect to be recognised in wastewater [4]. Spinel ferrites MFe_2O_4 , $\text{M} = \text{Ni, Mg, Ca, Co}$ have narrow band gaps (~ 2.0 eV), magnetic separability, and chemical stabilities so their nanoparticles could be potentially applied as photocatalysts for decontamination of environment because of their superiority in complete utilization of natural sunlight [5,6]. The application of magnetic semiconductor nanoparticles for treatment of polluted waters is attractive research field. Nickel ferrites with general formula (AB_2O_4) are among the most versatile magnetic materials due to the high Curie temperature, high saturation magnetization, chemical stability and relatively high permeability [7]. The use of activated carbons as materials for the photocatalysts' support shows many advantages because of the high specific surface areas, easy control of the surface chemistry and excellent adsorption capacity for organic compounds, high porosity and ability for recovering of active metal phase by burning the carbon support. The oxidative degradation rate under UV-light illumination is enhanced due to the porosity of the carbon feeding desorbed pollutant molecules to the photocatalytically active sites, suggesting also possible own photoactivity of the carbon support [8].

The nanosized composite NiFe_2O_4 /active carbon has already been used to remove Alizarine Yellow R and Methyl Orange azo dyes, from water [9]. The adsorption property of $\text{AC/NiFe}_2\text{O}_4$ magnetic composite was investigated with respect to Methyl Orange dye in ref. [10]. Another research group used the $\text{AC-NiFe}_2\text{O}_4$ as photo-Fenton catalyst for photo-Fenton degradations of Methylene Blue, Rhodamine B and Malachite Green as model pollutants, carried out in the presence of oxalic acid under $\lambda > 400$ nm visible light [11]. Zhao et al. [12] determined that NiFe_2O_4 -graphene

possesses significantly enhanced photocatalytic activity for the degradation of Methylene Blue under illumination of artificially simulated sunlight compared to bare NiFe_2O_4 nanoparticles. Photocatalytic activity of NiFe_2O_4 /MWCNTs hybrids has been studied in the photocatalytic decolorization of Congo Red in aqueous solution under simulated solar light irradiation in ref. [13]. The multi-walled carbon nanotubes CNTs and NiFe_2O_4 -MWCNTs were efficient adsorbents for the removal of Methylene Blue from polluted water [14]. The high photoactivity of NiFe_2O_4 /MWNT was established in the degradation of phenol and nitrophenols (o-nitrophenol, p-nitrophenol and picric acid) under UV light [15]. Ikenaga and coworkers determined that investigated activated carbon-supported ferrite had ten times higher hydrogen sulfide absorption rate than that of the ferrite prepared by the dry process [16]. The adsorptive ability of fly ash/ NiFe_2O_4 composites has been tested for removal of Congo Red dye from an aqueous solution by the authors [17]. Singh et al. [18] showed that cobalt-doped nickel ferrite/MWCNTs nanocomposites demonstrated a significant catalytic activity in the photo-Fenton process in the degradation of Rhodamine B dye, which completely degraded the dye molecule in 15–25 min. The photocatalytic activity of nickel ferrite samples $\text{Ni}_x\text{Fe}_{3-x}\text{O}_4$ ($0 \leq x \leq 1$) in the degradation of Malachite Green dye under UV irradiation was discussed in previous investigations [19].

The present paper is focused on the synthesis, physicochemical and photocatalytic properties of nickel ferrite-activated carbon materials having different compositions in the degradation of aqueous Malachite Green and Reactive Black 5 dyes under UV light.

2. Experimental

2.1. Synthesis of the nickel ferrite-activated carbon samples

The nickel ferrite-activated carbon (AC) materials having different compositions $\text{Ni}_{0.25}\text{Fe}_{2.75}\text{O}_4\text{-AC}$, $\text{Ni}_{0.5}\text{Fe}_{2.5}\text{O}_4\text{-AC}$ and $\text{NiFe}_2\text{O}_4\text{-AC}$ (denoted as S1, S2 and S3) were synthesized by the co-precipitation technique. The starting aqueous solutions of 0.03M $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (VWR Prolabo BDH chemicals) and

$\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (Alfa Aesar) were mixed at a preset ratio. After that 2g of activated carbon were added to the mixture. The carbon was produced from peach stones (supplied by Laboratory for "Chemistry of Solid Fuels" at the Institute of Organic Chemistry with Centre of Phytochemistry). The 0.3M NaOH solution (Valerus Co.) was used as precipitant by adding it dropwise slowly into the mixture upon continuous stirring. The addition of precipitating agent was discontinued at pH = 12.5 and then the mixture was continuously stirred for one more hour. The so synthesized materials were then centrifuged and washed with distilled water until neutral reaction medium (pH=7) was reached. Further the obtained precipitates were dried at 110°C for 3 hour in air media. The co-precipitated samples were thermally treated at 400°C for 3 hours and 30 minutes in inert nitrogen atmosphere.

2.2. Powder X-ray diffraction analysis (PXRD)

The powder X-ray diffraction analysis was carried out on a Bruker D2 Phaser diffractometer within the range of 2θ values between 5° and 65° using Cu K_α radiation ($\lambda = 0.154056$ nm) at 40 kV. The present phases were identified by using of JCPDS database (Powder Diffraction Files, Joint Committee on Powder Diffraction Standards, Philadelphia PA, USA, 1997).

2.3. Mössbauer spectroscopy

The Mössbauer measurements were performed on apparatus Wissenschaftliche Elektronik GmbH, working at a constant acceleration mode, $^{57}\text{Co}/\text{Rh}$ source (activity ≈ 50 mCi) and $\alpha\text{-Fe}$ standard. The parameters of hyperfine interactions of Mössbauer spectral components: isomeric shift (IS), quadrupole splitting (QS), hyperfine effective magnetic field in the sites of iron nuclei (H_{eff}), line widths (FWHM) and component relative weights (G) were calculated by computer fitting.

2.4. Photocatalytic investigations

The photocatalytic degradation of Malachite Green (MG) and Reactive Black 5 (RB5) dyes under UV-light irradiation was studied using obtained nickel ferrite/AC materials as photocatalysts. The photocatalytic experiments were carried out using polychromatic UV-A lamp illumination (18W) with maximum emission at 365 nm and illumination intensity 2.6 mW/cm². The reaction course was followed by UV-Vis spectrophotometer CamSpec M501. The aqueous solutions of Malachite Green ($\lambda_{\text{max}}=615$ nm) and Reactive Black 5 ($\lambda_{\text{max}}=599$ nm) dyes were with initial concentration 5 ppm and 20 ppm respectively. In order to establish adsorption equilibrium in system, the dye solution and photocatalyst were stirred in the dark for 30 min without any UV illumination. A semi-batch suspension photocatalytic reactor was equipped with two frits blowing tiny bubbles of air in order to saturate the solution in dissolved oxygen. The photocatalytic tests were carried at a constant stirring rate (400 rpm) under ambient conditions. The measurement of the photocatalytic efficiency of nickel ferrite – AC samples was performed by taking aliquot samples of the suspension out of the reaction vessel after regular time intervals. The powder was then separated from the aliquot solution by centrifugation before the UV-Vis spectrophotometric evaluation of the dye concentration, based on previous calibration. After that, the aliquot solution, together with the photocatalyst powder, were returned back into the reaction vessel, which ensured operation under constant volume and catalyst amount. The degree of degradation is estimated using dependence $(C - C_0/C_0) \times 100$, where C_0 and C are respectively initial concentration before turning on the illumination and residual concentration of the dye solution after illumination in the course of given time interval.

3. Results and discussions

Figure 1 represents the Powder X-ray diffraction patterns of the obtained calcined nickel ferrite – activated carbon materials showing the characteristic reflexes of non-stoichiometric and stoichiometric spinel nickel ferrite phase (PDF-86-2267; PDF-75-0449) and activated carbon also. The presence of additional hematite phase (PDF-89-0599) is registered in all thermally treated nickel ferrite-AC samples.

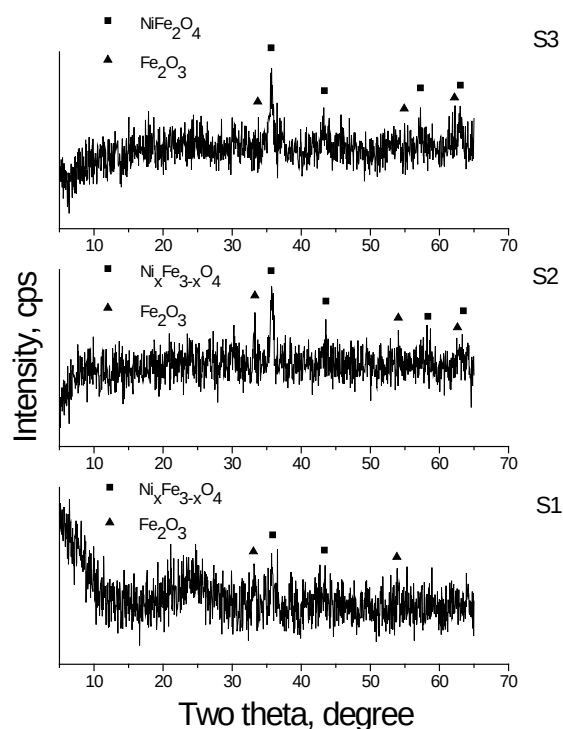


Fig. 1 PXRD patterns of nickel ferrite-AC photocatalysts after calcination.

The recorded room temperature Mössbauer spectra of thermally treated nickel ferrite-AC samples are displayed in Figure 2. The Mössbauer spectra of prepared materials represent a superposition of the sextet and superparamagnetic doublet components. The sextet-type components could be assigned to the presence of spinel ferrite and hematite phases [20].

The photocatalytic activities of the investigated samples were measured using two hazardous textile dyes - Reactive Black 5 (RB5) and Malachite Green (MG) as model pollutants. Figure 3 is illustrating the reaction course of both dyes degradation in solution under UV-A illumination over the investigated photocatalysts. The adsorption capacities of samples S1, S2 and S3 towards model pollutant MG dye are higher than those for RB5 dye, which is probably due to the amino groups in MG reacting readily with acidic sites on the surface of the photocatalysts. After half an hour in the dark the UV lamp was switch on and the photocatalytic degradation is started. The rate of oxidative discoloration reaction of studied powders regarding the RB5 dye is lower than MG dye, which can be attributed to the higher stability of RB5 molecule having a much larger conjugated system of single and double bonds.

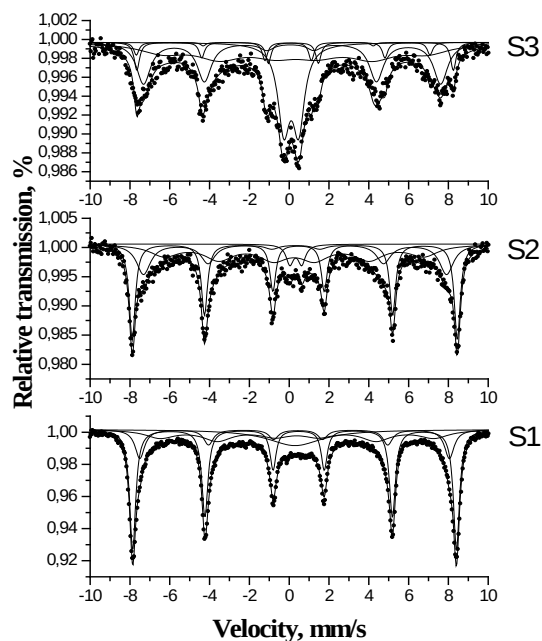


Fig. 2 Mössbauer spectra of calcined nickel ferrite-AC photocatalysts.

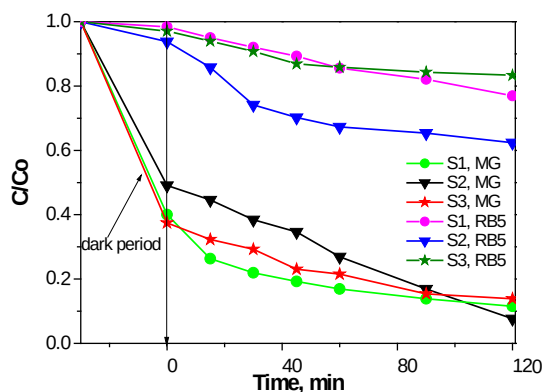


Fig. 3 Concentration changes of tested dyes based on changes in the intensity of the maximal absorbance peak at 599 nm for RB5 dye and at 615 nm for MG dye respectively, with the course of time.

Figure 4 shows degree of degradation of the dyes after 120 min under UV-A illumination over investigated photocatalysts. MG degradation conversion degrees of photocatalytic systems: S1, S2 and S3 are in the range 86÷92%, while they degrade weaker RB5 dye (17÷35 %).

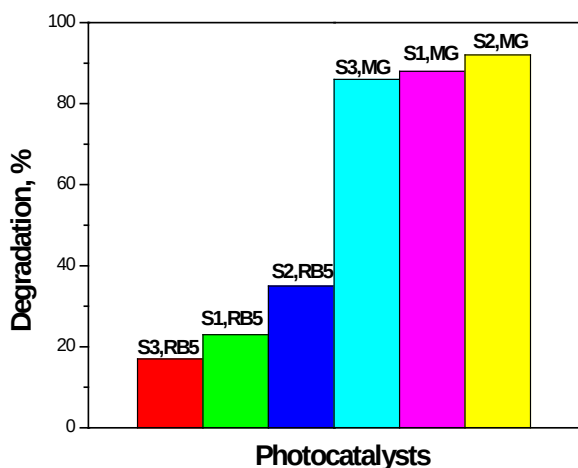


Fig. 4 Degradation degrees of investigated dyes: RB5 and MG using prepared nickel ferrite-AC photocatalysts.

Table 1 lists the rate constants and degradation conversion degrees of studied catalysts in the degradation of MG and RB5 dyes after 120 min work. Rate constants were calculated using the equation $-\ln(C/C_0) = kt$ on the basis of the slope of the linear logarithmic function. The degradation apparent rate constants (pseudo first order kinetics) decreased in the order: S2, MG ($15.1 \times 10^{-3} \text{ min}^{-1}$) > S1, MG ($9.1 \times 10^{-3} \text{ min}^{-1}$) > S3, MG ($8.7 \times 10^{-3} \text{ min}^{-1}$) > S2, RB5 ($3.2 \times 10^{-3} \text{ min}^{-1}$) > S1, RB5 ($2 \times 10^{-3} \text{ min}^{-1}$) > S3, RB5 ($1.3 \times 10^{-3} \text{ min}^{-1}$).

Zhu et al. [13] proposed the possible mechanism of the dye degradation on NiFe_2O_4 /carbon tubes composites. Firstly the dye molecules were adsorbed on the surface of NiFe_2O_4 /carbon nanotubes composite. Secondly, electrons in the valence band of NiFe_2O_4 can become excited to its conduction band under light irradiation, causing the photoproduced holes in the valence of NiFe_2O_4 simultaneously. The photoproduced electrons are able to quickly migrate towards the surface of carbon tubes because of the matching between the energy level of NiFe_2O_4 and carbon tubes and the chance of recombination of electrons and holes is greatly reduced. This could be explanation of promising photocatalytic activity of the NiFe_2O_4 /AC composites.

The photocatalytic performances and mechanism of dye degradation of the samples in the oxidative degradation of specific classes of dyes were influenced by some factors such as chemical composition, the morphology, degree of crystallinity, crystallites size etc. The functional groups of the dyes have also to be taken into account as well as the acidity/basicity of the photocatalyst surface.

Table 1: Rate constants and degradation conversion degrees for MG and RB5 of investigated nickel ferrite-AC photocatalysts.

Samples	$k \times 10^{-3}, \text{ min}^{-1}$	Degradation, %
S2, MG	15.1	92
S1, MG	9.1	88
S3, MG	8.7	86
S2, RB5	3.2	35
S1, RB5	2	23
S3, RB5	1.3	17

4. Conclusions

The nickel ferrite-AC photocatalysts were prepared by coprecipitation and calcination in inert atmosphere. The physicochemical characterization of the so synthesized samples by PXRD analysis and Mössbauer spectroscopy proved the existence of nickel ferrite and hematite as additional phase. Comparatively study of photocatalytic efficiency of the investigated materials confirmed the easier degradation of MG over RB5 dye in aqueous media. The tested photocatalyst $\text{Ni}_{0.5}\text{Fe}_{2.5}\text{O}_4$ -AC demonstrates the highest degree of degradation of MG (92%) and RB5 (35%) dyes compared to these over the other samples. The studies can be continued and extended further in the direction of involving TOC analysis of the total organic carbon in the decolorized solution thus evaluating not only the degree of discoloration but also the degree of total oxidation, which could shed some light on the different behavior of the two dyes. The present results determined that synthesized nickel ferrite-AC materials could be appropriate photocatalysts for removing of MG as contaminant from aqueous media.

Acknowledgements

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ANALYSIS AND PERFORMANCE OF TWO PV CELLS UNDER VARIOUS WEATHER CONDITIONS

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Abstract: This paper presents performances of two different types of PV cells under various temperature climate of Stip, R. Macedonia. Stip with geographical position 41.742N, 22.194E has 2260 sun hours yearly with average temperature 25 °C during spring.

The types of cells examined in this study are: crystalline silicon (c-Si) and polycrystalline silicon (p-Si). The calculations are made for various operating conditions and a comparison of I-V and P-V characteristics are represented here. Also, the efficiency and fill factor for photovoltaic (PV) cells is calculated based on simulation results.

Keywords: SOLAR CELL, EFFICIENCY, MAXIMUM POWER, CRYSTALLINE SILICON, POLYCRISTALLINE SILICON

1. Introduction

Photovoltaics use semiconductor materials to generate electricity from solar energy. Photovoltaic cells (PV) present a prime source of clean energy that utilizes energy from sunlight. Solar cells are used to convert solar energy directly into power. PV cells are manufactured from thin films or wafers made from silicon [1], [2].

PV cells are semiconductor devices and they are capable to convert solar light into DC current. Efficiency of produced power is changing in the interval from 3% to 17%, and that depends of different factors, such as kind of technology used, ambient temperature, the light spectrum, system design, semiconductor characteristics and material of solar cell [1], [2]. Solar cells can be connected serial or parallel depending on what we want to get high currents or high voltages. Different modules produce different amount of electricity according to required amount ranging from few watts to megawatts.

Photovoltaic energy conversion in solar cells consists of two basic steps: First, absorption of light generates an electron-hole pair. The electron and hole are then separated by the structure of the device; electrons go to the negative terminal and holes to the positive terminal, in effect generating electrical power. Solar energy has emerged as a renewable, clean and a free source of energy encapsulated in photovoltaic (PV) cells. In this paper, are analyzed two different types of solar cells and make the real comparison between their performances at different weather temperatures and solar irradiance of Stip, R. Macedonia. This study investigated theoretically and experimentally the effects of ambient air temperature on performance on PV panel under real outdoor conditions. The experimental results are obtained in PSIM software.

2. Technology of solar cells

Almost 95% of available solar cells are made from silicon. The advantage of using silicon is its mature processing technology. It is a semiconductor material suitable for PV applications, with energy gap of 1.1eV. This type of solar cell is in mass production and individual companies will soon be producing it at the rate of several hundred MW a year and even at the GW-scale. The silicon is used in PV cells for monocrystalline (m-Si) and polycrystalline (p-Si) wafer production of thin film silicon modules. Thus, silicon-based technology is very important for the production of the PV cells at present time. The manufacturing process of wafer-based silicon PV modules comprises four steps [3]:

1. Polysilicon production
2. Ingot/wafer production
3. Cell production
4. Module assembly

Crystalline silicon cells are classified into three main types depending on how the Si wafers are made. They are:

- Monocrystalline (Mono c-Si) sometimes called single crystalline (sc-Si)
- Polycrystalline (Poly c-Si), sometimes referred to as multi-crystalline (mc-Si)
- Ribbon silicon and silicon sheet – defined film growth

Commercial production of c-Si modules began in 1963 when Sharp Corporation of Japan started producing commercial PV modules and installed a 242 Watt (W) PV module on a lighthouse, the world's largest commercial PV installation at the time (Green, 2001). Crystalline silicon technologies accounted for about 87% of global sales in 2010 (Shott Solar, 2011). The efficiency of crystalline silicon modules ranges from 14% to 19% [4].

The development of Si-PV technology materials is driven by cost reduction. The large growth in PV market and need for lower cost material than monocrystalline make polycrystalline silicon a good alternative. Performance of monocrystalline silicon is more expensive but better in performance than the polycrystalline silicon wafers. In single crystal silicon, the crystal lattice of the entire sample is continuous and unbroken with no grain boundaries. Polycrystalline are composed of smaller crystals or multiple small silicon crystals. Polycrystalline can be recognized by a visible grain (metal flake effect) and are more sensitive to thermal processing. Polycrystalline silicon wafers are usually characterized by their grain sizes, orientations, and content of defects and impurities. Conversion efficiencies of commercial types of polycrystalline silicon cells are in range from 12% to 15% and could reach 17% using more sophisticated solar cell designs [5]. The efficiency of polycrystalline solar cells is mainly limited by minority carrier recombination. Depending on the crystallization process, materials develop different defect structure, which limit their efficiency. In order to improve polycrystalline cell efficiency, reduction of thermal load is required. Polycrystalline silicon is either grown by an ingot or ribbon technique. The microstructures of polycrystalline silicon materials differ considerably depending on whether the material is grown by an ingot or a sheet growth technique. Dislocations in ingot silicon are formed during crystal growth by plastic deformation to reduce the thermal stresses. These dislocations show high recombination rates and are thus very detrimental to the lifetime of minority charge carriers. To modify the performance of polycrystalline silicon wafers, it is necessary to minimize the level of transition metals in the raw silicon material.

3. Single-diode model

The equivalent model of PV cell (Fig.1) is consisted of a current source in parallel with diode and series and shunt resistances. The current source represents the light generated electric current I_{pv} and depends on solar irradiation. The output current is defined as:

$$I = I_{pv} - I_o \left[\exp \left(\frac{V + IR_s}{nV_T} \right) - 1 \right] - \left(\frac{V + IR_s}{R_{sh}} \right) \quad (1)$$

Where, I_o is diode reverse bias saturation current of the diode, $V_T = kT/q$ is thermal voltage, q is electron charge, k is Boltzmann constant, T is temperature of the p-n junction and n is diode ideality factor. The series resistor takes into account losses in cell, interconnection and junction, while the shunt resistor takes into account the current leakage through the high conductivity shunts across the p-n junction.

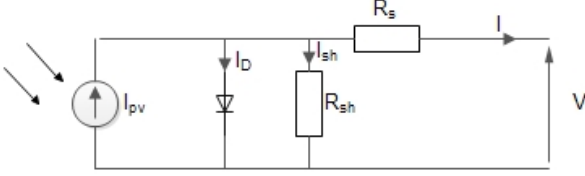


Fig. 1 Single diode model of PV cell

The characteristics of the most important parameters of PV cell can be determined by I-V curve. From this curve parameters such as the short circuit current, open circuit voltage, the maximum voltage and current can be read. Short circuit current I_{sc} is defined as:

$$I_{sc} = I = I_{pv} - I_o \left[\exp \left(\frac{IR_s}{nV_T} \right) - 1 \right] - \left(\frac{IR_s}{R_{sh}} \right) \quad (2)$$

The open circuit voltage for same radiance and temperature of the p-n junction is the greatest value of the voltage at the cell terminals and can be calculated as:

$$V_{oc} = nV_T \ln \left(1 + \frac{I_{sc}}{I_o} \right) \quad (3)$$

I-V characteristics of ideal solar cell have a rectangle shape with sides I_{sc} and U_{oc} . But, in practice the maximum power of real solar cell is smaller than the maximum power of ideal solar cell. The maximum output power is the point (I_{mp} , U_{mp}) at which the power dissipated in the load is maximum and is defined as:

$$P_{mp} = U_{mp} \left(I_{pv} - I_o \left[\exp \left(\frac{U_{mp} + I_{mp}R_s}{nV_T} \right) - 1 \right] - \frac{U_{mp} + I_{mp}R_s}{R_{sh}} \right) \quad (4)$$

The efficiency of the PV cell is ratio between the maximum power and the incident light power:

$$\eta = \frac{P_{mp}}{P_{in}} = \frac{I_{mp} U_{mp}}{AG} \quad (5)$$

where G is the ambient irradiation and A is cell area. The fill factor is a measure of squareness of I-V characteristic and can be calculated as ratio between the maximum power that can be delivered to the load and multiplication of I_{sc} and V_{oc} .

$$FF = \frac{P_{mp}}{V_{oc} I_{sc}} = \frac{I_{mp} U_{mp}}{V_{oc} I_{sc}} \quad (6)$$

4. Simulations scenario and results

The mathematical model for PV cell with single-diode model was implemented in PSIM simulator [6] using the physical model of solar cell shown in Fig. 2. I-V characteristics of monocrystalline solar cell and polycrystalline solar cell were obtained. The

simulations were performed under Standard Test Conditions STC (1000W/m² irradiance, 25°C cell temperature and AM1.5) and Nominal Operating Cell Temperature (800W/m² irradiance, 1m/s wind and 20°C cell temperature). The characteristics points of SPR-327 NE-WTH-D (SunPower Corporation) and JKM350P (Jinko Solar) modules are given in manufacture datasheets [7] and [8] are represented in Table 1 and Table 2, respectively. The ideality factor depends only on cell temperature not on irradiance. In [9] is proposed that ideality factor for monocrystalline has value 1.2 whereas for polycrystalline is 1.3. The value of ideality factor can be adjusted in order to improve the model fitting to the experimental data.

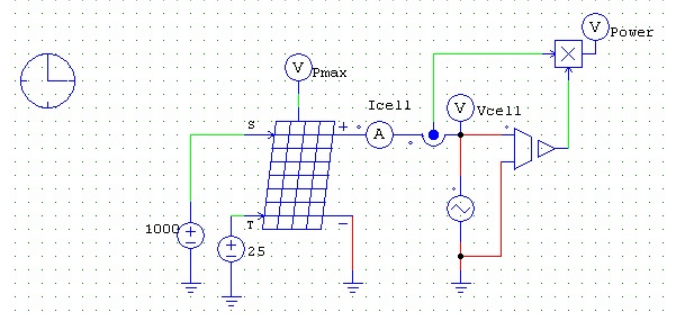


Fig. 2 Test circuit for solar cell (physical model)

Table 1: Parameters of model SunPower SPR-327NE-WHT-D

	STC	NOCT
Nominal power	327W	243W
Number of cells	96 monocrystalline silicon cells	
Voltage at P _{mp}	54.7V	50.4V
Current at P _{mp}	5.98A	4.82A
Open circuit voltage	64.9V	60.8V
Short circuit current	6.46A	5.22A
Temperature power coefficient	-0.38%/K	
Temperature voltage coefficient	-176.6mV/K	
Temperature current coefficient	3.5mA/K	

Table 2: Characteristics of Jinko Solar model JKM350P

	STC	NOCT
Nominal power	305W	225W
Number of cells	96 polycrystalline cells	
Voltage at P _{mp}	36.8V	34.0V
Current at P _{mp}	8.30A	6.62A
Open circuit voltage	45.6V	42.4V
Short circuit current	8.91A	7.21A
Temperature power coefficient	-0.41%/K	
Temperature voltage coefficient	-0.31%/°C	
Temperature current coefficient	0.06%/°C	

When temperature raises, the current increases while the voltage decreases and as a result the maximum point of I-V and P-V characteristics a decrease. I-V characteristics obtained through simulations of monocrystalline and polycrystalline solar module are represented in Fig 3 and Fig.4, respectively. In Fig.5 and Fig. 6 are represented the P-V characteristics of monocrystalline and polycrystalline module, respectively. Short circuit current is a linear function of the irradiation since photocurrent depends on the radiation, and thus higher the irradiation leads to higher current. Also, if the irradiation is reduced, the output voltage of the module decreases.

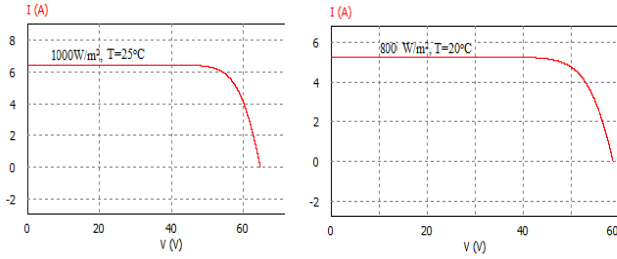


Fig. 3 I-V Characteristics of monocrystalline module SPR-327NE-WHT-D

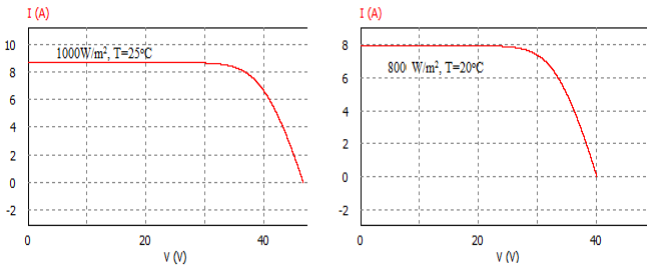


Fig. 4 I-V Characteristics of polycrystalline module JKM350P

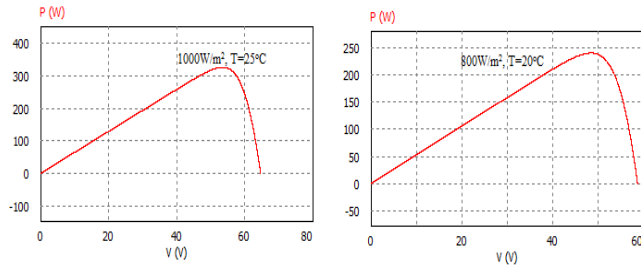


Fig. 5 P-V Characteristics of monocrystalline module SPR-327NE-WHT-D

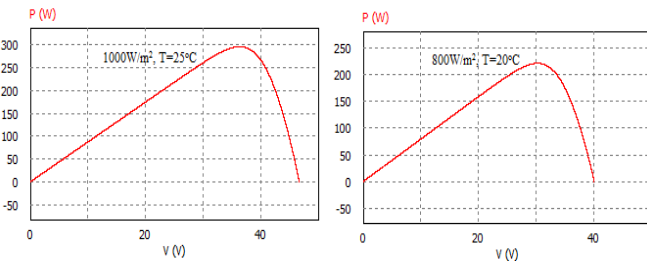


Fig. 6 P-V Characteristics of polycrystalline module JKM350P

PSIM simulator through its utility Solar Module (physical model) calculates the maximum power, maximum current and maximal voltage. These results are summarized in Table 3 and are used to calculate the efficiency and fill factor for both modules.

Table 3: Calculated maximum power at STC and NOCT conditions

	STC	NOCT
SPR-327NE-WHT-D	$P_{mp}=326,67W$ $I_{mp}=6.10A$ $U_{mp}=53.52V$	$P_{mp}=241.19W$ $I_{mp}=4.97A$ $U_{mp}=48.55V$
JKM350P	$P_{mp}=296,90W$ $I_{mp}=8.14A$ $U_{mp}=36.37V$	$P_{mp}=221,90W$ $I_{mp}=7.33A$ $U_{mp}=30.26V$

Using equation (5) and results obtained through simulation for standard test simulation the monocrystalline module has efficiency 20% while efficiency of polycrystalline is 15.25%. Also, using equation (6) and results obtained through simulations it is calculated that monocrystalline module has fill factor 77.91%, while the polycrystalline has fill factor 75.56%. 1000W/m², T=25°C

5. Conclusion

In this paper, PSIM simulations of equivalent single-diode model of solar cell for two commercial solar modules were performed to generate I-V and P-V characteristics. The simulations were performed under standard normal conditions and nominal operating cell temperature. The obtained results followed the expected values given in manufactures specifications.

Using the obtained numerical and graphical results, and data from manufactures this paper shows that the monocrystalline module has better performances in term of output voltage and power, efficiency and fill factor. This is due to higher silicone purity of monocrystalline cell because is consisted of a single ingot, whereas a polycrystalline cell is consisted of a multiple structures. In term of cost, monocrystalline solar modules are more expensive than polycrystalline modules.

6. References

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MHD THREE DIMENSIONAL STAGNATION-POINT FLOW OF A NEWTONIAN FLUID TOWARDS A UNIFORMLY HEATED AND MOVING PERMEABLE VERTICAL PLATE

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Abstract: We investigate the three dimensional stagnation-point flow of an electrically conducting incompressible viscous fluid towards a moving vertical permeable plate in the presence of a transverse uniform magnetic field. The partial differential equations governing flow and heat transfer are reduced to a set of nonlinear ordinary differential equations by using the appropriate transformations. The MATLAB routine BVP4c is successfully applied to solve these nonlinear ordinary differential equations. The results are compared with those known from the literature and an excellent agreement is found. The effects of the suction/injection parameter on the velocity components, wall shear stress, temperature and heat transfer are discussed through the graphs and tables.

Keywords: CONVECTION, MAGNETOHYDRODYNAMICS(MHD), NEWTONIAN FLUID, STAGNATION-POINT FLOW

1. Introduction

Flow and heat transfer over a moving flat surface is a significant factor in several industrial and practical engineering applications such as, cooling of electronic components, crystal growth, geothermal systems, heat exchangers, nuclear reactors, metallurgical processes, and others.

The analysis of classical two-dimensional stagnation point flow toward a rigid horizontal plane dates back to the pioneering investigation by Hiemenz¹. The corresponding temperature distribution was reported by Goldstein². The axisymmetric case was investigated by Homann³. Both two-dimensional and axisymmetric flows were extended to three dimensions by Howarth⁴ and Davey⁵. Stagnation point flows on moving plates were considered by Rott⁶, Wang⁷, Libby⁸, and Weidman and Mahalingam⁹. The most general solution of the Navier-Stokes equations and energy equation for non-axisymmetric three-dimensional stagnation-point flow and heat transfer on a flat plate was presented by Abbasi and Rahimi¹⁰.

Convection in a boundary layer flow was first considered by Sparrow et al.¹¹. They obtained similarity solutions for the combined forced and free convection flow and heat transfer about a non-isothermal body subjected to a non-uniform free stream velocity. Due to their importance in various branches of science, engineering, and technology, convection flows have been extensively studied by several authors and discussed in some articles¹²⁻¹⁶. Recently, Wang and Ng¹⁷ presented the solutions for the two-dimensional and axisymmetric stagnation flow toward a heated vertical plate with Navier's slip condition.

The effect of suction on the Hiemenz problem was first considered by Schlichting and Bussmann¹⁸. The heat and mass transfer on a stretching sheet with suction or blowing was investigated by Gupta and Gupta¹⁹. Hiemenz and Homann magnetic flows and heat transfer problems on a permeable surface were considered by Attia^{20,21} in the presence of uniform suction or injection. The effect of uniform suction or injection on the two-dimensional stagnation point flow towards a stretching horizontal plate with heat generation was examined by Attia and Seddeek²². Two-dimensional stagnation point flow and heat transfer problem towards a stretching vertical permeable sheet was studied by Ishak et al.²³.

Because of its increasing importance in recent years for its applications in MHD power generators, MHD pumps, MHD accelerators, and MHD flowmeters, flow and heat transfer problem of electrically conducting fluids has drawn the attentions of many investigators. The study of the hydromagnetic interaction of an electrically conducting viscous fluid with an applied magnetic field in stagnation-point flow was initiated by Neuringer and McIlroy²⁴. In their subsequent study²⁵, they considered the heat transfer aspect of the same problem. Ariel²⁶ reexamined the Hiemenz flow in hydromagnetics in general, and the numerical procedure given by Na²⁷ in particular. The problem of steady forced convection flow of

an electrically conducting and heat generating/absorbing fluid near a stagnation point was solved numerically by Chamkha²⁸. In a following paper Chamkha²⁹ obtained non-similar solution with the finite difference method for the problem of mhd mixed convection flow along a semi-infinite vertical plate embedded in a uniform porous medium with heat generation and magnetic dissipation. Attia³⁰ concerned with the axisymmetric stagnation point flow towards a stretching surface in the presence of uniform magnetic field with heat generation. Abbasbandy and Hayat³¹ developed the homotopy analysis solution for the problem considered by Chamkha²⁸. Recently, Borelli et al.³² studied numerically the steady three-dimensional stagnation-point flow of an incompressible, homogenous, electrically conducting Newtonian fluid over a flat plate. In a more recent study Demir and Barış³³ obtained the numerical solutions for the two-dimensional and axisymmetric stagnation-point flow of an electrically conducting incompressible viscous fluid towards a moving vertical plate in the presence of a transverse uniform magnetic field using MATLAB routine BVP4c.

The purpose of the present paper is to study the hydromagnetic viscous flow and heat transfer in the vicinity of a stagnation-point on a moving permeable vertical plate. A study of the problem under discussion was conducted by Demir and Barış³³ in the absence of suction or injection. The governing equations are transformed into a system of nonlinear ordinary differential equations by means of similarity variables. The resulting equations, together with their corresponding boundary conditions, are solved through the MATLAB routine BVP4c. Particular cases of our results are compared with existing results of Wang and Ng¹⁷ and Demir and Barış³³. An excellent agreement of the present results with existing results has been shown.

2. Formulation of Problem

We consider the three dimensional stagnation-point flow of an incompressible viscous fluid towards a moving permeable vertical plate. The flow is illustrated in Figure 1. The velocity components corresponding to the x -, y - and z - directions are respectively denoted by u , v and w . Far from the plate, as z tends to infinity, the velocity components are denoted by u_∞ , v_∞ and w_∞ . a is a physical constant, depending on the velocity in potential motion, T_w the temperature of the plate, T_∞ the temperature far from the surface, g the gravitational acceleration, V_0 the constant plate velocity in the y - direction and B_0 the external uniform magnetic field applied in the z - direction.

The fluid is electrically conducting in a transverse magnetic field. The induced magnetic field is neglected under the assumption of a small magnetic Reynolds number. We assume that the flow is steady and laminar, all the fluid properties are constant and the plate is electrically non-conducting. The effects of viscous dissipation, Ohmic heating and Hall current are not included in the analysis, since they are generally small in the stagnation-point region. Also,

the radiant heating is neglected. In addition, the imposed and induced electrical fields are assumed to be negligible.

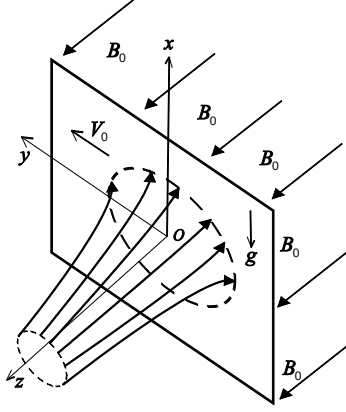


Fig. 2 Physical model and coordinate system.

Following Demir and Bariş³³, the three-dimensional Navier-Stokes equations with the Boussinesq term, the energy equation and the boundary conditions are written as:

$$\rho(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z}) = -\frac{\partial p}{\partial x} + \mu(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}) + g\beta(T - T_\infty) + F_x \quad (1)$$

$$\rho(u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z}) = -\frac{\partial p}{\partial y} + \mu(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}) + F_y \quad (2)$$

$$\rho(u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z}) = -\frac{\partial p}{\partial z} + \mu(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}) + F_z \quad (3)$$

$$\rho c_p(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z}) = k(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}) + Q_0(T - T_w) \quad (4)$$

$$\begin{aligned} z=0: \quad u=0, \quad v=V_0, \quad w=-W_0, \quad T=T_w \\ z \rightarrow \infty: \quad u \rightarrow u_\infty = ax, \quad v \rightarrow v_\infty = ay, \\ w \rightarrow w_\infty = -2az, \quad T \rightarrow T_\infty \end{aligned} \quad (5)$$

where ρ is the density, p the pressure, μ the dynamic viscosity, T the temperature, c_p the specific heat at constant pressure, k the thermal conductivity, Q_0 the volumetric rate of heat generation, β the coefficient of thermal expansion and (F_x, F_y, F_z) are the components of the source term $\mathbf{F} = \sigma_0(\mathbf{v} \times \mathbf{B}) \times \mathbf{B}$ due to the imposed magnetic field, where σ_0 is the electrical conductivity and $\mathbf{B} = (0, 0, B_0)$ is the transverse uniform magnetic field applied to the fluid. Following Wang and Ng¹⁷ and Demir and Bariş³³, we shall seek a solution of the form

$$\begin{aligned} u &= m(z) + xf'(z) \\ v &= h(z) + yf'(z) \\ w &= -2f(z) \\ T &= T_\infty + (T_w - T_\infty)\theta(z). \end{aligned} \quad (6)$$

where the prime denotes the differentiation with respect to z . Substituting Eq. (6) into Eqs. (1)-(4), eliminating the pressure term from these equations, and non-dimensionalizing the resulting equations using

$$\begin{aligned} \eta &= \sqrt{\frac{\rho a}{\mu}} z, \quad F(\eta) = \sqrt{\frac{\rho}{\mu a}} f(z), \\ H(\eta) &= \frac{1}{V_0} h(z), \quad M(\eta) = \sqrt{\frac{\rho}{\mu a}} m(z) \end{aligned} \quad (7)$$

we arrive at the following equations

$$F''' + 2FF'' - (F')^2 + \text{Ha}(1 - F') + 1 = 0 \quad (8)$$

$$H'' + 2FH' - F'H - \text{Ha}H = 0 \quad (9)$$

$$M'' + 2FM' - M'F - \text{Ha}M + \lambda\theta = 0 \quad (10)$$

$$\theta'' + 2\text{Pr}F\theta' + \alpha\text{Pr}\theta = 0 \quad (11)$$

$$\begin{aligned} \eta=0: \quad F(0) &= s, \quad F'(0) = 0, \quad H(0) = 1, \quad M(0) = 0, \quad \theta(0) = 1 \\ \eta \rightarrow \infty: \quad F'(\infty) &= 1, \quad H(\infty) = 0, \quad M(\infty) = 0, \quad \theta(\infty) \rightarrow 0. \end{aligned} \quad (12)$$

where the prime denotes the differentiation with respect to η . Ha is the non-dimensional magnetic parameter, λ is the non-dimensional convection parameter, Pr is the Prandtl number, α is the non-dimensional heat generation parameter and s is the suction/injection parameter and they are defined as:

$$\begin{aligned} \text{Ha} &= \frac{\sigma_0 B_0^2}{\rho a}, \quad \lambda = \frac{g\beta(T_w - T_\infty)\sqrt{\rho}}{a\sqrt{\mu a}}, \\ \text{Pr} &= \frac{\mu c_p}{k}, \quad \alpha = \frac{Q_0}{\rho c_p a}, \quad s = \frac{W_0}{2} \sqrt{\frac{\rho}{\mu a}} \end{aligned} \quad (13)$$

It should be noted that $s > 0$ is for mass suction and $s < 0$ is for mass injection^{19, 23}. The dimensionless expressions for the velocity components, shear stress on the plate in the x and y directions and the heat transfer rate per unit area on the plate are given through the following equations³³:

$$\begin{aligned} \frac{u}{ax} &= \frac{1}{x} \sqrt{\frac{\mu}{\rho a}} M(\eta) + F'(\eta), \quad \frac{v}{V_0} = H(\eta) + \frac{ay}{V_0} F'(\eta), \\ \frac{w}{2\sqrt{\mu a/\rho}} &= -F(\eta) \end{aligned} \quad (14)$$

$$\tau_{wx} = -\frac{1}{\mu a} t_{xz} \Big|_{z=0} = -\frac{1}{x} \sqrt{\frac{\mu}{\rho a}} M'(0) - F''(0), \quad (15)$$

$$\tau_{wy} = -\frac{1}{V_0 \sqrt{\mu \rho a}} t_{yz} \Big|_{z=0} = -H'(0) - \frac{ay}{V_0} F''(0)$$

$$q_w = -k \frac{\partial T}{\partial z} \Big|_{z=0} = -k \sqrt{\frac{\rho a}{\mu}} (T_w - T_\infty) \theta'(0). \quad (16)$$

3. Results and discussion

The present paper is an extension of the investigation by the authors³³ in which the suction/injection cases were not considered. Therefore, we aim in this section to study the effects of the suction/injection parameter on the behavior of the fluid velocity, the temperature distribution, the shear stresses and the heat transfer rate on the plate in the case of permeable sheet. The solution was obtained numerically by the MATLAB routine BVP4c. We refer the reader to the book by Shampine et al.³⁴ for details about how to solve boundary value problems with bvp4c. We set the relative and absolute tolerance equal to 10^{-7} and the corresponding differential

equations were integrated from $\eta=0$ to $\eta=\eta_\infty$, where η_∞ is a sufficiently large number. In practice, setting η_∞ as low as 12 yields satisfactory accuracy for the problem under discussion. As a test of the accuracy of the solution, the values of $F''(0)$, $M'(0)$ and $\theta'(0)$ are compared with corresponding numerical values reported by Wang and Ng¹⁷ and Demir and Barış³³. As shown in Table 1 an excellent agreement is found for $Ha = 0$, $\alpha = 0$, $\lambda = 1$, $Pr = 0.7$ and $s = 0$.

Table 1: Comparison of the numerical results with those of Wang and Ng (2013)

	Wang and Ng $Pr = 0.7$	Demir and Barış $Ha = 0, \alpha = 0, \lambda = 1,$ $Pr = 0.7$	Present Work $Ha = 0, \alpha = 0, \lambda = 1$ $Pr = 0.7, s = 0$
$F''(0)$	1.31194	1.311938	1.311938
$M'(0)$	0.4955	0.495440	0.495440
$\theta'(0)$	-0.6654	-0.665378	-0.665378

Figure 2 shows velocity component in the x- direction. It is clear from Figure 2 that in the case of mass suction ($s > 0$) the velocity component in the x- direction increases. On the other hand, we observe that the velocity component in the x- direction decreases for the case of mass injection ($s < 0$).

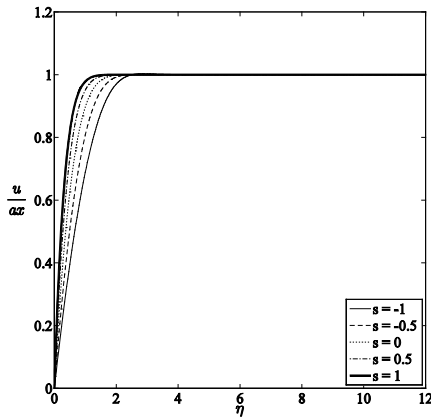


Fig. 2 Variation of the non-dimensional velocity component in the x-direction with suction/injection parameter s ($Ha = 1, Pr = 0.7, \alpha = 0.2, \lambda = 0.5, \sqrt{\mu/\rho\alpha x^2} = 0.4, ay/V_0 = 0.4$)

The velocity component in the y- direction is presented in Figure 3. From the figure, we observe that the velocity component in the y- direction increases for the case of mass injection ($s < 0$) while decreases for the case of mass suction ($s > 0$). Furthermore, the tangential velocity components approach the free stream values more quickly in the case of mass suction ($s > 0$). In other words, the velocity boundary layer is thicker in the case of mass injection ($s < 0$).

Figure 4 displays the effect of suction/injection parameter on the velocity component in the z- direction. The figure shows that the magnitude of velocity component in the z- direction decreases in the case of mass injection ($s < 0$) while increases for the case of mass suction ($s > 0$).

Figure 5 illustrates the temperature profiles for different values of the suction/injection parameter. The numerical results show that the effect of increasing values of suction/injection parameter results in a decrease of the thermal boundary layer thickness. It is apparent from Figure 5 that the temperature of the fluid decreases in the case of mass suction ($s > 0$) while increases in the case of mass injection ($s < 0$).

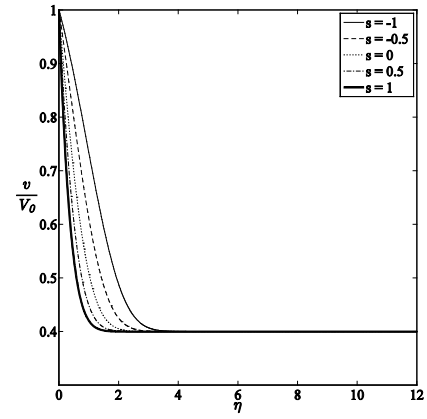


Fig. 3 Variation of the non-dimensional velocity component in the y-direction with suction/injection parameter s ($Ha = 1, Pr = 0.7, \alpha = 0.2, \lambda = 0.5, \sqrt{\mu/\rho\alpha x^2} = 0.4, ay/V_0 = 0.4$)

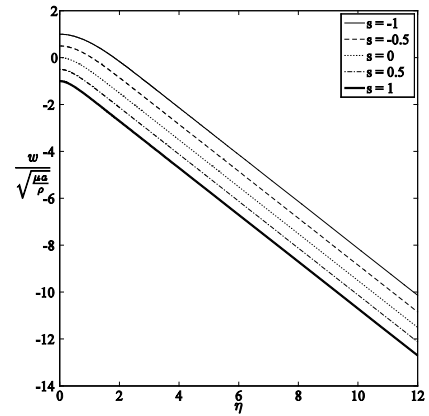


Fig. 4 Variation of the non-dimensional velocity component in the z-direction with suction/injection parameter s ($Ha = 1, Pr = 0.7, \alpha = 0.2, \lambda = 0.5, \sqrt{\mu/\rho\alpha x^2} = 0.4, ay/V_0 = 0.4$)

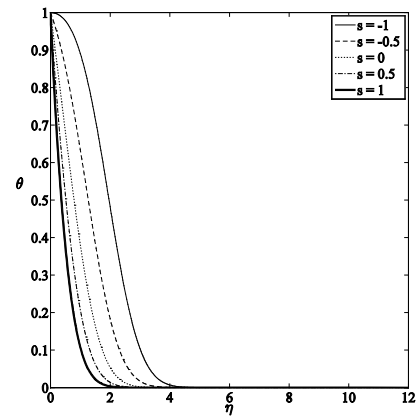


Fig. 5 Variation of the temperature profiles with suction/injection parameter s ($Ha = 1, Pr = 0.7, \alpha = 0.2, \lambda = 0.5, \sqrt{\mu/\rho\alpha x^2} = 0.4, ay/V_0 = 0.4$)

The values of tangential shear stresses and heat transfer rate on the plate are tabulated in Table 2 for different values of the suction/injection parameter. We conclude from this table that the magnitudes of tangential shear stresses and heat transfer rate increase with the increase in the suction/injection parameter.

Table 2. Shear stress and heat transfer rate on the plate ($Ha = 1$, $Pr = 0.7$, $\alpha = 0.2$, $\lambda = 0.5$, $\sqrt{\mu/\rho\alpha x^2} = 0.4$, $ay/V_0 = 0.4$)

s	τ_{wx}	τ_{wy}	$-\theta'(0)$
-1	-0.892956	0.199941	-0.000230
-0.5	-1.241543	0.382210	0.214127
0	-1.732019	0.685898	0.608957
0.5	-2.355983	1.093726	1.129628
1	-3.085162	1.571353	1.721611

Conclusions

In this paper, we investigated the effect of the suction/injection parameter on the hydromagnetic three-dimensional stagnation-point flow against a moving vertical plate that is described by systems of coupled nonlinear ordinary differential equations were given by Demir and Barış³³. The results were obtained using the popular MATLAB routine BVP4c. The graphical and tabular presentation of the results revealed the effects of the relevant parameters on the velocity components, temperature distribution, tangential shear stresses and heat transfer.

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THE SOLUTION OF THE SYNTHESIS PROBLEM OF PARTIAL MOTION CONTROL OF A RIGID BODY IN AN INCOMPRESSIBLE VISCOUS FLUID

РЕШЕНИЕ ЗАДАЧИ СИНТЕЗА ЧАСТИЧНОГО УПРАВЛЕНИЯ ДВИЖЕНИЕМ ТВЕРДОГО ТЕЛА В ВЯЗКОЙ НЕСЖИМАЕМОЙ ЖИДКОСТИ

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Abstract: The report presents an analytical and numerical analysis of mathematical model of the control synthesis of a solid body moving in an incompressible viscous fluid. It is assumed that the body does not have its own propulsion system, but is equipped with controlled rudders - wings of finite span. It pops up under the influence of the buoyancy force and wings lift. The basic mathematical model was presented by the authors at XII MTM Congress held in September 2015.

KEYWORDS: MOTION OF SOLIDS IN A FLUID, TRAFFIC CONTROL, BUOYANCY FORCE, ENSURING ACCESS TO THE GIVEN POINT, WINGS OF FINITE SPAN, WINGS LIFT

1. Introduction

The effectiveness of observations and measurements obtained in the study of the underwater world via underwater vehicles, in particular, unmanned, depends on minimizing the impact of these submersible crafts to surrounding underwater environment. First of all, it refers to a moving apparatus, which movement is carried out by various power plants (screw propeller or other propulsion). Therefore, the reduction or elimination of such effects is an important application. The ideal situation would obviously be the complete lack of engine. This means that movement control of the body can be carried out only by natural hydrodynamic forces, for instance, the Archimedes buoyancy or an wing lift effect (the body can be equipped with wing). Basic terminology and classical results for the bodies motion in continuum can be found in books [1,2].

2. Mathematical model

A large borehole bottom reservoir with an ideal incompressible low-conductivity stratified liquid is considered. There are assumed each layer has uniform density, which is known. Furthermore, liquid in each layer can move rectilinearly and uniformly along the horizontal axis.

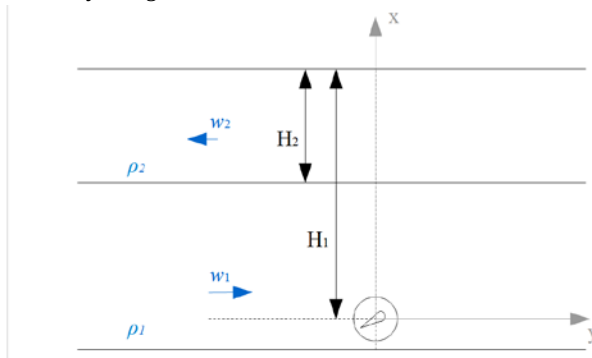


Fig. 1. Double-layer continuum figure.

In this paper the authors consider two-dimensional motion of submersible craft case. At the initial time this body is located at a predetermined depth in stationary state (fig. 1).

It is assumption to consider an uniform sphere-shaped rigid body with two similar symmetrically located around the ball centre wings (fig. 2).

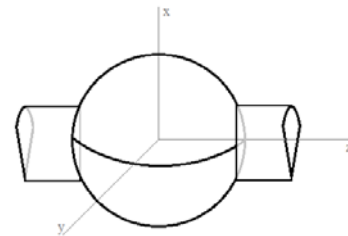


Fig. 2. Schematic submersible craft image.

At the previous authors paper [3] mathematical model of the submersible craft plane motion was constructed. It allows to control the body through wings angle of attack modifications:

$$\begin{cases} \left(m + \frac{2}{3}\rho\pi R^3\right)\frac{d^2x}{dt^2} = F_{arch} - 2F_i\cos\delta - (F_{drag}^{(1)} + 2F_{drag}^{(2)})\cos\delta - 2F_{lift}\sin\delta - F_g; \\ \left(m + \frac{2}{3}\rho\pi R^3\right)\frac{d^2y}{dt^2} = -2F_i\sin\delta - (F_{drag}^{(1)} + 2F_{drag}^{(2)})\sin\delta - 2F_{lift}\cos\delta. \end{cases}$$

F_{arch} – buoyancy force, $F_{drag}^{(j)} = C_X^{(j)}S^{(j)}\frac{\rho v^2}{2}$ – head resistance force for sphere ($j=1$) and wings ($j=2$), $F_{lift} = \rho v^2 S \frac{k\alpha}{1+\mu_0}$ – wing lift, $F_i = \frac{\rho}{2}v^2 S \frac{\mu_0}{2k} \left(\frac{2k\alpha}{1+\mu_0}\right)^2$ – induced drag force (details can be found in [3]).

This paper devotes to an constructed mathematical model analysis of control possibility of rising trajectory of the submarine craft. Besides, it is necessary to estimate in what measure parametric variations leads to motion trajectory of the body variations.

It is supposed that an attack angle is a small quantity [4]. We also allow this assumption. The attack angle smallness necessitates the angle δ smallness. Therefore, we can accept $\sin\delta \approx \delta, \cos\delta \approx 1$.

Using the change of variables

$$\begin{aligned} x &= z_1 & y &= z_3 \\ \dot{x} &= \dot{z}_1 = z_2 & \dot{y} &= \dot{z}_3 = z_4 \end{aligned}$$

we transform the mathematical model to a nonlinear differential equation system:

$$(1) \quad \begin{cases} \dot{z}_1 = z_2, \\ \dot{z}_2 \cdot b_0 = b_1 - (b_2 \cdot \alpha^2 + b_3 + 2b_4) \cdot (z_2^2 + z_4^2) - 2b_5 \cdot \alpha \cdot z_4 \cdot \sqrt{z_2^2 + z_4^2}, \\ \dot{z}_3 = z_4 + w, \\ \dot{z}_4 \cdot b_0 = -(b_2 \cdot \alpha^2 + b_3 + 2b_4) \cdot z_4 \cdot \sqrt{z_2^2 + z_4^2} + 2b_5 \cdot \alpha \cdot (z_2^2 + z_4^2). \end{cases}$$

where:

$$b_0 = m + \frac{2}{3}\rho\pi R^3, \quad b_1 = \rho gV - mg, \quad b_2 = \rho S_{kp} \frac{2k\mu_0}{(1+\mu_0)^2}, \quad b_3 = c_{0_sph} \frac{\rho\pi R^2}{2}, \quad b_4 = c_{0_w} \frac{\rho S_w}{2}, \quad b_5 = \rho S_{kp} \frac{k}{1+\mu_0}.$$

A motion trajectory of the submarine craft can be modified by the attack angle α values variations. For instance, we will consider three cases:

- The zero attack angle;
- An piecewise constant attack angle value;
- An attack angle is a small nonzero constant.

If H_1 is an initial immersion depth of the submarine craft and H_2 is an second layer thickness, we can find an required displacement vector of the body in the near-bottom layer from system (1) using zero initial conditions. In the second layer calculations are done similarly with consistent substitution of initial conditions

2.1. Numerical examples.

The examples of calculation on the basis of found equations (1) are described below. We use the software called MATLAB 7.10.0 (R2010A).

Motion trajectories of the submarine craft for different attack angles in a double-layer liquid with differently directed flows ($\vec{w}_1 \uparrow \downarrow \vec{w}_2$) are presented on the figure 3.

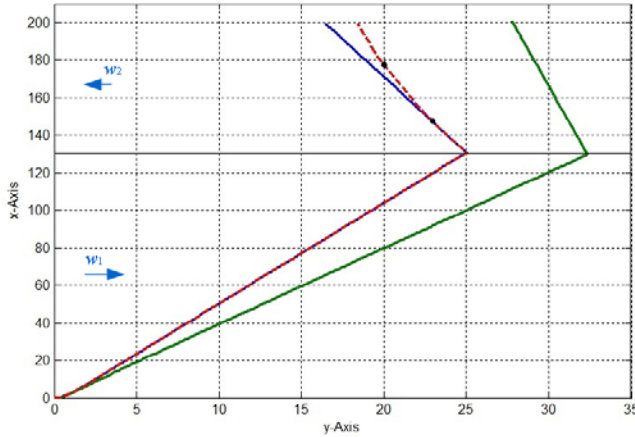


Fig. 3. Motion trajectories of the submarine craft for different attack angles:

blue - for the zero attack angle;

green – for the attack angle $\alpha = 0.2$;

red – for the piecewise constant attack angle value (firstly, $\alpha = 0$; in second layer, when $y = 23$ $\alpha = 0.1$ and when $y = 20$ $\alpha = 0.2$).

The motion trajectory of the submarine craft in homogeneous liquid without any shear flows for the piecewise constant attack angle value is presented on the figure 4. The law of the attack angle variation is displayed in Table 1.

Table 1. The law of the attack angle variation.

The attack angle value	Conditions of the attack angles changing
$\alpha = -0.2$	$y = -2$
$\alpha = -0.1$	$y = -3$
$\alpha = 0$	$x = 100$
$\alpha = 0.1$	$y = -1.5$
$\alpha = 0.2$	$x = 200$ (The body had surfaced.)

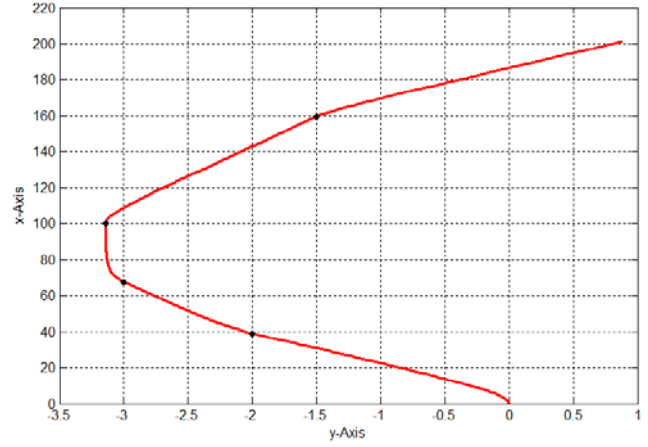


Fig. 4. Motion trajectory of the submarine craft for the piecewise constant attack angle value in homogeneous liquid.

At these examples the following values of a quantities are offered. The diameter of the surfaced body (ball) is 1 meter; its mass is calculated like $m = 0.98\rho V$, where ρ is averaged body density. It is assumption to consider rectangular wings with wingspan 1 meter, aspect ratio of the wing 5 and relative maximum thickness 16 %. An initial immersion depth H_1 equals 200 meters. The second layer depth H_2 is 70 meters. Liquid densities in different layers equals $\rho_1 = 1050 \text{ kg/m}^3$ and $\rho_2 = 1025 \text{ kg/m}^3$. Shear flows have speeds $|\vec{w}_1| = 0.15 \text{ m/s}$ and $|\vec{w}_2| = 0.1 \text{ m/s}$.

3. Conclusion

At this paper the motion trajectory of the submarine craft calculation algorithm is presented. Mentioned body can rise up under the influence of the Archimedes buoyancy and an wing lift effect.

The attack angle control possibility of the submarine craft movement is analyzed. A problem of optimal wings forms and sizes remains open.

4. Literature

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MICROSTRUCTURAL CHANGES IN THE FORGE WELD AREA DURING HIGH-FREQUENCY ELECTRIC RESISTANCE WELDING

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Abstract: High-frequency electric resistance welding is one of the most common process for production of longitudinal seam welded carbon steel pipes suitable for line pipe, casing and tubing. In this pipe production process, the hot rolled strip goes into the forming mill where it is gradually cold formed into a tubular shape in several stages of forming rolls and its edges are continuously joined by a combination of localized electrical resistance heating and forge pressure. High frequency electric resistance welding generally involves high temperature, forge pressure and subsequent cooling, and as the result of this thermal cycle occurs significant microstructural changes. These microstructural changes provides a wealth of information on weld seam quality and edge preparation of hot rolled strips.

In this paper, microstructural changes in the forge weld area during high frequency electric resistance welding (HFERW) of longitudinal seam welded pipes $\varnothing 114.3 \times 5.21 \text{ mm}$ were investigated.

Keywords: MICROSTRUCTURAL CHANGES, WELD AREA, HEAT AFFECTED ZONE, STEEL PIPES

1. Introduction

Welding is a complex process and the quality of a weld is a function of interaction of significant number of variables together with the microstructural changes attendant upon welding. High-frequency electric resistance welding (HFERW) process is one of the most extensively methods for production high quality longitudinal seam welded carbon steel pipes suitable for line pipe, casing and tubing. In this process, hot rolled strip is gradually formed into round shape through roll-forming stands, and its edges are joined by a combination of localized high-frequency electric resistance heating and forge pressure, as schematically illustrated in Figure 1 [1,2]. Most of these pipes are produced according to API Standard [3] plus client supplementary requirements. Under this heat input condition and forge pressure it is possible to improve the weld joint quality and productivity of longitudinal seam welded carbon steel pipes.

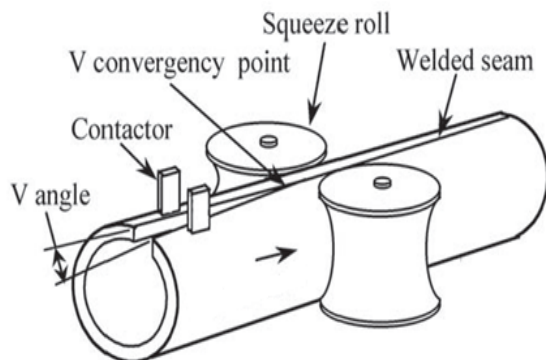


Fig.1 Schematic illustration of HFERW

The high-frequency current applied to the strip edges through sliding contacts, concentrated on the surface layer of the strip edges due to the “skin” and “proximity” effects, generate joule heat and the hot “Vee” converge edges are forged together in the weld squeeze rolls and a forge type weld is achieved [4]. The HF weld is a true forge weld in that no filler metal is added and, if done properly, no molten or oxidized metal is left on the bond line. Figure 2 shows that all of the molten thin layer and metal oxides and other inclusions are squeezed out of the weld toward the outside and inside surfaces as the edges pass between the weld rolls.

The high frequency current follows a “Vee” shaped path down one edge of the “Vee” and up the other, from one sliding contact (A) to the other (B), completing electrical circuit, Figure 3.

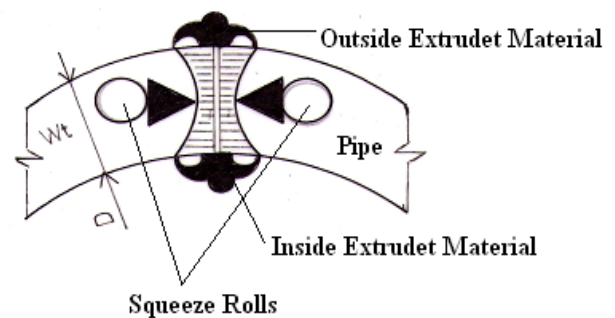


Fig.2 High frequency electric resistance forge weld

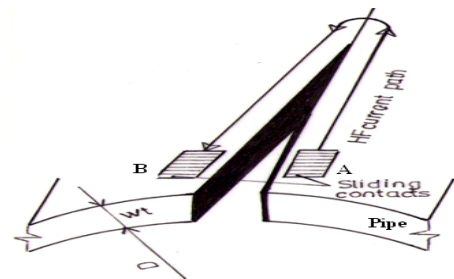


Fig.3 Sliding contacts of high frequency current

During high frequency heating, high frequency current enters the strip edge from the top and the side of the edge. The parent metal melting occurs in butting (roughness) surfaces and this molten layer formed is squeezed out from the edges together with the oxide films. Heat penetration produced by high frequency current into the edges of the parent metal is greater at the top and bottom corners and less at the middle wall thickness, Figure 4.

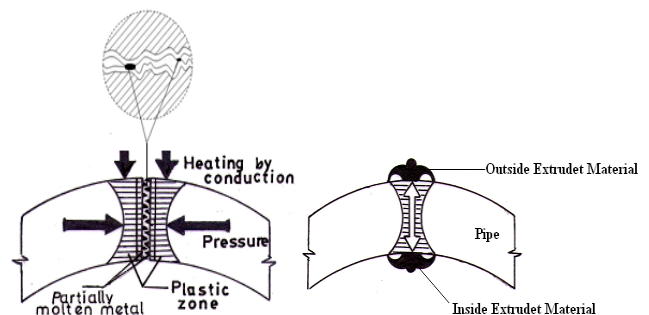


Fig.4 Schematic sequence of HFERW

From the metallurgical point of view, high frequency electric resistance welding (HFERW) is characterized by extremely rapid heating and cooling over a very short period combined with forging pressure. This specific thermal cycles combined with forging pressure are important metallurgical factors. As a result of these metallurgical factors some complex microstructure changes can occur.

The material extruded on the inside and outside weld surfaces, usually removed by scarfing while still hot and forms a typical HFERW weld with narrow bond line (BL) or fusion line (FL) and associated local heat affected zone (HAZ) is formed [4]. The high frequency electric resistance welded seam is subjected to post weld heat treatment in-line such as induction heating and gradually air cooling, the purpose of which is to eliminate zones of excessive hardness from the initial welding process as such zones could be susceptible to various forms of environmental cracking.

Microstructural changes that takes place during the welding covers the properties of welded pipes, defects associated with welding and the performance of welded pipes in service.

The normal HFERW weld area is shown in Figure 5 [4]. Note that the heat affected zone (HAZ) is shaped like an hourglass. Weld fusion line (FL) or weld bond line (BL) is in the centre of the heat affected zone, vertical to the pipe wall thickness. The flow lines are symmetrical around the bond line.

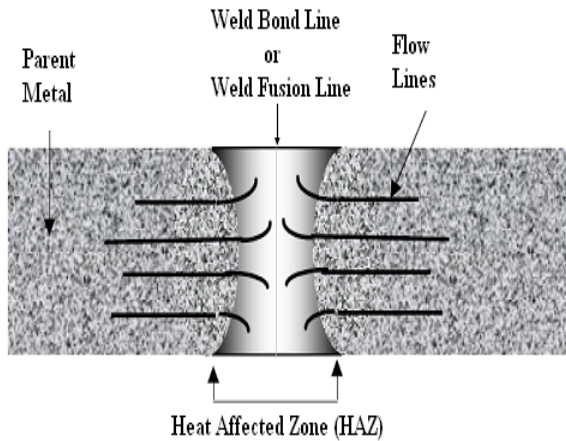


Fig.5 High frequency electric resistance weld area

Hot rolled coils used for HFERW pipes has fine grained microstructure showing a prominent banding as a results of the rolling operations at the steel mill. These bands are usually straight, running along the rolling direction [5]. Hot rolled coils or skelp used for HFERW steel pipes often contain alternating thin layers or bands of ferrite and pearlite.

The plastic deformation which is realized under the action pressure of the squeezing rolls caused metal flows of the hot rolled coils towards the outside and inside surfaces of the bond line. This flow pattern consists of streaks and striations. The orientation of this pattern, with respect to the new surface, indicates the direction of metal flow lines (fibres), respectively flow angles during plastic deformation [6]. The flow lines, respectively flow angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$), Figure 6, are a natural consequence of applied mechanical pressure of the squeezing rolls. The orientation of the flow lines indicates the direction of the metal flow during plastic deformation. By the measurement of the flow angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$) it is possible to determine directly whether the squeezing pressure and relevant welding temperature are correct or not.

The high frequency electric resistance welded joint is subjected to a local post weld heat treatment (PWHT) in-line by the inductive heating, followed by air cooling, Figure 7. The aims of this heat treatment is to produce certain microstructure and desired mechanical properties (hardness, yield strength, ultimate tensile

strength, toughness, ductility etc.). During local post weld heat treatment (PWHT) of the welded joint, depending on the temperature range and the cooling rate, microstructural changes takes place and these changes covers the properties of the welded joint and the performance of welded pipes in service

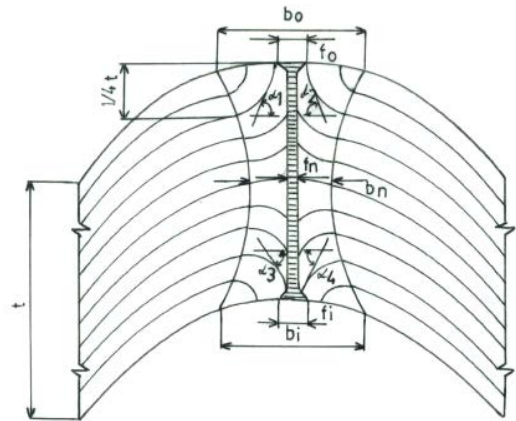


Fig.6 Flow lines (fibres) and flow angles around bond line during plastic deformation

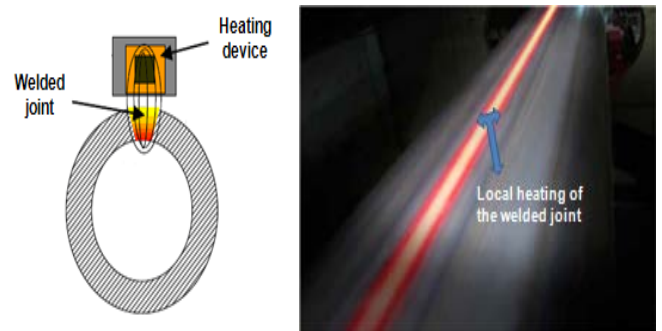


Fig.7 Local postweld normalizing heat treatment of HFERW

Forge weld area of HFERW may be divided into four zones, Figure 8, [4]: 1-bond line (BL) or fusion line (FL); 2-heat affected zone (HAZ); 3-Edge of the heat affected zone and 4-base metal (BM). These different zones are normally defined by the peak temperature experienced at certain distance from the fusion line during welding. Each zone in the weld area is characterized by a unique microstructure and hence different mechanical properties. The zones of the weld area are quite narrow and it is difficult to investigate the behavior of specific location without interference from the adjacent zones with different properties.

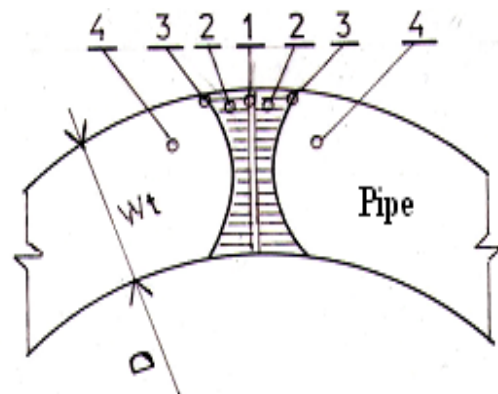


Fig.8 Schematic illustration of constitutive parts of weld area

2. Experimental procedure

High-frequency electric resistance welding was conducted using an L-16 in, pipe mill Newco IMK-Ferizaj, Kosova. Newco IMK-Ferizaj-Kosova produces high frequency electric resistance longitudinal seam welded steel pipes with Ø114.3-406.4mm diameter and 3.2-12.7mm wall thickness. Casing pipes Ø114.3x5.21mm are typical case in the mill production schedule, hence in this paper these pipes were investigated. Pipes Ø114.3x5.21mm were fabricated from high strength steel coils J55 according to API [3] standard, using the pipe mill equipped with a contact type high frequency electric resistance welding machine-Thermatool. The frequency of current was 400kHz.

Chemical composition and mechanical properties of the used steel are given in Table 1 and 2.

Table 1: Chemical composition of used steel coils J55

Steel coils	Chemical composition [wt-%]							
	C	Mn	Si	P	S	Al	Nb	N
API grade J55	0.141	1.113	0.229	0.014	0.008	0.047	0.017	0.0072

Table 2: Mechanical properties of used steel coils J55

Steel coils	Mechanical properties		
	Re	Rm	A _{2"}
	[MPa]		[%]
API grade J55	453	557	32.5

Whether or not appropriate welding has been performed was confirmed by conducting flattening test and metallographic examination [7].

Two rings (10-15cm long) were extracted from several pipes for use as the specimens for flattening test, Figure 9.

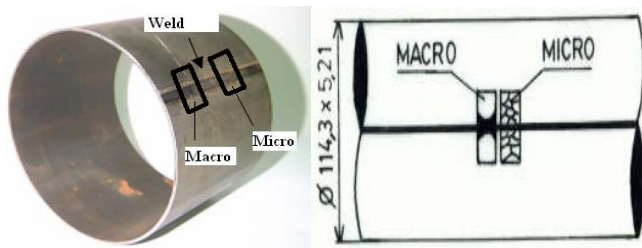


Fig.9 Sketch illustrating the orientations of the metallographic specimens used

Specimens for metallographic examination were cut out from the weld joint of casing pipes Ø 114.3x5.21mm, perpendicular to the welding direction.

In order to determine metallographic macro and micro analysis, the metallographic specimens were prepared by standard metallographic techniques that includes grinding, polishing and etching with suitable etchant (nital and Oberhoffer) to reveal the macro and microstructure.

Mechanical grinding is performed in successive steps using SiC abrasive papers of different grit sizes, usually 180, 220, 320, 600, 800 and 1000 with continuous grit cooling to avoid structural changes. Mechanical polishing is performed using diamond paste on a short nap cloth disc. After polishing, the specimens were etched with suitable etchant (nital and Oberhoffer), followed by thorough washing and finally rinsed in alcohol and dried in a stream of warm air.

Macro metallographic analysis is performed on a etched cross section of the welded joint by standard visual examination with the naked eye and with optical microscope, NEOPHOT 21, at low magnification.

Micro metallographic analysis is performed on a etched cross section of the welded joint by optical microscope NEOPHOT 21, at high magnification.

3. Results and discussion

The test specimens were flattened in a hydraulic press, DIHNAFORIN PS 2043, at room temperature between to parallel plates with the weld line located 90° and 0° to the applied force. The specimens (rings) were flattened to a specified height according to API, Figure 9.

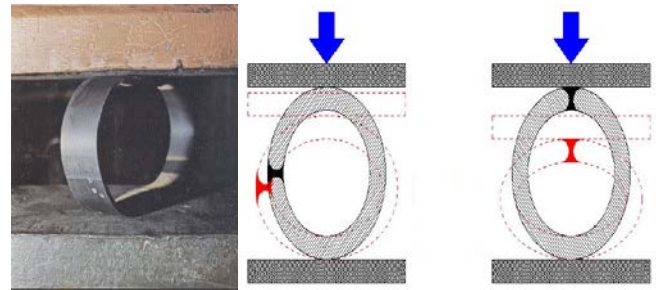


Fig.10 Schematic illustration of flattening test

During flattening testing, in all rings, there is no occurrence of cracks or breaks in the weld area in the position (90° and 0°) until the height specified according to API.

The shape, width and uniformity of the weld area as well as the degree of upset of the flow lines (fibres) and flow angles are presented in Figure 11, 12 and 13.

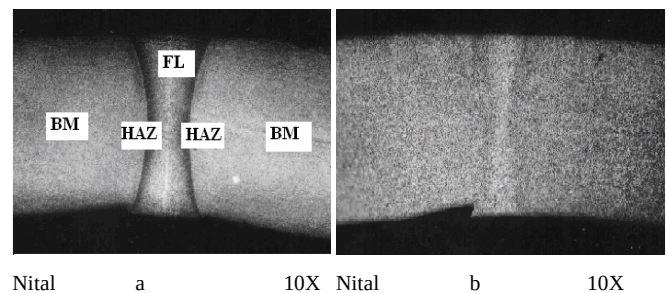


Fig.11 Macrostructure of a cross-section weld area

Macrostructure in Figure 10a shows a cross section of a typical high frequency electric resistance weld of the longitudinal steel pipes in the as welded condition prior to heat treatment. The width of the weld is uniform from top to bottom, indicating that the heat energy input was uniform. The fusion line (FL) or bond line (BL) is vertical to the wall thickness and is usually light colored because it is very low in carbon. Due to high temperature, the carbon amount at the fusion line oxidizes, leaving the iron without carbon to darken it. This part of the weld area called decarbonisation layer or light area [8].

Adjacent to the fusion line (FL) is the heat affected zone (HAZ) where the materials is affected by the heat of the welding process. The heat affected zone (HAZ) is shaped like an hourglass as a result of the heat generated by the high frequency current.

Macrostructure in Figure 10b indicates that after normalizing heat treatment, the forge weld areas is indiscernible from the rest of the base metal (BM).

Microstructure of the base metal (BM) and heat affected zone (HAZ) are shown by the photomicrographs in Figure 12. The photomicrograph on the left shows the microstructure of the base metal (BM), whereas the photomicrograph on the right shows the microstructure of the heat affected zone (HAZ) after normalizing heat treatment. The base metal (BM) has fine grained ferrite-pearlite microstructure with some bands in the entire the wall thickness. The heat affected zone (HAZ) has also fine grained ferrite-pearlite microstructure as a result of the proper normalizing heat treatment.



Fig.12 Microstructure of a cross-section weld area

Flow lines and flow angles, Figure 13 illustrates the influence of the forge pressure in the weld area.

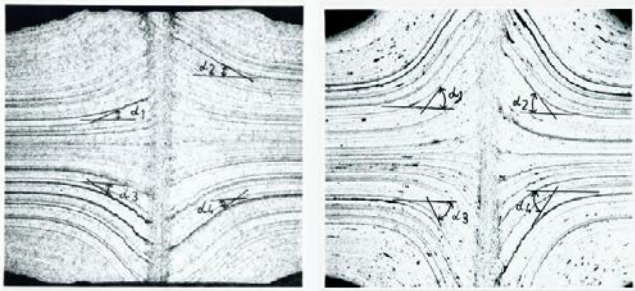


Fig.13 Flow lines and flow angles in the weld area

The flow lines are visible in all metallographic specimens and the degree of upset is different, depending from the intensity of plastic deformation of squeeze weld rolls. Figure 13 shows flow lines, respectively flow angles from some characteristic metallographic specimens of HFERW pipes Ø 114.3x5.21mm.

4. Conclusion

Following conclusions can be drawn from the present study:

Forge weld area during high frequency electric resistance welding (HFERW), undergoes considerable microstructural changes. Microstructural changes that occur in the forge weld area during high frequency electric resistance welding (HFERW) of carbon steel API Grade J55 are a result of the complex simultaneous interactions between thermal and mechanical factors. These microstructural changes affect the mechanical properties of the weld area and the performance of the welded joint.

Microstructural changes in the forge weld area can provide a wealth of information on the mill setup operations, weld quality, edge preparation and normalizing heat treatment in line as an important part of the production process.

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STUDY OF THE STRESS-STRAIN STATE OF THE VIBRATING EQUIPMENT

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Abstract In this paper is studied a vibratory conveyor that is placed on an elastic base. Using the closed contours method it was determined the system that needs to be solved to obtain graphical representation for the generalized coordinates determining the position of the mechanical system elements. The shaking conveyor represents the chase hanged or supported to the fixed section. The chase commits oscillating motions hereupon the cargo which is in the chase, migrates concerning to the chase. The nature of the flow and its parameters are determined by the nature of the oscillating committed by the chase. Justifying the dynamic parameters of the shaking conveyor and a study of the stress-strain state. Installation causes fluctuations fixed tray. Uniformly distributed load on the tray acts in each element of the mechanism. On the basis of the program APM structure 3D investigated the stress-strain state and determined movement of each link mechanism with results and calculations.

KEY WORDS: STRESS-STRAIN STATE, VIBRATING CONVEYOR, EQUATION

1. Introduction

The big application in various fields of the industry was received by the vibrating conveyors applied to transportation of hot, poisonous, chemical aggressive cargoes by the supplement of complete tightness of their relocation [4], and also for transportation of the metallic cuttings damped with emulsion and oil, hot earth which has been beaten out from casting forms, small casting, foundry fusion mixture, etc. The vibrating conveyor represents the chase hanged or supported to the fixed section. The chase commits oscillating motions hereupon the cargo which is in the chase, migrates concerning to the chase [5-8]. The nature of the flow and its parameters are determined by the nature of the oscillating committed by the chase. Vibrating conveyors on the conditions of the chase flow and nature of cargo movement are subdivided on inertial (with variable and constant stress of cargo to the chase) in which [9] cargo under the influence of inertia force glides on the chase, and on vibrating in which cargo tears off the chase and migrates along the chase. The vibrating conveyors [1-3] are widely applied owing to a number of advantages in these latter days. The questions of the kinematic and dynamic study of the vibrating

feeder intended for dosing of the fusion mixture loading of the melting furnaces of foundry production are considered in the presented work [11-16]. The principle of operation of the vibrating conveyor is described, and it is devoted the kinematic analysis of the action. The differential equation of the link move of the reduction of the vibrating conveyor is considered in the difference method (the approximate method) solutions of the equation of move of the vibrating conveyor is resulted [10]. It is devoted to the analysis of the equations solutions of conveyor move. Here tables of the results and relocation drawing and velocity of the leading link depending on time are resulted.

2. Materials and Methods

2.1. Differential equations of the link move of the reduction of the vibrating conveyor

It is the action of the III class. The crew BED basic crew from which there are three leads FE, AB, GD. The link OA is a leading link.

Table 1. The action has following performances.

№	links				
	1	2	3	4	5
mass, kg	$m_1 = 30$	$m_2 = 65$	$m_3 = 1160$	$m_4 = 59$	$m_5 = 59$
length units, mm	$l_1 = 60$	$l_2 = 430$	$l_3 = 1100$	$l_4 = 440$	$l_5 = 440$

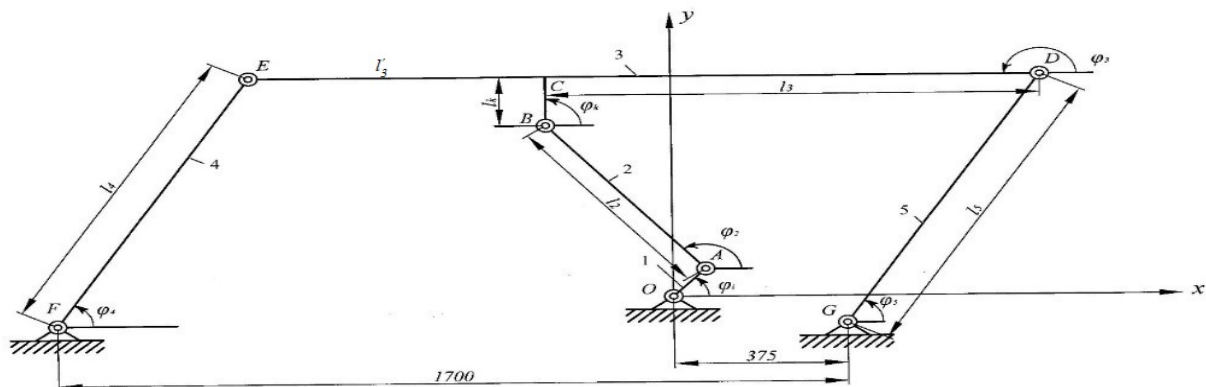


Fig. 1. Kinematic scheme of the vibrating conveyor mechanism

This action has one axis of motion, therefore relocation, velocities and speed-up of the driven link and action dots are functions of the relocation, velocities and speed-up of the leading link. Therefore we will find analytical dependences between relocations, velocities of the driven links and leading link. As the leading link enters into the rotational pair with the console we set function. By the solution of the action move problem with one degree of freedom we will use the equation of the action move of the engine aggregate. $\varphi_1 = \varphi_1(t)$

$$I_K(\varphi_1) \frac{d\omega_1}{dt} = \frac{\omega_1^2}{2} \frac{dI_k(\varphi_1)}{d\varphi_1} = M_k - M_k \quad (1)$$

It is known to us dependence $M_P(\omega)$ and $M_R(\varphi_1)$. We determine $M_R(\varphi_1)$ the resulted moment of resistance forces from power equalling of the resulted moment of force resistance and the sum of powers of the moments [5] of resistance forces of operating in links E, D, F, G.

$$\begin{aligned} M_K \omega_1 &= M_E^{\kappa e \partial} \omega_4 + M_D^{\kappa e \partial} \omega_5 + M_F^{\kappa e \partial} \omega_4 + M_G^{\kappa e \partial} \omega_5 \\ M_K &= M_E^{\kappa e \partial} \frac{\omega_4}{\omega_1} + M_D^{\kappa e \partial} \frac{\omega_5}{\omega_1} + M_F^{\kappa e \partial} \frac{\omega_4}{\omega_1} + M_G^{\kappa e \partial} \frac{\omega_5}{\omega_1} = \\ &= M_E^{\kappa e \partial} u_{41} + M_D^{\kappa e \partial} u_{51} + M_F^{\kappa e \partial} u_{41} + M_G^{\kappa e \partial} u_{51} = 4 \cdot u_{41} M_k \end{aligned}$$

Let's find resulted moment of the flywheel actions $I_k(\varphi_1)$ from equalling condition of kinematic energy of reduction link to the kinematic energy sum of all links of the action.

$$I_k(\varphi_1) = I_{S1} + m_2 \mathcal{G}_{S2\varphi_1} + I_{S2} u_{22}^2 + m_3 \mathcal{G}_{S3\varphi_1}^2 + (I_{4F} + I_{5G}) \cdot l_{41}^2 \quad (2)$$

We determine inertia moments of the first, second, fourth and fifth links.

$$\begin{aligned} I_{S1} &= m_1 \cdot \frac{l_1^2}{2} \\ I_{S2} &= m_2 \cdot \frac{l_2^2}{2} \\ I_{4F} &= I_{S4} + m_4 \cdot l_4' = m_4 \cdot \frac{l_4^2}{2} + m_4 \cdot \frac{l_4^2}{4} \\ I_{5G} &= I_{S5} + m_5 \cdot l_5' = m_5 \cdot \frac{l_5^2}{2} + m_5 \cdot \frac{l_5^2}{4} \end{aligned}$$

We differentiate the resulted inertia moment on φ_1 : For this purpose we substituted all above found values in the equation.

$$\begin{aligned} \frac{dI_k(\varphi_1)}{d\varphi_1} &= 2 \cdot m_2 \sqrt{(l_1 \sin \varphi_1 + l_2' \sin \varphi_2 \cdot u_{21})^2 + (l_1 \cos \varphi_1 + l_2' \cos \varphi_2 \cdot u_{21})^2} \cdot \omega_1 \cdot \\ &\cdot \left\{ \omega_1 [l_1 (\cos \varphi_1 - \sin \varphi_1) + l_2' \cdot u_{21}^2 (\cos \varphi_2 - \sin \varphi_2)] + l_2' \frac{du_{21}}{d\varphi_1} (\sin \varphi_2 + \cos \varphi_2) \right\} \\ &\cdot \frac{1}{\sqrt{(l_1 \sin \varphi_1 + l_2' \sin \varphi_2 \cdot u_{21})^2 + (l_1 \cos \varphi_1 + l_2' \cos \varphi_2 \cdot u_{21})^2}} + 2I_{S2} \frac{l_1}{l_2} \frac{\sin(\varphi_4 - \varphi_1)}{\sin(\varphi_2 - \varphi_1)} \cdot \\ &\cdot \frac{l_1}{l_2} \left[\frac{u_{41} \cos(\varphi_4 - \varphi_1) - \cos(\varphi_4 - \varphi_1)}{\sin(\varphi_4 - \varphi_2)} - \frac{[u_{21} \cos(\varphi_4 - \varphi_2) - u_{41} \cos(\varphi_4 - \varphi_2)] \cdot \sin(\varphi_4 - \varphi_1)}{\sin^2(\varphi_4 - \varphi_2)} \right] + \\ &+ 2m_3 \omega_1^2 \left[-l_1 (\cos \varphi_1 + \sin \varphi_1) - l_2 \cdot u_{21}^2 (\cos \varphi_2 - \sin \varphi_2) + l_2 \frac{du_{21}}{d\varphi_1} (\cos \varphi_2 - \sin \varphi_2) + \frac{du_{51}}{d\varphi_1} (a \cdot \cos \omega_5 t - b \cdot \sin \omega_5 t) \right] + \\ &+ 2(I_{4F} + I_{5G}) \cdot \frac{l_1}{l_4} \left\{ \frac{\cos(\varphi_1 - \varphi_2) u_{21} - \cos(\varphi_1 - \varphi_2)}{\sin(\varphi_2 - \varphi_4)} - \frac{[\cos(\varphi_1 - \varphi_2) u_{21} - \cos(\varphi_1 - \varphi_2) \sin(\varphi_2 - \varphi_1)]}{\sin^2(\varphi_2 - \varphi_4)} \right\} \frac{l_1}{l_4} \frac{\sin(\varphi_2 - \varphi_1)}{\sin(\varphi_2 - \varphi_4)} = \\ &= 2 \cdot m_2 \cdot \omega_1^2 \left[l_1 \cdot (\cos \varphi_1 - \sin \varphi_1) + l_2' \cdot u_{21} (\cos \varphi_2 - \sin \varphi_2) + l_2' \frac{du_{21}}{d\varphi_1} (\sin \varphi_2 - \cos \varphi_2) \right] + \\ &+ 2 \cdot I_{S2} \cdot \frac{l_1^2}{l_2^2} \frac{\sin(\varphi_4 - \varphi_1)}{\sin(\varphi_2 - \varphi_4)} \left\{ \frac{u_{41} \cos(\varphi_1 - \varphi_4) - \cos(\varphi_4 - \varphi_1)}{\sin(\varphi_2 - \varphi_4)} - \frac{[u_{21} \cos(\varphi_4 - \varphi_2) - u_{41} \cos(\varphi_4 - \varphi_2)] \sin(\varphi_4 - \varphi_1)}{\sin^2(\varphi_4 - \varphi_2)} \right\} - \end{aligned}$$

$$-2m_3\omega_1^2\left[l_1(\cos\varphi_1+\sin\varphi_1)+l'_2\cdot u_{21}^2(\cos\varphi_2-\sin\varphi_2)-l_2\frac{du_{21}}{d\varphi_1}(\sin\varphi_2-\cos\varphi_2)-\frac{du_{51}}{d\varphi_1}(a\cdot\cos\omega_5t-b\cdot\sin\omega_5t)\right]+$$

$$+2(I_{4F}+I_{5G})\cdot\frac{l_1^2}{l_4^2}\frac{\sin(\varphi_2-\varphi_1)}{\sin(\varphi_2-\varphi_4)}\cdot\left\{\frac{\cos(\varphi_1-\varphi_2)u_{21}-\cos(\varphi_1-\varphi_2)}{\sin(\varphi_2-\varphi_4)}-\frac{[\cos(\varphi_1-\varphi_2)u_{21}-\cos(\varphi_1-\varphi_2)]\sin(\varphi_2-\varphi_1)}{\sin^2(\varphi_2-\varphi_4)}\right\};$$

The move equation of the reduction link of the action looks like:

$$I_{S1}+m_2\cdot\omega_1^2\left\{\left[(l_1\sin\varphi_1+l'_2\sin\varphi_2\cdot u_{21})^2+(l_1\cos\varphi_1+l'_2\cos\varphi_2\cdot u_{21})^2\right]+I_{S2}\frac{l_1^2}{l_2^2}\frac{\sin^2(\varphi_4-\varphi_1)}{\sin^2(\varphi_2-\varphi_4)}+\right.$$

$$+m_3\cdot\omega_1^2\left[(-l_1\sin\varphi_1-l_2\sin\varphi_2\cdot u_{21}+a\cdot u_{51}\cdot\cos\omega_5t)^2\right]+\left[(l_1\cos\varphi_1+l_2\cos\varphi_2\cdot u_{21}-b\cdot u_{51}\cdot\sin\omega_5t)^2\right]+$$

$$+(I_{4F}+I_{5G})\frac{l_1^2}{l_4^2}\frac{\sin^2(\varphi_2-\varphi_1)}{\sin^2(\varphi_2-\varphi_4)}\left\}\cdot\frac{d\omega_1}{dt}+\frac{\omega_1^2}{2}\left\{2\cdot m_2\cdot\omega_1^2\left[(l_1\sin\varphi_1+l'_2\sin\varphi_2\cdot u_{21})\cdot(l_1\cos\varphi_1\cdot u_{21}^2+l'_2\sin\varphi_2\frac{du_{21}}{d\varphi_1})+\right.\right.$$

$$+(l_1\cos\varphi_1+l'_2\cos\varphi_2\cdot u_{21})(-l_1\sin\varphi_1-l'_2\sin\varphi_2\cdot u_{21}^2+l'_2\cos\varphi_2\frac{du_{21}}{d\varphi_1})\left.\right]+$$

$$+2\cdot I_{S2}\frac{l_1^2}{l_2^2}\left[\frac{(\cos(\varphi_1+\varphi_4)-\cos(\varphi_1-\varphi_4))\sin(\varphi_1-\varphi_4)}{\sin^2(\varphi_2-\varphi_4)}\right]+2m_3\omega_1^2\left[(-l_1\sin\varphi_1-l_2\sin\varphi_2\cdot u_{21}+\right.$$

$$+a\cdot u_{51}\cos\omega_5t)\left(-l_1\cos\varphi_1-l_2\cos\varphi_2u_{21}^2-l_1\sin\varphi_2\frac{du_{21}}{d\varphi_1}+a\cos\omega_5t\frac{du_{51}}{d\varphi_1}\right)+$$

$$+(l_1\cos\varphi_1+l_2\cos\varphi_2\cdot u_{21}-b\cdot u_{51}\sin\omega_5t)\cdot\left(-l_1\sin\varphi_1+l_2\sin\varphi_2\cdot u_{21}^2+l_2\cos\varphi_2\frac{du_{21}}{d\varphi_1}-b\sin\omega_5t\frac{du_{51}}{d\varphi_1}\right)\left.\right]+$$

$$+(I_{4F}+I_{5G})\left[2\frac{l_1^2}{l_2^2}\cdot\frac{[\cos(\varphi_1+\varphi_2)-\cos(\varphi_1-\varphi_2)]\sin(\varphi_2-\varphi_1)}{\sin^2(\varphi_2-\varphi_4)}\right]\left.\right\}=$$

$$=M_{k_o}-\alpha\cdot\omega_1-4u_{41}(M'_k+K_0\varphi_5) \quad (3)$$

For solution of the equation (3) there are following initial conditions: at $t=0$, $\omega_1=0$, $\varphi_1=60^\circ$

2.2 The approximate method of the equation solutions of the vibrating conveyer

For constructing on the piece $t \in [0, T]$ of the approximate solution of the move equation (3), we copy it in the following kind:

$$R(t)\frac{d\omega_1}{dt}+Q(t)\cdot\omega^2(t)=W(t) \quad (4)$$

where $R(t)=I_{S1}+(m_2A(t)+m_3H(t)\omega_1^2+B(t)+D(t)$

$$A(t)=l_1^2+2l_1l'_2(\sin\varphi_1\cdot\sin\varphi_2+\cos\varphi_1\cdot\cos\varphi_2)\cdot u_{21}+l_2'^2\cdot u_{21}^2.$$

$$H(t)=l_1^2-l_2^2\cdot u_{21}^2+(a^2\cos^2\omega_5t+b^2\sin^2\omega_5t)\cdot u_{51}^2+2l_1l_2\cdot u_{21}(\sin\varphi_1\sin\varphi_2+$$

$$+\cos\varphi_1\cos\varphi_2)-2l_1\cdot u_{51}(a\cdot\sin\varphi_1\cos\omega_5t+b\cdot\cos\varphi_2\sin\omega_5t)-2l_2\cdot u_{21}(a\cdot\cos\omega_5t\sin\varphi_2+$$

$$+b\cdot\sin\omega_5t\cdot\cos\varphi_2)$$

$$B(t)=I_{S2}\frac{l_1^2\sin^2(\varphi_4-\varphi_1)}{l_2^2\sin^2(\varphi_2-\varphi_4)}; \quad D(t)=(I_{4F}+I_{5G})\frac{l_1^2\sin^2(\varphi_2-\varphi_1)}{l_4^2\sin^2(\varphi_2-\varphi_4)}$$

$$Q(t)=(m_2E(t)+m_3F(t))\cdot 2\omega_1^2+2I_{S2}\frac{l_1^2}{l_2^2}N(t)+M(t)$$

$$\begin{aligned}
E(t) &= (l_1 \sin \varphi_1 + l_2^1 \sin \varphi_2 \cdot u_{21}) \cdot \left(l_1 \cos \varphi_1 + l_2^1 \cos \varphi_2 \cdot u_{21}^2 + l_2^1 \sin \varphi_2 \frac{du_{21}}{d\varphi_1} \right) + \\
&+ (l_1 \cos \varphi_1 + l_2^1 \cos \varphi_2 \cdot u_{21}) \cdot \left(-l_1 \sin \varphi_1 - l_2^1 \sin \varphi_2 \cdot u_{21}^2 + l_2^1 \cos \varphi_2 \frac{du_{21}}{d\varphi_1} \right); \\
F(t) &= (-l_1 \sin \varphi_1 - l_2 \sin \varphi_2 \cdot u_{21} + a \cdot u_{51} \cos \omega_5 t) \cdot \left(-l_1 \cos \varphi_1 - l_2 \cos \varphi_2 \cdot u_{21}^2 - l_1 \sin \varphi_1 \frac{du_{21}}{d\varphi_1} + a \cdot \cos \omega_5 t \frac{du_{51}}{d\varphi_1} \right) + \\
&+ (l_1 \cos \varphi_1 + l_2 \cos \varphi_2 \cdot u_{21} - b \cdot u_{51} \sin \omega_5 t) \cdot \left(-l_1 \sin \varphi_1 - l_2 \sin \varphi_2 \cdot u_{21}^2 + l_2 \cos \varphi_2 \frac{du_{21}}{d\varphi_1} - b \cdot \sin \omega_5 t \frac{du_{51}}{d\varphi_1} \right) \\
N(t) &= \frac{(\cos(\varphi_1 + \varphi_4) - \cos(\varphi_1 - \varphi_1)) \sin(\varphi_1 - \varphi_4)}{\sin^2(\varphi_2 - \varphi_4)} \\
M(t) &= (I_{4F} + I_{5G}) \left[2 \frac{l_1^2}{l_2^2} \frac{(\cos(\varphi_1 + \varphi_2) - \cos(\varphi_1 - \varphi_2)) \sin(\varphi_2 - \varphi_1)}{\sin^2(\varphi_2 - \varphi_4)} \right] \\
W(t) &= M_{\mathcal{J}_o} - \alpha \cdot \omega_1 - 4 \cdot u_{41} (M'_{K_o} + K_o \varphi_5)
\end{aligned}$$

3. Results and Discussion

The system of differential equations modeling the movement of the material particle on the vibrating plate belonging to the conveyor was solved using Zinovyeva method. Our goal was to find

the optimal values of some parameters that allow the obtaining of maximum speed of a vibratory movement on the plate. The basis of the program APM structure 3D investigated the stress-strain state and determined movement of each link mechanism with results and calculations.

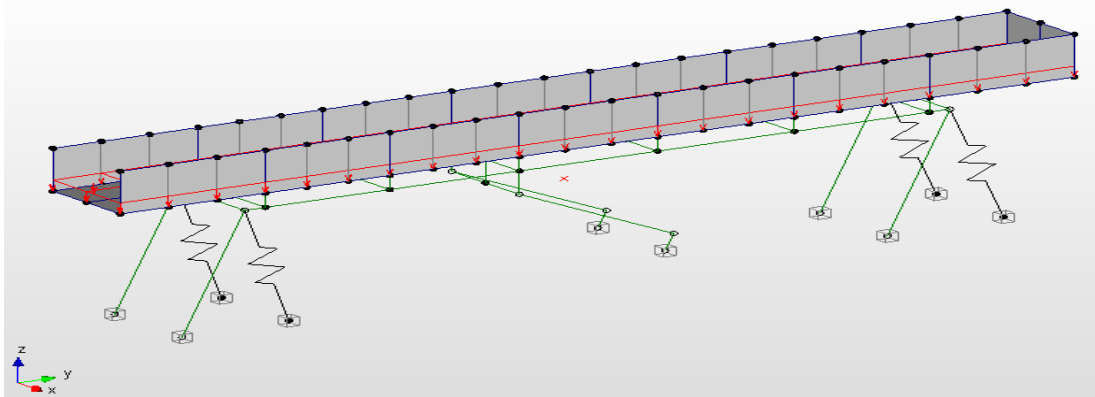


Fig. 2. Vibrating conveyor mechanism 3D model

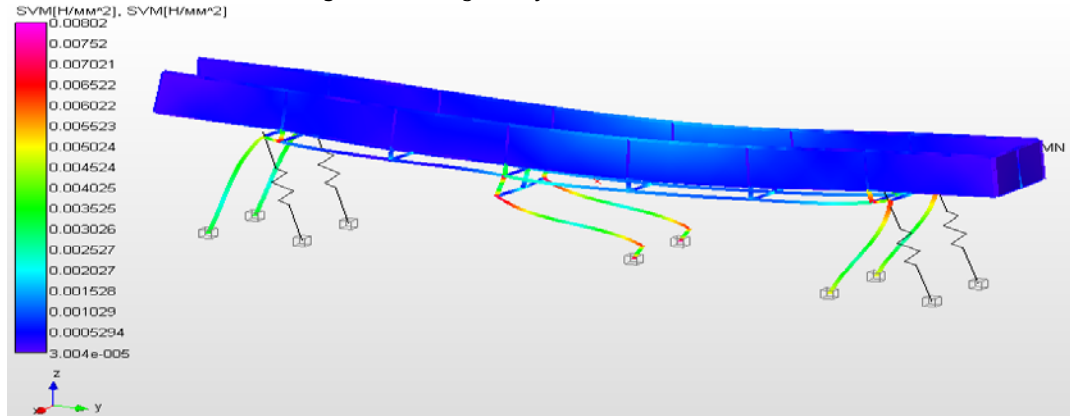


Fig. 3. Computed plot of the stress-strain state σ_x .

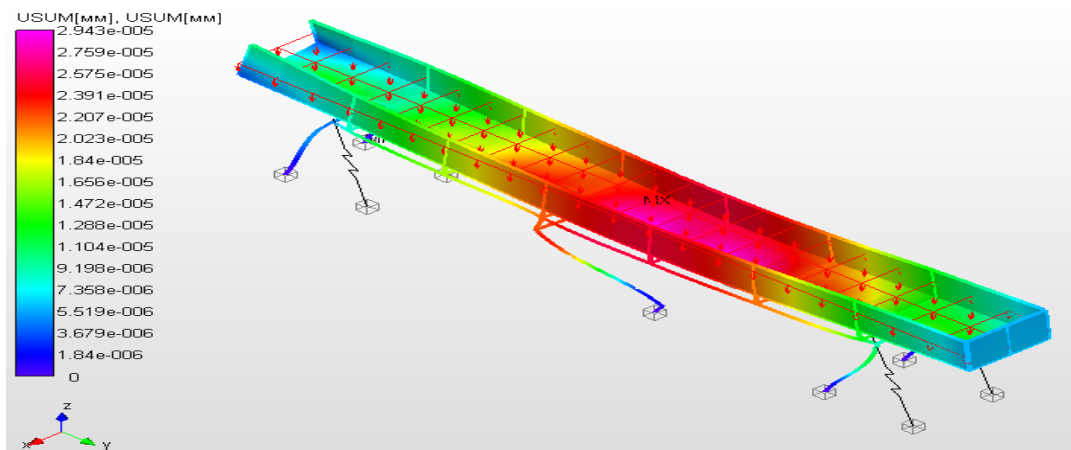


Fig. 4. Computed plot of the moving.

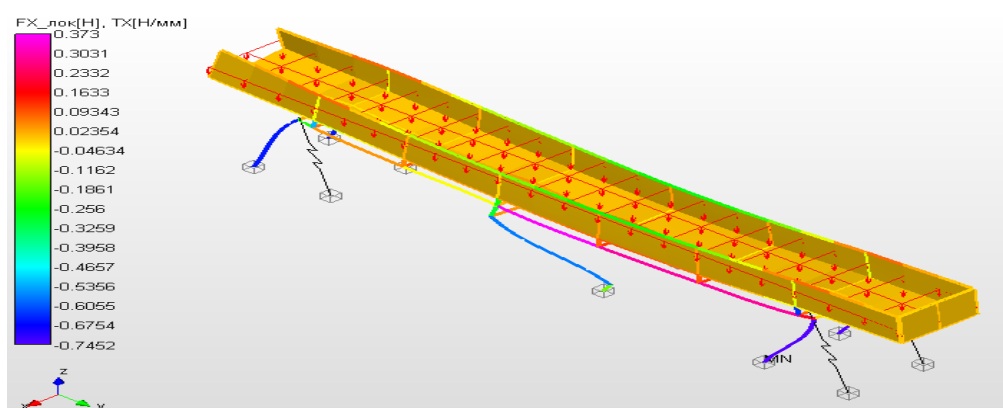


Fig. 5. Computed plot of the F_X and T_X .

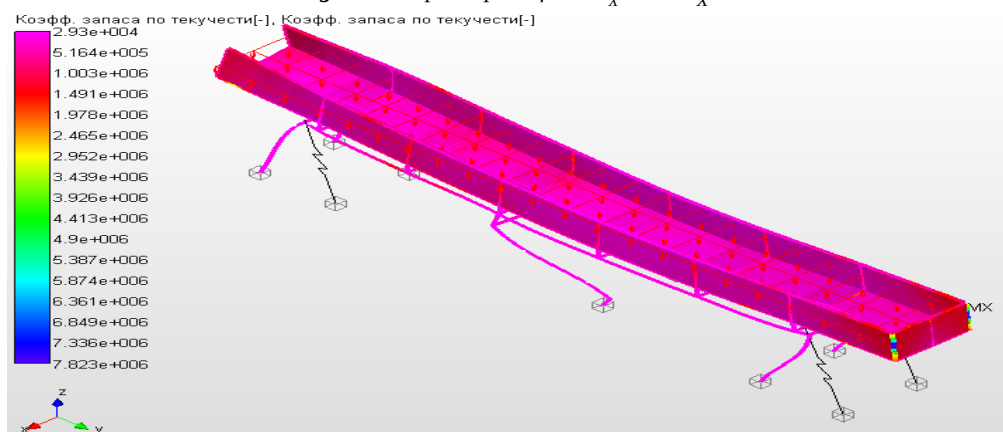


Fig. 6. Computed plot of the Safety factor for yield.

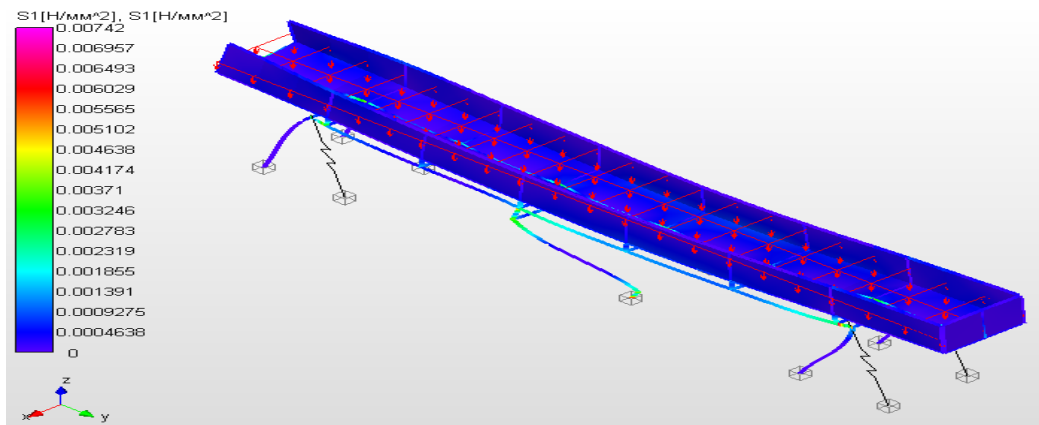


Fig. 7. Computed plot of the stress-strain state τ_{YZ} .

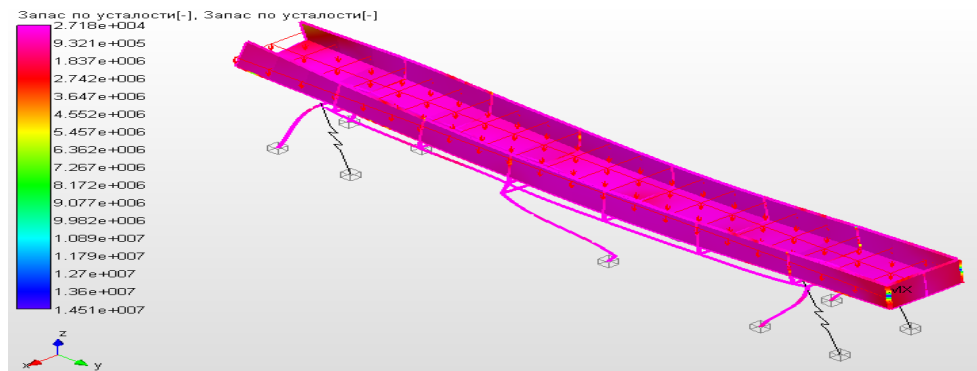


Fig. 8. Computed plot of the margin fatigue.

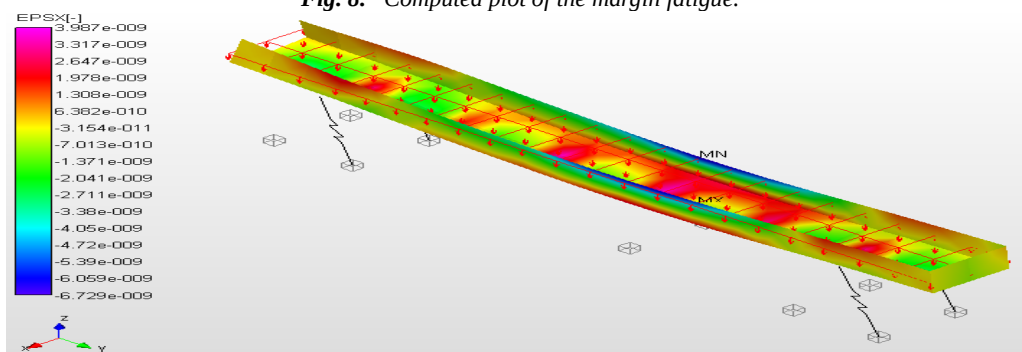
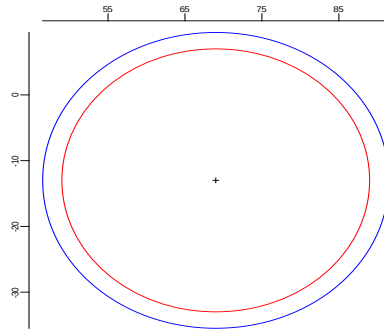


Fig. 9. Computed plot of the main deformation.

Table 2. The reactions in the supports

№ joint	№ node	Reaction R_X [H]	Reaction R_Y [H]	Reaction R_Z [H]	Moment M_X [HM]	Moment M_Y [HM]	Moment M_Z [HM]
1	18	0,0046	0,2484	0,6074	-3,6181	0,6038	-0,3482
2	20	0,0057	0,2141	0,7151	7,2149	0,7702	-0,3027
3	27	0,0045	-0,4624	0,3450	19,72251	0,5502	0,2877
4	47	0	0,0004	0,0001	0	0	0
5	48	0	-0,0005	-0,0002	0	0	0



Tube 45x2.5 GOST 8732-78

Options section

The area of 333.70 square millimeters

The center of mass: X = 69.000, Y = -13.000mm

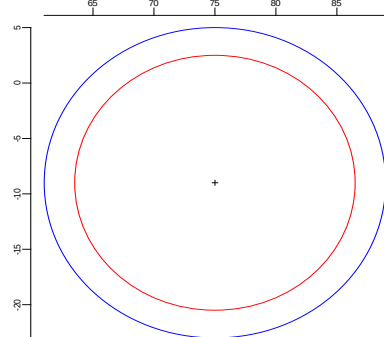
Moment of inertia:

rel. X axis 75605.68mm⁴

rel. Y axis 75605.68mm⁴

polar 151211.35mm⁴

The angle of the principal central axes 0.00 gradus



Tube 28 x 2.5 GOST 8732-78

Options section

The area of 200.23 square millimeters

The center of mass: X = 75.001, Y = -8.999mm

Moment of inertia:

rel. X axis 16434.12mm⁴

rel. Y axis 16434.12mm⁴

polar 32868.25mm⁴

The angle of the principal central axes 0.00 gradus

Fig.10. Model information: List of cross section and options section.

The center of gravity model (-0.000000, 919.880834, 469.928355) [MM].

The moments of inertia model (1280707.633013, 159169646.605358, 28044219.772722) [кг*мм*мм].

4. Conclusions

1. Formulas for the position determination and velocity of conducted links depending on position and velocity of the leading link are received.

2. The differential equations of the link move of the action reduction are received.

3. On the basis of the profiles variation analysis of the angular rate of the leading link it is possible to make the following concluding:

- with the growth of the starting driving moment middle angular of the action grows;
- with reduction of the starting driving moment middle angular rate of the action is decays;
- with coefficient increase α_0 , ω_{cp} grows;

4. The basis of the program APM structure 3D investigated the stress-strain state and determined movement of each link mechanism with results and calculations.

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SOME PHYSICAL AND MECHANICAL PROPERTIES OF TURKISH HAZELNUT (*CORYLUS COLURNA* L.) WOOD

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Abstract: The aim of this study was to determine some of the physical and mechanical properties of Turkish hazelnut (*Coryluscolurna*L.) wood. Hazelnut is an endemic species in Turkey and the trees used for the study were taken from the Pınarbaşı District of Kastamonu Province. As a result of experiments carried out to evaluate the physical properties, it was found that the values of dry and air dry density were 0.636 gr/cm³ and 0.672 gr/cm³, radial, tangential and longitudinal swelling values were 4.60%, 7.48% and 0.41%, radial, tangential and longitudinal shrinkage values were 5.11%, 8.49% and 0.59%, respectively. According to the related standards, the mechanical properties of bending strength (98.5 N/mm²), modulus of elasticity in bending (8273.4 N/mm²), compressive strength parallel to the grain (50.09 N/mm²), dynamic bending strength (impact strength) (0.71 kN/cm), tensile strength perpendicular to the grain (5.09 N/mm²), and hardness values of cross, radial and transverse sections (72.55 N/mm², 47.32 N/mm², 46.13 N/mm², respectively) were also determined.

Keywords: TURKISH HAZELNUT, *CORYLUS COLURNA*, MECHANICAL PROPERTIES, PHYSICAL PROPERTIES

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1. Introduction

Turkish hazelnut (*Coryluscolurna* L.), one of the endemic species in Turkey, has a smooth stem and can reach 80 cm in diameter and 15-20 m in height. Some trees in Kale Forest District of Bolu Regional Forest Headquarters have attained a diameter of 1 m and height of 30-35 m¹, and trees growing in graveyards and at the edges of fields in Merkezler village in Bolu Province were measured at more than 80 cm in diameter. This tree species is rarely used in the timber industry because its technological properties are not well known. Turkish hazelnut grows naturally in western Anatolia (Kazdağı/Bolu, Kastamonu and Yenice/Karabük) and eastern Anatolia (Rize and Trabzon).¹ It can grow at an altitude of 1600 m in Yığılca/Düzce, Köstebek Forest/Nallıhan, Kastamonu between Azdavay and Cide and on Gavur Mountain in Tosya, and in Amasya on Sana Mountain. It is found at 1160 m in Ayancık, Çingen Konağı and Zindan/Sinop, and at 800 m in Mihaliççik, Çatacık Forest/Eskişehir. Turkish hazelnut trees are most commonly located in the northwest of the country at a vertical distribution of between 800-1700 m, in small groups or individually, together with other species such as oak, beech, maple and fir.² The wood of this species is red in color and when well-polished is used for the manufacture of furniture.³

Forest villagers in the mid and western Black Sea region have made use of Turkish hazelnut for the production of wooden souvenir items and furniture. When assessing the possibility of utilizing tree species in terms of suitable areas of the forest products industry, it is very important to determine the chemical, physical, mechanical, drying, machining and conservation properties of those tree species. At present, only the anatomical properties of the Turkish hazelnut tree have been investigated for this purpose. This study is very important because the technological properties of this tree species have not been previously determined. Accordingly, Turkish hazelnut has been underutilized in the forest product industry. Depending upon the development of increased industrial applications, this tree could be more widely cultivated. Nonetheless, to begin with, the wood properties of the Turkish hazelnut must be determined. The aim of this research was to investigate the physical and mechanical properties of Turkish hazelnut and to interpret the results with regard to possible industrial utilization.

2. Materials and Methods

In order to examine the distribution areas of Turkish hazelnut, sample trees belonging to this protected species

were taken from Pınarbaşı District in Kastamonu Province. An official description of the study area is given in Table 1.

Table 1: Study area data

Area No.	1
Regional Forest Headquarters	Kastamonu
Forest Management Directorate	Pınarbaşı
Forest Management Office	Kurtgirmez
Division No.	160
Location	Kastamonu Province, Pınarbaşı District, Kurtgirmez Mountain, east of Büyükkış Hill
Coordinates	41° 35' 43.6" (N) 33° 13' 29.2" (E)

A total of six trees representing the study area were cut. Information about the sample trees is given in Table 2.

Table 2: Sample trees

Sample Tree No.	1	2	3	4	5	6
Division No.	115	115	115	115	115	115
Direction	East	East	West	East	North	West
Proximity	3	3	3	3	3	3
Flora	Buxus	Buxus	Buxus	Buxus	Buxus	Buxus
Altitude	1290	1290	1290	1290	1290	1290
Slope(%)	30	30	47	30	30	41
Diameter (cm)	50	29	35	33	31	27
Dry branch (m)	6.90		6.30			9.10
Wet branch (m)	6	10.30	11.90	9.40	5.85	10.40
Height (m)	16.35	11.20	14.90	12.60	14.10	13.80
Middle diameter (cm)	27	26	25	23	24	20

In order to determine the physical properties, a total of 32 sections, 15cm in length, were taken from each sample tree at heights of 0.30m, 1.30m, 2.30m, 4.30m, 6.30m, 8.30m and 10.30m. A total of five sample logs, 1.5 m in length, were taken from each sample tree for mechanical testing, according to TS 2470 (1976)⁴ standard.

The physical properties of oven and air dry density (TS 2472, 1976)⁵, radial, tangential (TS 4083, 1976)⁶ and volumetric (TS 4085, 1983)⁷ shrinkage, and radial, tangential (TS 4084, 1976)⁸ and volumetric (TS 4086, 1983)⁹ swelling were investigated. The mechanical properties of bending strength (TS 2474, 1976)¹⁰, modulus of elasticity in bending (TS 2478, 1976)¹¹, tensile strength perpendicular to the grain (TS 2476, 1976)¹², impact bending strength (TS 2477, 1976)¹³, compression strength parallel to the

grain (TS 2595, 1977)¹⁴ and Janka hardness (TS 2479, 1976)¹⁵ of Turkish hazelnut wood were also examined.

First, sections obtained from the sample trees were cut and left under a covered outdoor area until the fiber saturation point was reached. The specimens for physical tests were then prepared according to standards. A total of 400 specimens for density and 50 specimens for each of the other physical tests were prepared. All samples used for the physical and mechanical tests were acclimatized according to TS 642 ISO 554 (1997)¹⁶ to attain the air dry state (12%). The section parts used for physical test specimens are shown in Figure1.



Fig 1: Timber used to prepare the mechanical test specimens.

The timber sections used for mechanical test specimens are shown in Figure 2.



Fig 2: Timber used to prepare the mechanical test specimens.

In order to determine the physical properties, a total of 32 sections, 15cm in length, were taken from each sample tree at heights of 0.30m, 1.30m, 2.30m, 4.30m, 6.30m, 8.30m and 10.30m. A total of five sample logs, 1.5 m in length, were taken from each sample tree for mechanical testing, according to TS 2470 (1976)⁴ standard.

The bending strength, modulus of elasticity (MOE), compression strength parallel to the grain, impact bending strength, tension strength perpendicular to the grain, and hardness values were determined. After the mechanical tests, the moisture content of each specimen was measured and the values of samples having different air dry moisture content were converted to 12% values.

3. Results and discussion

The density and sorption values of Turkish hazelnut are given in Table 3.

Table 3: Density and sorption values of Turkish hazelnut wood.

Properties	Number of	Mean (X)	Standard deviation	Min. value	Max. value
------------	-----------	----------	--------------------	------------	------------

		samples (N)		(s)	(Xmin)	(Xmax)
Density (g/cm ³)	Oven dry	400	0.636	0.07	0.817	0.405
	Air dry	400	0.672	0.07	0.855	0.436
Shrinkage (%)	Radial	50	4.60	0.64	5.85	3.16
	Tangential	50	7.48	0.86	9.79	6.07
	Longitudinal	50	0.41	0.18	0.84	0.07
	Volumetric	50	12.49	1.36	15.37	10.03
Swelling (%)	Radial	50	5.11	0.56	6.34	4.05
	Tangential	50	8.49	1.01	10.71	6.55
	Longitudinal	50	0.59	0.14	0.95	0.33
	Volumetric	50	14.18	1.42	17.35	11.98

The mechanical values of Turkish hazelnut are given in Table 4.

Table 4: Mechanical values of Turkish hazelnut wood.

Properties	No. of samples (N)	Mean (X)	Standard deviation (s)	Max. value (Xmax)	Min. value (Xmin)
Bending strength (N/mm ²)	50	98.5	18.5	137.6	51.9
Modulus of elasticity (N/mm ²)	50	8273.4	1295.6	12004.9	5307.8
Impact bending (J/cm ²)	50	7.1	3.1	14.2	3.3
Compression strength (N/mm ²)	50	50.1	4.7	60.5	40.3
Tension strength perpendicular to grain (N/mm ²)	50	5.1	0.7	6.9	3.1
Janka hardness (N/mm ²)	Cross	50	72.5	9.7	93.0
	Radial	50	47.3	8.6	72.0
	Tangential	50	46.1	8.6	68.1

The density test results of Turkish hazelnut along with the values of other broad-leaved native species in Turkey are given in Table 5.¹⁷

Table 5: Density values of some Turkish wood species.

Species	Oven dry density (g/cm ³)	Air dry density (g/cm ³)
Turkish hazelnut	0.636	0.672
Beech	0.64	0.66
Oak	0.67	0.69
Chestnut	0.59	0.63
Elm	0.64	0.68
Maple	0.59	0.63
Alder	0.49	0.53
Ash	0.65	0.69
Poplar	0.41	0.45
Lime tree	0.49	0.53

As seen in Table 5, except for alder, poplar, and lime tree, the density values of Turkish hazelnut are similar to those of other broad-leaved tree species. Turkish hazelnut has medium density according to the classification values presented by Bozkurt and Erdin (1990)¹⁸.

The shrinkage test results of Turkish hazelnut and other broad-leaved native species in Turkey are given in Table 6.^{17,19}

Table 6: Shrinkage values of some Turkish wood species.

Species	Shrinkage (%)			
	Radial	Tangential	Longitudinal	Volumetric
Turkish hazelnut	4.60	7.48	0.41	12.49
Beech	5.0	10.5	0.5	15.5
Oa	4.0	7.8	0.4	12.2
Ash	5.0	8.0	-	13.2
Elm	4.6	8.3	-	13.2
Maple	3	8.0	-	11.5
Alder	4.4	7.3	-	12.6
Ash	5.0	8.0	0.2	13.2
Poplar	3.5	6.7	0.5	10.7
Lime tree	5.5	9.1	0.3	14.9

In terms of density, the values of Turkish hazelnut are similar to those of beech, whereas its shrinkage values are lower. This is a positive feature. In terms of radial, tangential and volume shrinkage values, Turkish hazelnut is classified as being ‘moderately shrinkable’. The ratio of tangential and radial shrinkage is 1.62, which is only slightly lower than the general mean ratio of 1.65. The difference between tangential and radial shrinkage is 2.88%. With a value greater than 2.5, as in this case, the deformation risk increases during the wood drying.²⁰

The swelling test results of Turkish hazelnut and other broad-leaved native species in Turkey are given in Table 7.²¹⁻²⁴

Table 7: Swelling values of some Turkish wood species.

Species	Swelling (%)			
	Radial	Tangential	Longitudinal	Volumetric
Turkish hazelnut	5.11	8.49	0.59	14.18
Beech	5.2	12.6	0.3	17.8
Oak	5.0	10.0	-	14.9
Maple	4.8	9.3	0.16	14.4
Poplar	4.3	8.2	0.3	12.8

The difference between tangential and radial swelling is 3.38%. When this value is greater than 3, as in this case, the risk of deformation increases during the wood drying.²⁰ Although the risk of deformation is decreased with higher sorption values and a lower difference between radial and tangential sorption values, the deformation risk is increased with lower sorption values and a higher difference between radial and tangential sorption values.²⁰

The mechanical test results of Turkish hazelnut and some other broad-leaved native species in Turkey are given in Table 8.¹⁷

Table 8: A comparison of mechanical test results of some Turkish wood species.

Mechanical properties	Turkish Hazelnut	Beech	Chestnut	Ash	Oak	Hornbeam
Bending strength (N/mm ²)	98.5	112	77	120	108	160
Modulus of Elasticity (N/mm ²)	8273.4	13082	9000	13400	11056	16200
Impact bending (kJ/cm)	0.71	0.95	0.57	0.65	0.78	0.8
Compression strength(N/m ²)	50.1	57	50	52	65	82
Tension perpendicular (N/mm ²)	5.1					
Janka hardness N/mm ²	Cross	72.5			78	
	Radial	47.3			56.6	
	Tangent	46.1				

The bending strength of Turkish hazelnut is moderate. But its MOE is low. In other words, under a certain load it shows more deformation (bending). Its compression strength is also moderate. It exhibits high impact bending, and for this reason it can be employed where high impact performance is needed. At the same time, Turkish hazelnut wood can be considered for applications that require bending properties, because it has a relatively high impact bending strength comparable to that of beech, oak, ash, elm and maple. Turkish hazelnut displays high hardness parallel to the grain. The same point is also true for hardness perpendicular to the grain.

4. Conclusion

Because of its high hardness value, Turkish hazelnut wood can be used for parquet flooring, and it is also suitable for the production of sports equipment, machine parts, tool handles, stairs, furniture and other wooden structures, especially in areas exposed to shock. In addition, as its bending properties are considered to be appropriate for certain applications, further bending tests must be performed to investigate these possibilities; however, the chemical, anatomical, drying and machining properties should also be taken into account.

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MECHANICAL PROPERTIES OF WOOD POLYPROPYLENE COMPOSITES PRODUCED BY USING RESIN IMPREGNATED PAPER WASTE

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Abstract: In this study, it was evaluated some mechanical properties of polypropylene composites reinforced with resin impregnated paper waste (MIPW) obtained from the particleboard and fiberboard factories. To meet this objective, resin impregnated paper waste and pine wood flour were compounded with polypropylene with coupling agent (MAPP) in a twin screw co-rotating extruder and then was manufactured by injection molding process. Injection molded composites were prepared from the wood flour, MIPW powder and polypropylene with maleic anhydride-grafted polypropylene (MAPP) at 10, 20, 30, 40, and 50 wt % contents of the MIPW powder. The tensile and flexural properties of wood polypropylene composites filled with resin impregnated paper waste were decreased. But still, the test results showed that the MIPW can be efficiently used as reinforcing filler for polypropylene composite due to satisfactory mechanical properties of the composites.

Keywords: WOOD - POLYPROPYLENE COMPOSITE, MECHANICAL PROPERTIES, RESIN IMPREGNATED PAPER WASTE

1. Introduction

Wood plastic composites (WPCs) have attracted considerable attention from industry in recent years. WPCs approximately have average annual growth rate of 18% in Northern America and 14% in Europe.^{1,2} The use of wood flour or fiber as fillers and reinforcements in thermoplastics has been gaining acceptance in the applications of commodity plastics in the past few years.³ The advantages of using a wood component in thermoplastic composites are that the biobased resource is nonabrasive, low in cost, widely available, sustainable, high filling levels possible, high specific properties, lower density per weight of raw material, flexible, and recyclable.⁴ The physical form can vary from fine wood flour to wood fibers.⁵ The cost and performance of the final composite products dictate the form of the wood to be used in the plastics. The typical plastics used in this technology are various types of polyethylene, PP, and polyvinyl chloride.

Current growth rate of the WPC market is 22% for North America and 51% for Europe.⁶ Decking for outdoor applications represent the largest market for WPCs both in North America and Europe and in both regions growth is most rapid in the decking segment.⁷ WPC market share in the European decking sector is estimated to be around 6%. In Europe, total WPC production amounts to 120 thousand tons (excluding product destined for the auto industry). Around 68 thousand tons of this production is currently destined for the decking sector. The positive growth in WPC decking has led manufacturers to introduce residential construction applications include siding, roofing, windows, door frames, and outdoor furniture. Further expansion into the residential construction industry and development of applications for the furniture industry require an understanding of the fire performance of the WPCs.

Biocomposites reinforced with wood fibers and mineral fillers have attracted a great attention as alternative materials. Particularly, researches with regard to WPC (wood plastic composite) materials have been continuously increased within the last 20 years because of the advantageous characteristics of each constituent in composite materials.⁸ Among the reinforcing agents, natural fibers have significant advantages such as low cost, highly available and renewable, with low density and high specific properties as well as biodegradable and less abrasive to processing equipment.⁹ Among commodity thermoplastics, polypropylene (PP) possesses outstanding properties such as low density, good flex life, sterilizability, good surface hardness, very good abrasion resistance, and excellent electrical properties.¹⁰ However, the main drawback of PP is low modulus when compared with the wood. The purpose

for the addition of cellulose-based fillers to thermoplastics is to reduce the cost per unit volume and to improve stiffness. Enhancing bending and tensile properties of the filled-polypropylene (PP) composites can expand applications in buildings and structures. There have been different attempts to improve the bending and tensile properties of flat-pressed thermoplastic composite panels. One option is to incorporate nanoscale reinforcing fillers such as nanoclay and carbon nanotube into the composite panel.^{11,12}

In the recent years the use of the resin impregnated decorative and overlay paper sheets has significantly increased in the furniture and laminate flooring industries in European countries and Turkey. As a result of increasing decorative and overlay paper sheet production, the amount of the impregnated paper waste produced by square-trimming the paper has dramatically increased in the factories. The impregnated paper waste is a major challenge for recycling due to the high volume needed worldwide and its low biodegradability. The amount of this dry waste is considerable, running up to 400 t/year in just a medium sized paper impregnating factory.¹³ A better approach for this material is through reusing or recycling in order to decrease the permanent waste volume. Because of its good bondability, the use of recycled alpha cellulose papers containing the melamine resin can be an alternative way for waste minimization. In a previous study, it was reported that impregnated decorative paper waste can be used successfully as a binder of particleboard.¹⁴

Mechanical properties of polypropylene composites filled with melamine impregnated paper waste (MIPW) instead of wood flour were investigated according to ASTM standards. Injection molded composites were prepared from the wood flour, MIPW powder and polypropylene with maleic anhydride-grafted polypropylene (MAPP) at 10, 20, 30, 40, and 50 wt % contents of the MIPW powder.

2. Experimental

2.1. Materials

Pine wood (*Pinus sylvestris* L.) was used as lignocellulosic filler in the thermoplastic composites. Air-dry density, modulus of rupture (MOR), modulus of elasticity (MOE), and compression strength of poplar wood are 0.52 g/cm³, 98 N/mm², 11700 N/mm², 54 N/mm², respectively.¹⁵ Pine wood having a moisture content of 20–30% based on the oven-dry weight of the wood was processed by a rotary grinder and retained on a 60-mesh screen.

The waste decorative and overlay papers were supplied from Yildiz Entegre Company, which has melamine impregnated paper line in Kocaeli, Turkey. They were obtained from the edge trimming of partially cured, dried melamine papers used for low pressure laminates from the production line. Polypropylene (PP) ($T_m = 160\text{ }^{\circ}\text{C}$, $\rho = 0.9\text{ g/cm}^3$, and $\text{MFI}/230\text{ }^{\circ}\text{C}/2.16\text{ kg} = 6.5\text{ g}/10\text{ min}$) was used as the polymeric material produced by Petkim Petrochemical, Turkey. Maleic anhydride-grafted PP [MAPP-OPTIM-425; reactive modifier maleic anhydride (MAH) content = 1 wt %] was obtained from Pluss Polymers, India.

2.2. Methods

2.2.1. Preparation of injection-molded PP composite samples

The wood flour, melamine impregnated paper waste, PP matrix, and MAPP granulates were processed in a 30-mm co-rotating twin screw extruder with a length-to-diameter (L/D) ratio of 30:1. The barrel temperatures of the extruder were controlled at $170\text{ }^{\circ}\text{C}$, $180\text{ }^{\circ}\text{C}$, $185\text{ }^{\circ}\text{C}$, and $190\text{ }^{\circ}\text{C}$ for zones 1, 2, 3, and 4, respectively. The temperature of the extruder die was held at $200\text{ }^{\circ}\text{C}$. The extruded strand passed through a water bath and was subsequently pelletized. The pellets were stored in a sealed container and then dried to the moisture content of 1–2% in a laboratory oven before the injection molding. The temperature used for injection molded samples was $180\text{--}200\text{ }^{\circ}\text{C}$ from feed zone to die zone. The PP composite samples were injected at injection pressure between 4 and 5 MPa with cooling time of about 20 s. Finally, the samples were conditioned at a temperature of $23\text{ }^{\circ}\text{C}$ and relative humidity of 50% according to ASTM D 618¹⁶. Air dry density values of the filled PP samples varied from 0.99 to 1.04 g/cm^3 . Polypropylene, pine wood flour, resin impregnated paper waste and the coupling agent were then weighed according to the formulations given in Table 1.

Table 1: Comparison of the injected molded composite types.

Composite type	Wood flour wt%)	Resin Impregnated Paper Waste	Polypropylene (PP) (wt%)	Coupling agent (MAPP) content (wt%)
Control	50	0	50	3
A	40	10	50	3
B	30	20	50	3
C	20	30	50	3
D	10	40	50	3
E	0	50	50	3

2.2.2. Determination of Mechanical Properties

The flexural properties of the specimens with dimensions of $127 \times 12.7 \times 3.2$ (thickness) mm^3 , flexural modulus and strength, were measured in three-point bending test using a standard material testing system (Lloyd) at a crosshead speed of 1.3 mm/min in accordance with ASTM D 790.¹⁷ Tensile strength and modulus of the specimens [dogbone shape (Type III)] were tested with a crosshead speed of 5 mm/min in accordance with ASTM D 638.¹⁸ Ten replicate specimens were tested for the tensile and flexural properties of each composite formulation.

3. Results and discussion

3.1. Mechanical Properties

In this study, six different groups were manufactured and their mechanical properties were determined. The flexural and tensile values of the WPC (Control group), melamine impregnated paper waste filled polypropylene composites are presented in Table 2. The highest and lowest results in flexural strength of composite types were found to the control group (compose of 50% wood flour, 50% PP, %3 MAPP) and group B (compose of 30% wood flour, 20%

MIPW, 50% PP, %3 MAPP), respectively. The highest and lowest results in flexural modulus of composite types were found to group A (compose of 40% wood flour, 10% MIPW 50% PP, %3 MAPP) and group E (compose of, 50% MIPW 50% PP, %3 MAPP), respectively.

Table 2: The flexural and tensile values of the WPCs.

Mechanical Properties				
Composite type	Flexural Strength (MPa)	Flexural modulus (MPa)	Tensile strength (MPa)	Tensile modulus (MPa)
Control	54,70	3565	31,8	3842
A	49,2	4061	29,0	3467
B	34,1	3596	20,3	2963
C	39,2	3167	27,8	3043
D	41,7	3074	30,23	2881
E	42,4	2670	26,2	2619

The results of the tensile strength test were similar to the results of the flexural strength test. Control group (contents of 50% wood flour, %50 PP, 3% MAPP) among composite types was given to 31.8 MPa the highest result in tensile strength but B group (compose of 30% wood flour, 20% MIPW, 50% PP, %3 MAPP) was given to 20.3 MPa the lowest result of that. The highest and lowest values in tensile modulus are given to the control group (3842 MPa) and E group (2619 MPa), respectively.

According to the result of this study, melamine impregnated paper waste used instead of the wood flour in WPC production were observed to reduce the flexural properties of WPC. The reduction in the flexural strength of the samples due to MIPW content was mainly attributed to the poor compatibility between thermoset MIPW and polypropylene, which forms weak interfacial regions. Poor dispersion of the fillers in the polymer matrix could be reason for lower tensile strength for the samples with content of the MIPW. Since there was not good bonding between the MIPW and polymer matrix, test samples were broken at lower loads.

4. Conclusion

The results of this study showed that the MIPW was capable of serving as new reinforcing filler in the manufacturing of polypropylene composite materials, which reduced cost and environmental benefits. In general, the flexural and tensile strengths of the composites decreased with the MIPW flour content. The test results showed that the MIPW could be efficiently used as reinforcing filler for polypropylene composites with MAPP used for decking products, due to satisfactory mechanical properties of the composites.

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ACCESS TO MODELING OF TRUSS-JOINTS ON CARRYING STRUCTURE-LATTICE GIRDER

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Abstract: This paper presents an access to modeling riveted and welded truss-joints on carrying structure with spatial lattice girder design. The paper illustrates the real model (geometric model) of the most loaded truss-joint on specific carrying structure with its overall complexity. It also illustrates the mathematical model (FE model) of the truss-joint in two designs introducing simplicity, in order to analyze the truss-joint by using a computer and an appropriate software package. FE models (the finite element models) keep up all the characteristics of the geometrical model of the truss-joint, ushering in suitable methodology for this purpose. The need for modeling truss-joints imposes itself as a prior step to further local analysis of stress-deformed conditions of the joint-steel plate under the influence of outside loads. The parallel modeling of the same truss-joint in two constructive designs enables further comparative analysis of stress-deformed shape under same loads and summarize more appropriate constructive design of the truss-joint and emphasizes the need for its optimization.

Keywords: MODELING, RIVETED TRUSS-JOINT, WELDED TRUSS-JOINT, CARRYING STRUCTURE-LATTICE GIRDER

1. Introduction

The carrying structure, which is the subject of research in this paper, is a spatial lattice girder with a complex design. The truss-joints of this structure connect the constructive elements (trusses) with the intersections derived by connecting two or more standard profiles having several characteristic forms for these constructions. The attachment of the truss to the joint-steel plate is often attained by riveting, but nowadays even oftener by welding. Because the working conditions of the carrying structure as a whole, and thereby all its structural elements, are exposed to complicated dynamical loads which are often unpredictable, it brings about a complicated stress situation. The knowledge relative to the stress-deformed shape, especially concerning the most loaded truss-joint of the carrying structure, has special significance for the regular work and long exploitation lifetime of the components as well as for the whole structure. To this purpose, it is necessary to establish a methodology for modeling of this specific truss-joint.

2. Geometric model of the most loaded truss-joint

The global static analysis of the carrying structure has determined that the most loaded truss-joint of this construction is the truss-joint 24 (indicated in Figure 1). The geometric model of this most loaded truss-joint together with the configuration of the connected trusses is shown in Figure 2, and the 3D geometric model of this truss-joint is displayed in Figure 3. The figures point out that the constructive performances of this truss-joint are very complicated ones due to several reasons: the truss-joint connects eight trusses, each of the trusses having complex transversal section generated by linking of profiled carriers, whilst the mounting of the eight trusses onto the joint steel plate is carried out via rivets or welds, the constructive design of the truss-joint being a three-dimensional one.

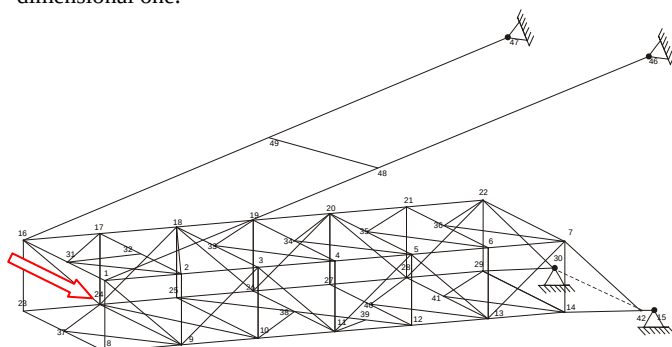


Fig. 1 Geometric model of the carrying structure with the layout of all the truss-joints with the most loaded truss-joint marked by red pointer

The modeling of the truss-joint is made by using the software package ALGOR-FEA. In the process of modeling, attention has been paid to all geometry features of the truss-joint in following manner: accurate geometrical measurements of the joint-steel plate, identical layout of the trusses in the real model of the truss-joint as well as in the transversal sections of the trusses, exact positioning of the holes for the rivets in the riveted truss-joint and the welds in welded truss-joint on the joint-steel plate per size and location. Employing all these features, the model of the truss-joint 24 has been designed in order to obtain a model suitable for computer analysis of its stress-deformed shape, using the above mentioned software package.

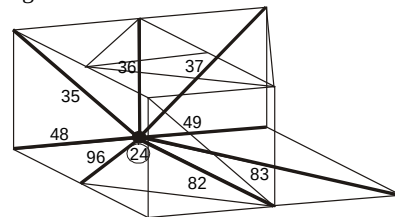


Fig. 2 Geometric model of the most loaded truss-joint on the carrying structure with the layout of the connected trusses

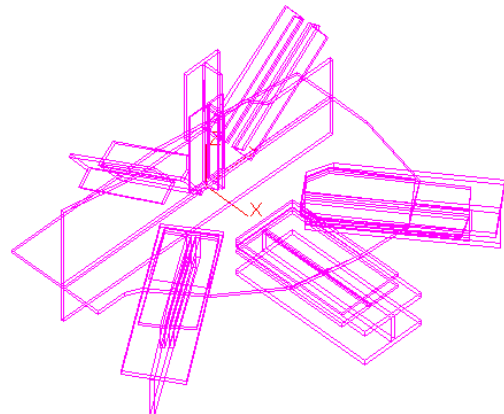


Fig. 3 3D geometric model of the most loaded truss-joint

3. FE models of the most loaded truss-joint

The FE model of the truss-joint 24 with a computer-designed mesh of finite elements is shown in Figure 4 regarding the riveted truss-joint. The creation of finite elements, being one the most difficult problems in modeling, is made via combination of manual and automatic creation, having in mind the complex geometry of the truss-joint and its 3D configuration, the same being limited by the software package for this purpose. The model employs 3D finite elements with triangular and quadrangular transversal section. The

final model has following features: a total of 79924 lines whereof 79753 lines have been processed, and 15624 3D final elements, whereby 96.2 % of the program memory has been employed, indicating the complexity of this model.

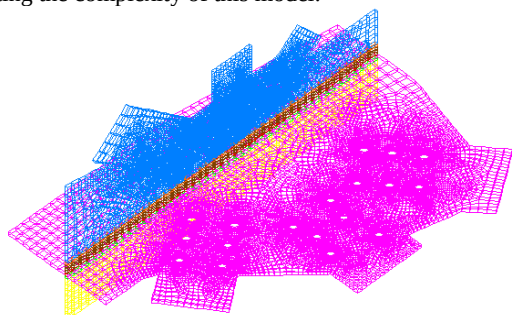


Fig. 4 FE model of the riveted truss-joint

The FE model of the truss-joint 24 with computer-designed mesh of finite elements is shown in Figure 5 relative to welded truss-joint. The creation of the finite elements like most difficult problem in modeling, is made by combining manual and automatic generation, considering the complex geometry of the truss-joint having spatial configuration and identical limitations as to the software package intended for this purpose. The employed spatial (3D) finite elements have triangular and quadrangular transversal section. The final model has following characteristics: total of 19340 lines whereof 19168 lines have been processed, 3496 3D final elements, whereby 22.12 % of the program memory has been engaged, something which indicates simplified mathematical model compared to the mathematical model of riveted truss-joint.

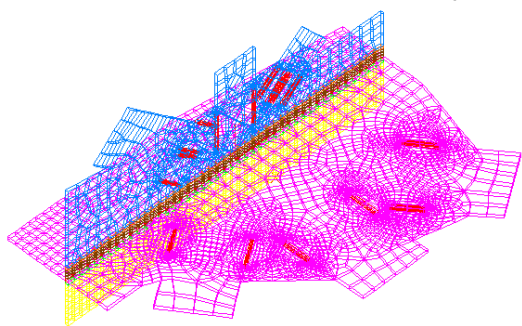


Fig. 5 FE model of the welded truss-joint

Entered data during the examination of the stress-deformed shape of the truss-joint are the loads (forces of tension or pressure) at the joining trusses of the truss-joint. The forces are defined within the subprogram SuperDraw II by entering direction, sense, point of action and magnitude. The direction of the forces runs along the geometrical axis of the trusses, the sense being the sense of tension force or pressure. The points of action of the forces are at the truss-joints of the FE model, which are located next to the geometrical axis of the trusses (the location where the intersection of the trusses has largest dimensions) on both sides of joint-steel plate, the sections of the trusses being designed via placing of elements on the both sides of the joint-steel plate. The intensities of the forces are given as numerical data.

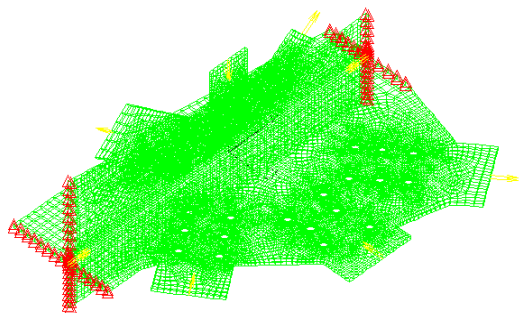


Fig. 6 FE model of the riveted truss-joint with loading forces

The methodology of applying loads on the FE model of the truss-joint is shown in Figure 6 relative to the riveted truss-joint,

and in Figure 7 regarding the welded truss-joint. The boundary conditions for the structure analysis of the truss-joint are defined by the points of connection of the joint on the carrying structure, shown in Figures 6 and 7, which also show the loading forces.

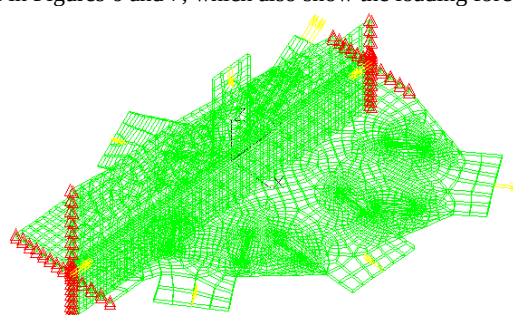


Fig. 7 FE model of the welded truss-joint with loading forces

The truss-joint is manufactured from steel (Č0371 in accordance with the national standard MKS) wherefore the following properties are well-known: modulus of elasticity E , modulus of elasticity in shear G , Poisson's coefficient ν , coefficient of linear extension α and density ρ , entered as starting data in FE analysis.

These above mentioned FE models can be used for analysis of the stress-deformed shape of the truss-joint exposed to static and dynamic loadings.

4. Conclusion

The presented access to modeling of the most loaded truss-joint of the carrying structure with a spatial lattice girder design defines a methodology for complete modeling of the truss-joint in its most frequently employed designs by means of riveting or welding in newer structures.

Modeling methodology is applied to a truss-joint of the specific carrying structure and the real (geometric) model of the truss-joint and the mathematical models (FE models) of the truss-joint in both constructive designs have been obtained. The paper provides guidelines as well for modeling of the loads and boundary conditions.

FE models are used for the structural analysis of the truss-joint in the finite element method (FEA for the truss-joint) by using a computer and appropriate software package.

The parallel modeling and the structural analysis of the truss-joint for both constructive designs enable comparative analysis of the stress-deformed shape having the same loads and infers more appropriate constructive design of truss-joint and a need for its optimization.

This methodology can be used for modeling of other truss-joints on the carrying structure as well as for truss-joint on other carrying structures with the same or similar constructive design.

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DESIGN OF A TEST CELL FOR MODEL HYDRAULIC TURBINES

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Abstract: Test rigs for model hydraulic turbines are used to perform various standardized tests on model turbines by simulating characteristics of the running water, at which the actual turbine will work. Test cell is a frame structure that is placed between the high head and the low head reservoirs of a test rig. It accommodates a generator-bearing assembly and the model turbines to be tested. Since model turbines are custom made systems, the frame structure is required to be designed according to the highest possible loading condition, within the capacity of the test rig, to ensure structural integrity while also considering the ease of assembly. A custom hydrostatic bearing for generator is required to support the potentially harmful axial and radial forces, and bending moments produced by the turbine. In this study, design of a test cell for a hydraulic model turbine test rig is presented.

Keywords: MODEL TURBINE TEST, TEST CELL, HYDROSTATIC BEARING

1. Introduction

Hydraulic turbines are designed by using improved numerical methods and computational fluid dynamics techniques. Although these tools provide precision and accuracy in turbine design and analysis, experiments are still required to validate the designs. Model turbines of typically 1/5 to 1/10 scale are used to perform validation tests. A test rig for model hydraulic turbines is essentially a hydroelectric power plant in small scale. Characteristics of the running water, at which the actual turbine will work, are simulated by applying certain similarity relationships. Cavitation characteristics, efficiency, torque and pressure differences are some of the parameters investigated in the experiments which are standardized by the International Electrotechnical Commission (IEC) [1]. Flexibility of the test rig is a key feature such that a range of turbines with varying dimensions and characteristics can be tested with minimum modification.

There are several model hydraulic turbine test laboratories with various capabilities. Some of them are established by companies manufacturing hydraulic turbines and some by academic institutions. Fine Institute of Hydraulic Machinery [2], S.Morgan Smith Memorial Hydraulic Laboratory of Voith [3] and Laboratory for Hydraulic Machines of Ecole Polytechnique Fédérale de Lausanne (EPFL) [4] are such laboratories. Fine Institute of Hydraulic Machinery has the capability to test Francis-type, Kaplan-type, Bulb-type turbines and reversible pump-turbines with two test rigs. In this laboratory, tests up to 90 m head and up to 1.8 m³/s flow rate can be performed. Francis-type and Kaplan-type turbines are put to performance and cavitation tests in S.Morgan Smith Memorial Hydraulic Laboratory of Voith with a maximum head of 131 m and a maximum flow rate of 1.13 m³/s. Laboratory for Hydraulic Machines of EPFL introduces three test rigs appropriate to tests up to 120 m head and up to 1.4 m³/s flow rate for every type of hydraulic turbine.

This paper presents the design of a test cell for a model turbine test rig, which has a maximum pumping power of 2 MW. Heads from 10 m to 160 m and flow rates from 0.2 m³/s to 2 m³/s can be simulated on model turbines having up to 650 mm runner diameter. The test cell is a frame structure which accommodates a generator-bearing assembly and the model turbines to be tested. It is placed between the high head and low head reservoirs, and its outer dimensions are constrained by the layout of the test rig. The test cell must be adjustable in order to position various model turbines that are within the capacity of the test rig. Hence, the highest possible loading condition designates the test cell. Design validation work including finite element analysis of stress, deformation and vibration are conducted to ensure structural integrity of the test cell. Fine Institute of Hydraulic Machinery and S.Morgan Smith Memorial Hydraulic Laboratory of Voith both introduce a simple design for the test cell, a platform supported by four columns. The model turbine and the generator bearing-assembly are assembled to the platform. On the other hand, Laboratory for Hydraulic Machines of EPFL has the test stand including a lot of moveable columns to

support the platform at any height and distance. In similar approach with Laboratory for Hydraulic Machines of EPFL, to have a rigid structure with the necessary load carrying capability, an improved design with the flexibility presented in this study.

Design of the generator bearing is another important aspect of this study. A custom hydrostatic bearing is designed to couple the runner of the model turbine to the generator and support the potentially harmful axial and radial forces. The bearing also enables torque measurement and calibration according to the standards of the International Electrotechnical Commission (IEC).

2. Preliminary Design of the Test Cell

The test cell, which is essentially a frame structure, is required to accommodate the generator-bearing assembly and model turbines to be tested. Model turbines are custom made systems. Their dimensions and consequently their location on the test cell varies from one turbine to another. Therefore, the frame structure must be designed according to the most critical loading condition. The largest model turbine, within the capacity of the test rig, has 1.5 m length, 1.5 m width and 1 m height, and such a turbine weighs approximately 100 kN. Structural design of the test cell frame is based on these values.

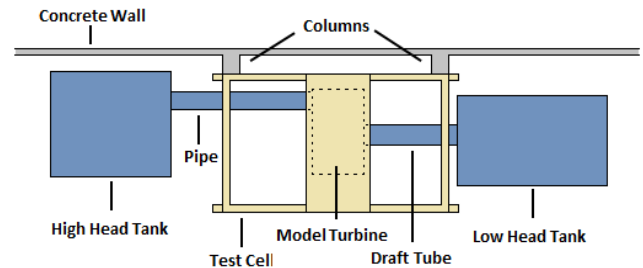


Fig. 1 Top view of the test cell

Layout of the test rig determines the position of the test cell and constrains the outer dimensions (Fig. 1). It is required that the test cell is located between the high head and low head tanks. This is the length constraint. For extra support, the test cell frame is fixed to the concrete columns of the test rig building. The width must enable the largest possible turbine to be connected to the pipe coming from the high head tank and the draft tube. Although not critical, the height of the test cell is constrained by the height of the generator assembly and the hoist crane in the building. Finally, the overall dimensions of the test cell frame are set as 9600 mm x 5750 mm x 4830 mm (length x width x height).

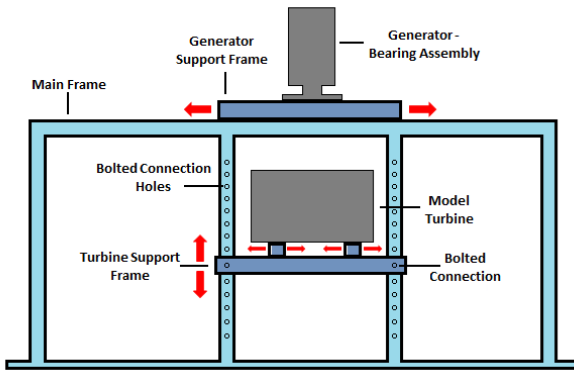


Fig. 2 Side view of the test cell

Fig. 2 shows the side view of the test cell. Positions of the model turbine and the generator-bearing assembly are independently adjusted on the main test cell frame, with the help of their respective support frames, and fixed with bolted connections. This provides adaptability to a range of model turbines and enables easy installation.

3. Design of the Hydrostatic Bearing

The total torque on the generator shaft is the sum of the torque produced by the turbine and the friction torque due to bearings and seals. Section 3.6 of the IEC60193 standard [5] of The International Electrotechnical Commission specifically requires the measurement of the net torque produced by the model turbine. To comply with this requirement, a hydrostatic bearing unit is designed such that the stator of the generator is allowed to rotate freely around the shaft axis (Fig. 3). Then, the rotation is constrained by a lever arm attached to a force transducer, which is fixed to the generator support frame. This arrangement allowed measurement of the tangential reaction force on the generator. Consequently, the net torque produced by the turbine is calculated as the product of the measured tangential force and the length of the lever arm. This method is referred as the primary method for torque measurement in the standard [1].

During operation, forces are applied to the turbine runner in radial and axial directions. The generator must be isolated from these forces for safety and longer life. For this purpose the spindle, which connects the shafts of the turbine and the generator, is supported by two additional hydrostatic bearings at either side of the main generator bearing as shown in Fig. 3. The bearings are designed extra safely to support up to 75 kN and 20 kN in axial and radial directions, respectively.

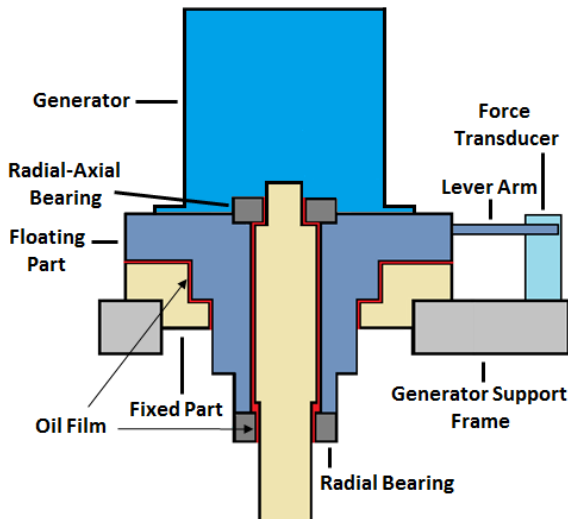


Fig. 3 Generator-hydrostatic bearing assembly

4. Finite Element Analysis Aided Detail Design

An iterative approach is followed for the detail design of the test cell to stay within the design limits given in Table 1. Initially, a simple box shaped frame is designed in Solidworks 2014 [5], by using standard IPN and UPN beams of St-52-3 and St-44 steel material (see Fig. 4, only used for turbine support frame). Then, more beams are added for extra support, according to the results

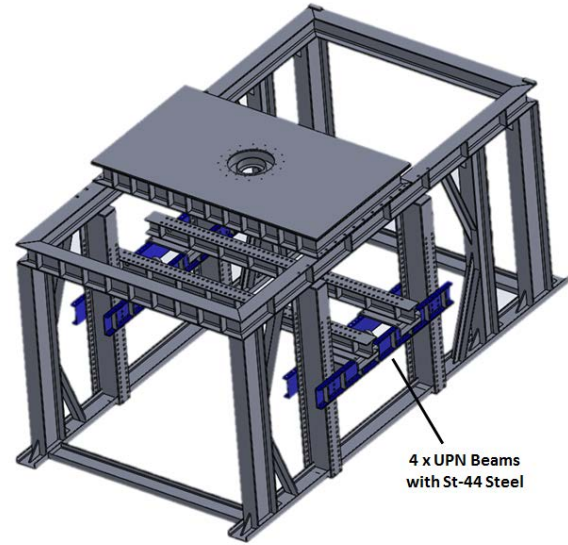


Fig. 4 CAD model of the test cell

Table 1: Design limits for the test cell frame

Criteria	Design limit for St-44 beams	Design limit for St-52-3 beams
Max. equivalent stress (% 50 of yield strength)	137.5 MPa	177.5 MPa
Max. shear stress (%15 of yield strength)	41.25 MPa	53.25 MPa

Static finite element analyses are conducted by using 'Static Structural' module of ANSYS 14 [6]. Firstly, the test cell geometry is imported from Solidworks to ANSYS. Then, it is meshed using 1333445 elements and 248024 nodes. Fixed support is defined for the bottom surface of the test cell as boundary condition and forces of 150 kN and 100 kN are applied, respectively, to the generator support frame and the turbine support frame, as shown in Fig. 5. Also, standard earth gravity is included to take the weights into consideration. Additionally, a horizontal acceleration of 0.2 g is added to the analysis to account for unexpected events such as an earthquake. Finally, the simulation outputs are selected to be equivalent stress, shear stress and total deformation.

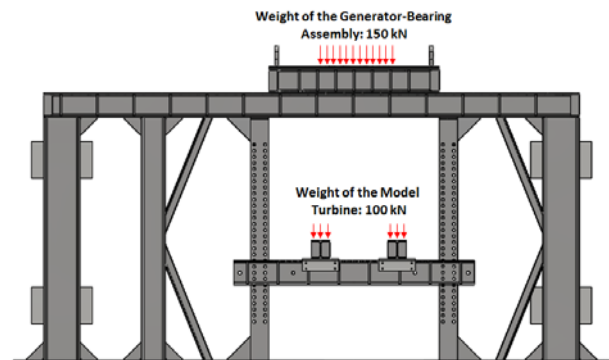


Fig. 5 Test cell frame loading

5. Results of the Finite Element Analysis

Fig. 6 presents equivalent stress analysis results of the test cell. As expected, stress concentration takes place on the support frames of the turbine and the generator. However, the maximum equivalent stress is found as 71 MPa, which is much lower than the design limits given in Table 1. Shear stress analysis results are given in Fig. 7. The maximum shear stress of 38 MPa is also safely within the design limits. Although not specified as a design target, deformation of the structure is also investigated and the results are provided in Fig. 8. The maximum deformation occurs near the largest applied force at the generator support frame, and it is found to be 1.86 mm, which is insignificant compared to much larger dimensions of the components.

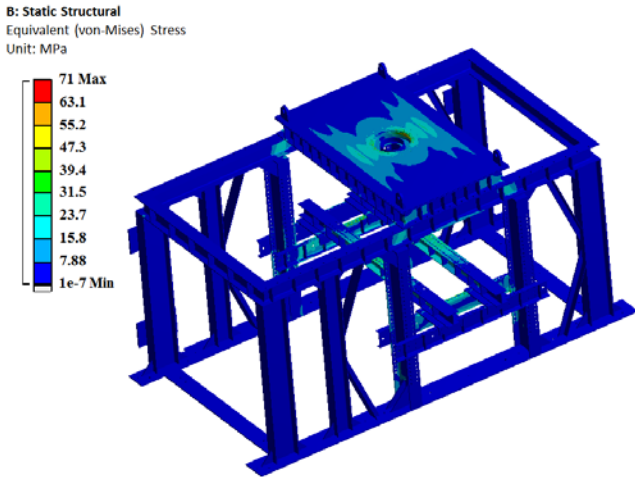


Fig. 6 Equivalent stress on the test cell

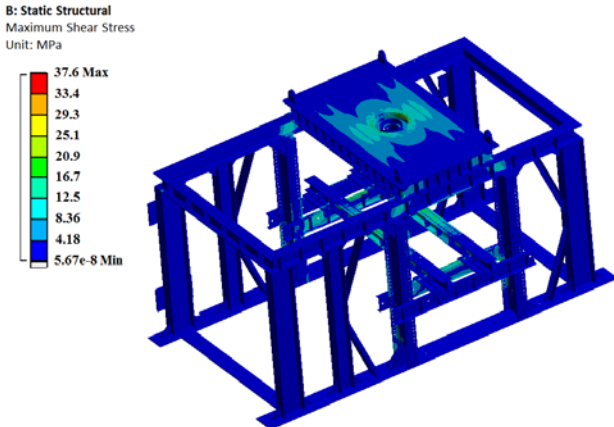


Fig. 7 Shear stress on the test cell

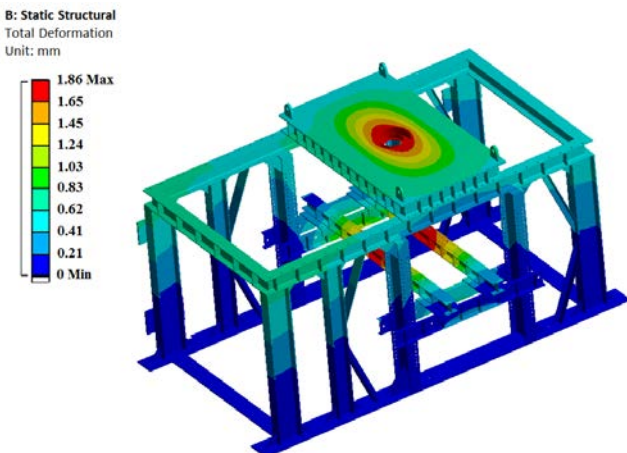


Fig. 8 Total deformation on the test cell

Vibration is another important aspect to consider. The natural frequency of the test cell must be kept away from the working frequency of the generator, which is 50.2 Hz, to prevent resonance. Modal vibration analysis is also performed. Solution of the static analysis is connected to the setup of the modal analysis in order to use the required pre-stress option. Natural frequencies for 20 modeshapes are obtained and the ones that are close to the working frequency of the generator are presented in Table 2. It can be seen that the natural frequency of the test cell approaches to the generator frequency at higher modeshapes (i.e. 14 onwards), at which the small amplitudes do not pose a threat to the test cell structure.

Table 2: Natural frequencies of the test cell

Modeshape	Natural frequency (Hz)
14	47.23
15	48.04
16	49.28
17	52.68
18	54.54

6. Conclusion

In this paper, a test cell is designed for a model turbine test rig, which has a maximum pumping power of 2 MW. The test cell accommodates generator-bearing assembly and model turbines to be tested. The geometry is modeled by regarding adaptability of the test cell and the design is analyzed to check the stresses, deformations and vibrations against design limits. A custom hydrostatic bearing unit is designed to isolate the generator from potentially harmful axial and radial forces, and bending moments produced by the turbine. The bearing unit also allows direct measurement of the net torque produced by the turbine as required by the standards of the IEC.

7. Acknowledgments

This research is financially supported by Turkish Ministry of Development.

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PRODUCTION OF LAYERED MDF PANEL HAVING FINE FIBERS IN FACE LAYERS AND COARSE FIBERS IN CORE LAYER FOR FURNITURE INDUSTRY

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Abstract: MDF (Medium Density Fiberboard) which is one of the wood-based panels used for industrial applications such as furniture, building materials, and laminate flooring the conventional MDF panels are produced using single layer in the mat forming machine. In this study, it is aimed to produce layered MDF panel for the furniture industry. The surface layers of the MDF consist of fine while the core layers consist of coarse fibers. The MDF panels having different face and core layer ratios could be produced using different defibrator disc gap, which results in different fiber sizes. In the production of layered MDF production, the MDF companies should change their mat forming system, which look like the mat forming of three layers particleboard. The MDF companies having the layered mat forming machine can also use the conventional production which is one layer mat forming production in the MDF. The advantages of three layer MDF are as follows; (1) The amounts of wood and adhesive can be decreased by using the cores fibers used in the core layer of the MDF, (2) The fiber production capacity of the defibrator can be increased using cores fibers, which positively affect the energy saving in the defibrator, (3) The splitting caused by side screw withdrawal resistance can be prevented using core layer consist of coarse fibers.

Keywords: MDF, FINE FIBERS, COARSE FIBERS, FURNITURE INDUSTRY, LAYER

1. Introduction

Conventional wood-based composites are manufactured products made primarily from wood with only a few percent resin and other additives. A useful way to classify conventional wood-based composites based on specific gravity, density, raw material, and processing methods is shown in Figure 1.

The term of fiberboard includes hardboard, medium-density fiberboard (MDF), and cellulosic fiberboard. Several things differentiate fiberboard from particleboard, most notably the physical configuration of the wood element. Because wood is fibrous by nature, fiberboard exploits the inherent strength of wood to a greater extent than does particleboard.

Fiberboard is normally classified by density and can be made by either dry or wet processes (Fig. 1). Dry processes are applicable to boards with high density (hardboard) and medium density (MDF). Wet processes are applicable to both high-density hardboard and low-density cellulosic fiberboard. The following subsections briefly describe the manufacturing of high- and medium-density dry-process fiberboard, wet-process hardboard, and wet-process low-density cellulosic fiberboard.

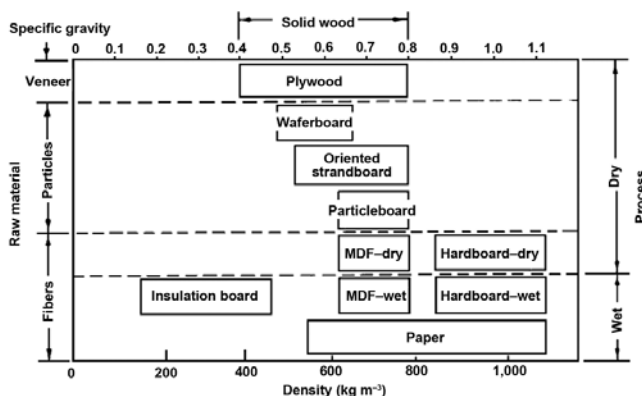


Fig. 1: Classification of wood composite panels by particle size, density, and process (Suchsland and Woodson 1986). Note that insulation board is now known as cellulosic fiberboard.

2. MDF Production

MDF is engineered wood-based panel materials made by bonding together wood fibers with a synthetic resin adhesive. Medium Density Fiberboard (MDF) is used the most commonly which is made by drying process.

MDF is used extensively in factory-assembled and ready-to-assemble furniture, as well as in cabinets, underlayment, drawer

fronts, molding, and countertops due to its ability to be produced in molded form, as well as in straight-edged flat panels.

Medium density fiberboard (MDF) is primarily used for industrial applications such as furniture, building material, and laminate because of its good mechanical and economical aspects is usually high in strength, easy to machine, and has good weathering properties (Suchsland and Woodson, 1986).

MDF can be manufactured with either softwood or hardwood species. Most MDF is composed primarily of softwood, although some individual brands may contain a higher percentage of temperate hardwood, depending on the location of the factory to the local forest resource.

Manufacturing Process

A typical process involves reducing wood down to small chips, which are then thermally softened and mechanically refined into fibres. These are then mixed with a synthetic resin binder. The resonated fibres are dried and then formed into a mattress ready for pressing. The mattress is pressed between heated polished press plates to the desired thickness.

Standard forms of MDF typically have densities as follows:

- Average density: 700 kg/m³ to 800 kg/m³
- Core density: 600 kg/m³ to 700 kg/m³
- Face density: 1000 kg/m³ to 1100 kg/m³

MDFs can have densities that range from below 450 kg/m³ up to 800 kg/m³ and above.

The Types of MDF which are used in furniture industry commonly;

- Fine Thickness MDF
- Middle-Coarse Thickness MDF
- Coarse Thickness MDF

Fine thickness MDF has 1.8-2.5 mm thickness. Its usage areas are such as drawer stands, furniture or cabinet backs and door panels.

Middle-Coarse Thickness MDF has 3-6 mm thickness. Almost all furniture's main structure consists from middle-coarse MDF.

Coarse Thickness MDF has 45-60 mm thickness. It can be used for architectural purposes and belt or column in buildings.

The face of particleboard usually consists of fine wood particles and the core is made of coarser material. The result is a smoother surface for laminating, overlaying, painting or veneering.

The purpose of this project is producing MDF by using thinner fibers for the surface and a bit more coarser fibers for the core differently from particleboard.

In this study, it is aimed to produce layered MDF panel for the furniture industry. The surface layers of the MDF consist of fine while the core layers consist of coarse fibers. The MDF panels having different face and core layer ratios could be produced using different defibrator disc gap, which results in different fiber sizes. In the production of layered MDF production, the MDF companies should change their mat forming system, which look like the mat forming of three layers particleboard.

Thus, there will be some advantages such as;

1. The amounts of wood and adhesive can be decreased by using the cores fibers used in the core layer of the MDF.
2. The fiber production capacity of the defibrator can be increased using cores fibers, which positively affect the energy saving in the defibrator.
3. The splitting caused by side screw withdrawal resistance can be prevented using core layer consist of coarse fibers.

3. Available Methods for Manufacturing

Some methods for the realization of this production are below:

- a. Change the wood species used
- b. Change the size of fibers (figure 2)
- c. Make some changes the density profile of wood material (figure 3)
- d. Change amount of adhesive

Changing the wood species using on the surface and core layers of MDF is one of the most important influence to decrease splitting during the screwing. According to this information, soft wood fibers (such as pine fibers) using on the surface of MDF while hard wood fibers (such as beech or oak fibers) using on the core of MDF.

During the conventional produce of MDF fine fibers are used on the core layer. It is caused side splitting during screwing because of MDF core layers having harder and denser structures. To prevent this, it should consist of coarse fibers.



Fig 2: Fine fibers use of the surface layer(left), coarse fibers use of core layers (right)

The density profile mainly means that a density changing in the board thickness. If the density of the core layer is decreased, side splitting is diminished during the screwing.

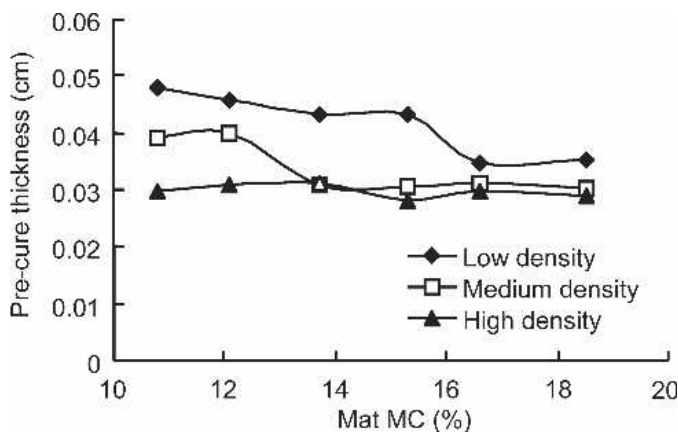


Fig. 3: Density ratios for different MDF panels.

Boards which are used coarse fibers inside the core layer, require less amount of adhesive. In this way, companies' adhesive costs are declined.

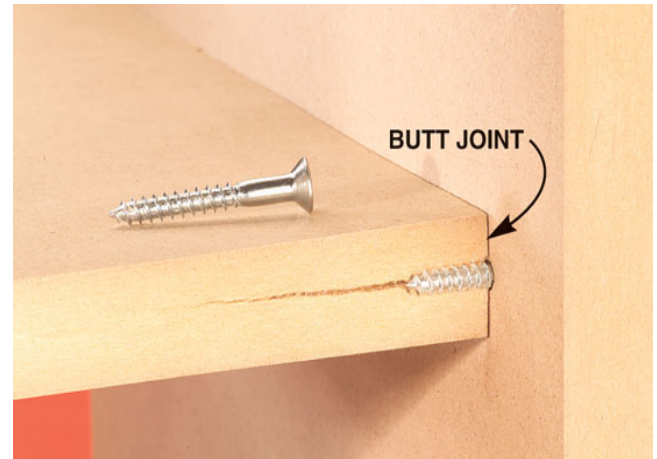


Fig. 4: Edge splitting during the screwing

4. Conclusion

In this study, it is intended to reduce side splitting, high costs because of using excessive adhesive and high density problems and to overcome the problems mentioned before. This study is a preliminary study due to has not completed yet and lack of relevant literature. The limits of this study are the process of preparation of fibers and the absence of information to be compared due to the literature scarcity.

In the future, it is recommended that for researchers who will perform similar research to use different wood species, different density profile values and mechanical sifting system.

5. Acknowledgement

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INLINE PIPE FRANCIS TURBINE DESIGN

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Abstract: Inline pipe Francis turbine design is proposed. Spiral case is not used in inline pipe Francis turbines and the flow can enter the stay vanes directly. The flow rate can be distributed uniformly around stay vanes. Another advantage of the new design is that the static pressure drop of the flow is less than that of conventional Francis turbines, which minimize the losses. Working range of the turbine is increased in the new design, as well.

Keywords: FRANCIS TURBINE DESIGN, COMPUTATIONAL FLUID DYNAMICS, INLINE PIPE TURBINE

1. Introduction

Francis type turbines are the most widely used hydraulic turbines because of their wide operating ranges. Francis type turbines comprise mainly of a spiral case, stay vanes, guide vanes, a runner and a draft tube. Spiral case must supply water uniformly along the perimeter of stay vanes with minimum hydraulic losses [1]. Stay vanes provide structural strength for the spiral case. Guide vanes regulate the flow rate and the power of the turbine. They rotate around their axis. Water enters the runner radially and exits axially. Draft tube connects the runner outlet and tail water. The draft tube increases water pressure up to the atmospheric pressure. Figure 1 illustrates the main components of a Francis turbine [2].

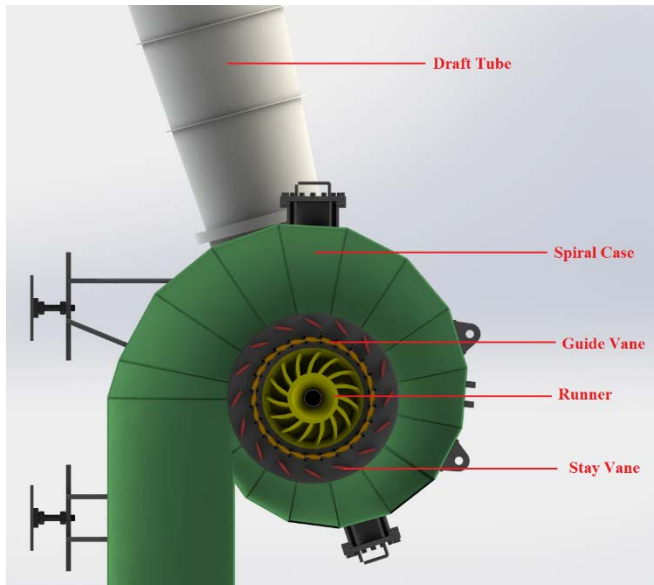


Fig. 1 Main components of a typical Francis turbine

Water must be distributed to each runner blade equally, this effects the turbine efficiency and the generated power directly. Nonuniform flow can also cause vibration in the runner, which consequently can results in erosion of the blades. Therefore, spiral case design gains importance.

To avoid all these problems, a new inline pipe Francis turbine design is proposed for a hydroelectric power plant that is located in Bursa, Turkey. The turbines of the power plant was designed by our group in 2014 [3]. The power plant has 1.40 MW power capacity, 78 m net head and 2 m³/s flow rate. The design was a typical Francis Turbine. However, in the current study, an alternative approach is used. The spiral case is avoided and the flow can enter the stay vanes directly [4]. The new design is based on Computational Fluid Dynamics (CFD) analysis. CFD analyses are performed for different head and flow rate values to indicate the operating range of the inline pipe turbine. The flow rate can be distributed uniformly around the stay vanes. The stay vanes and guide vanes are redesigned using the same runner and draft tube.

2. Nomenclature

Θ_i	Angle definition of cylindrical coordinates [°]
P_s	Static pressure [Pa]
P_t	Total pressure [Pa]
H	Head [m]
H_{loss}	Head loss [m]
Q	Flow rate [m ³ /s]
η	Efficiency [%]
P	Power [W]
TD	Typical design
IPD	Inline pipe design

3. Design Methodology

CFD aided turbine design is based on three main steps, preliminary design, geometry generation and CFD [5]. The design methodology is shown in Figure 2. The design process starts with the specification of head and the flow rate.

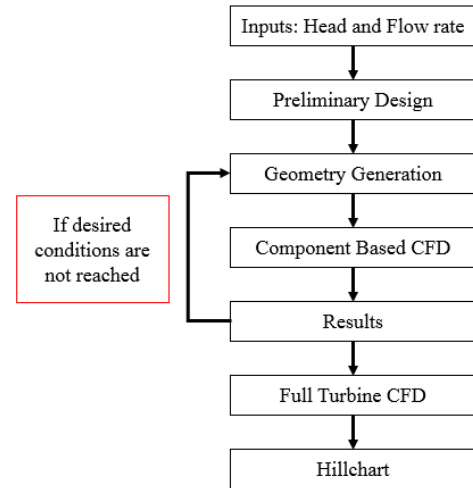


Fig. 2. CFD-based design methodology

Spiral case and draft tube geometries are generated with Autodesk Inventor [6]. Stay vanes, guide vanes and runner is generated with Ansys BladeGen [7]. Mesh of the spiral case and draft tube are generated in Ansys Mesh Module. On the other hand, stay vanes, guide vanes and runner are meshed with Ansys Turbogrid [7]. Ansys CFX tool is used to perform the CFD analyses [7]. High resolution advection scheme is chosen for solver settings. Reynolds Averaged Navier – Stokes equations are solved and k – ϵ turbulence model is used [8]. The results are evaluated to find out if the required flow rate and efficiency are reached. Analyses are repeated until the desired results are obtained. The final design and

full turbine analyses are performed for different head and flow rate values to obtain the operating region of the turbine.

The pipe geometry is generated with Solidworks 2014 [9]. The pipe is meshed using 6015550 tetrahedral elements and 1535774 nodes. Total pressure inlet for 78 m and mass flow outlet for 2000 kg/s are used for the boundary conditions. The analyses are continued until minimum hydraulic loss is reached and uniformly distributed velocity and pressure contours are obtained.

The stay vanes are redesigned to direct the flow with desired flow angle to the guide vanes. The flow has 50° flow angle at the inlet of the stay vanes and 30° at the stay vane outlet. But the flow enters with a 90° flow angle to stay vanes for the inline pipe turbine. The new stay vanes should direct the flow from 90° to 30° with minimum hydraulic losses. The new stay vane geometry design is also generated in Ansys Bladegen. The geometry is meshed using the H/J/C/L and O grid topology. One stay vane is meshed using 88230 elements and 97825 nodes. After determining the pipe, stay vane and guide vane geometries, full turbine analysis are performed to specify the operating range of inline pipe turbine. The analyses are performed for 50 m to 110 m head values and 15° to 40° guide vane opening angles. Full turbine domain has 15103458 elements and 11408860 nodes. Total pressure inlet for head values at pipe inlet and static pressure outlet for draft tube outlet boundary conditions are given. The hill chart (flow rate versus head with respect to efficiency of turbine) is generated.

4. Results

Total pressure, static pressure, head losses and efficiency results are given on Table 1 for typical design spiral case and inline pipe design pipe. The efficiency is increased with inline turbine.

Table 1: Performance results of spiral case and pipe

	TD Spiral Case		IPD Pipe	
	Inlet	Outlet	Inlet	Outlet
P_t [Pa]	866496	864240	866505	865933
P_s [Pa]	856334	824943	865734	854926
H_{loss} [m]	0.23		0.06	
η [%]	99.4		99.9	

Total pressure, static pressure, head losses and efficiency results are given on Table 2 for typical design stay vane and inline pipe design stay vane.

Table 2: Performance results of stay vane

	TD Stay Vane		IPD Stay Vane	
	Inlet	Outlet	Inlet	Outlet
P_t [Pa]	863518	860971	866088	862843
P_s [Pa]	822689	817139	854031	746073
α_0 [°]	50.9	30.9	89.9	29.4
H_{loss} [m]	0.26		0.33	
η [%]	99.8		99.6	

The streamlines of typical design stay vanes and guide vanes are shown in Figure 3. The velocity streamlines of inline pipe design stay vanes and guide vanes is shown in Figure 4. It shows that the flow is uniformly following the blade surfaces, as opposed to conventional design. There is no flow separation for the stay vanes and guide vanes.

The runner results of conventional design and inline pipe design are given on Table 3.

Table 3: Performance results of runner

	TD Runner		IPD Runner	
	Inlet	Outlet	Inlet	Outlet
P_s [Pa]	560443	59416	586172	51082
H [m]	75.4		75.0	
Q [m ³ /s]	1.99		2.19	
η [%]	95.8		96.1	
P [kW]	1405.5		1539.5	

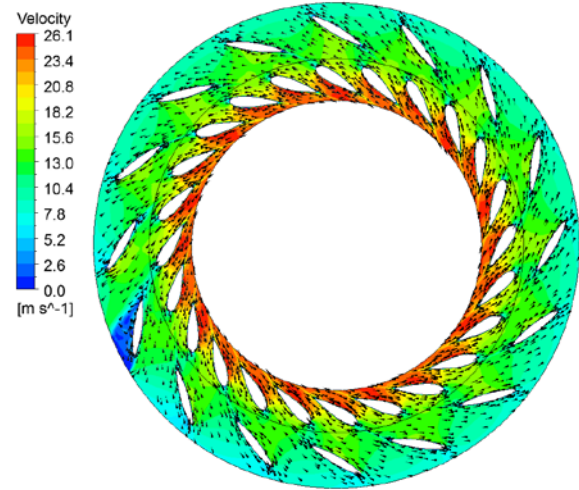


Fig. 3 Velocity contours and vectors of stay vanes and guide vanes for typical design

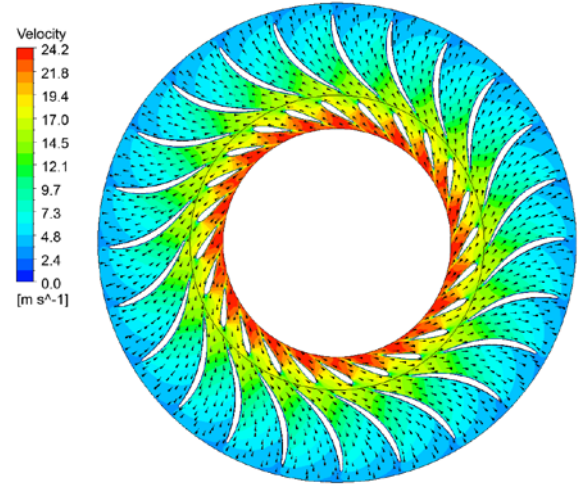


Fig. 4 Velocity contours and vectors of stay vanes and guide vanes for inline pipe design

The hill chart of the turbines are generated from full turbine CFD analyses. The hill chart of the conventional design turbine is given in Figure 5 and inline pipe design turbine in Figure 6. It is shown in Figure 5 that the turbine can operate up to 93% efficiency between 1.5 to 2.2 m³/s flow rate and 70 to 80 m head.

The advantage of the new design is that the static pressure drop of the flow is less than that of conventional turbine, which minimizes the losses. Working range of the turbine is increased in the new design, as well. Inline pipe turbine can operate on a wider range of flow rate and head values more efficiently. It is easily understood from Figure 6 that high efficiency operating area is enlarged for inline pipe design turbine. The turbine could operate up

to 93% efficiency between 1.2 to 2.7 m³/s flow rate and 60 to 90 m head so it means that the inline pipe turbine could operate at highest efficiency approximately for all working conditions. Also the generated turbine power is increased.

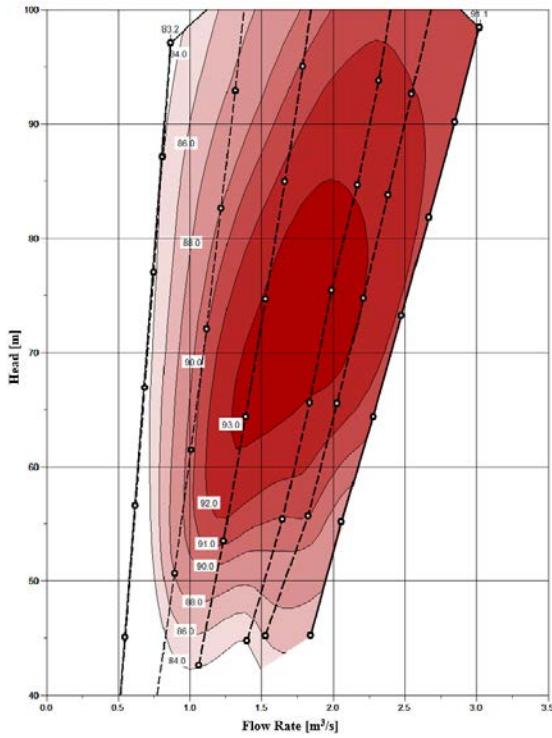


Fig. 5 Hillchart of the typical turbine

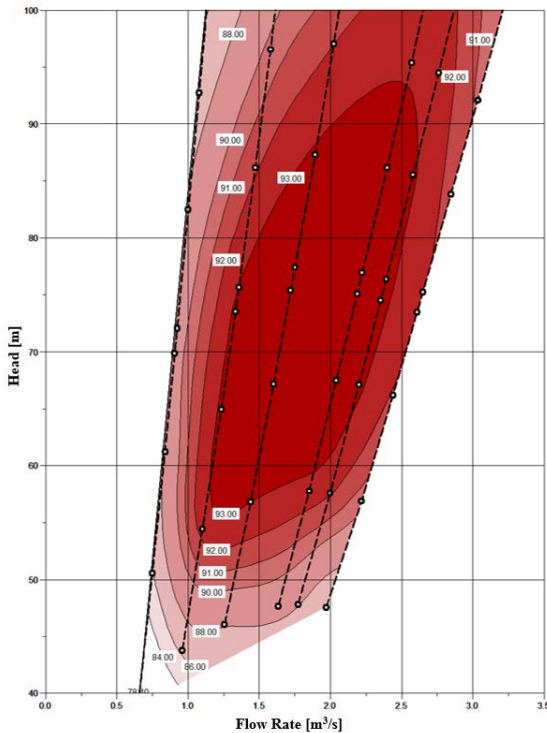


Fig. 6 Hill chart of the inline pipe turbine

The elimination of spiral case also reduces the design and production costs. Moreover, the turbine takes less space in the power plant. The general view of inline pipe turbine is shown in Figure 7.

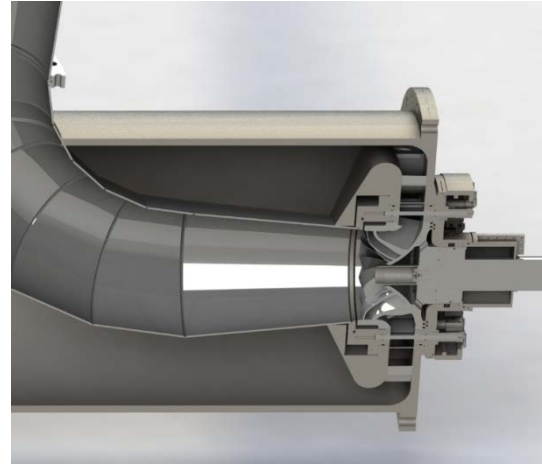


Fig. 7 General view of inline pipe turbine

5. Conclusion and Discussions

A new type of Francis turbine design is proposed to improve the operating range of the turbine which was designed using conventional techniques, before. Inline pipe Francis turbine design is proposed so that the spiral case is not used in the new design. The flow enters the stay vanes directly so non-uniform flow rate distribution is avoided. In addition to this, the static pressure drop is less than typical design so the produced power is increased as well. Full turbine analyses are performed to generate hill chart of turbine to determine the operating region of turbines. In conclusion, the operating region of the turbine is expanded considerably for the inline pipe design. The inline pipe turbine design also has some other advantages. It is compact and takes up less space in the power plant that can reduce the construction costs of the power plant. Also the elimination of spiral case reduces the design and manufacturing costs.

6. Acknowledgment

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APPROACH FOR SOFTWARE DEVELOPMENT FOR GENERATION OF CONTROL PROGRAMS BASED ON IEC 61499 STANDARD

ПОДХОД ЗА РАЗРАБОТВАНЕ НА СОФТУЕР ЗА ГЕНЕРИРАНЕ НА УПРАВЛЯВАЩИ ПРОГРАМИ БАЗИРАНИ НА СТАНДАРТА IEC 61499

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Abstract: This paper presents an approach for software development that generates control programs in the field of reconfigurable manufacturing systems. The proposed approach proposes the use of developed domain ontologies merged in a meta ontology which is based on the standard for integrated production systems and management IEC / ISO 62264. The article addresses the main graphic elements of the software that are being developed as well the principle of generating control programs.

Keywords: IT, ontologies, interoperability, RMS, IEC / ISO 62264, IEC 61499.

1. Introduction

In the field of the reconfigurable manufacturing systems there are too many problems – both hardware and software – that prevent the mass deployment of these systems on the world market. One of the main software problems is the interoperability issue. According to [1], interoperability is the ability of two or more systems to exchange information and to use it. The interoperability allows drastically reducing the number of necessary interfaces for communication among different devices, machines and systems and furthermore reduces the time and cost of implementing new production systems and consequently the price of the final product should be reduced. There are some research areas for the development of interoperability and according to [2] one of them is the ontology area. Through the use of a shared ontology some standards such as IEC/ISO 62264, ISO 10303 (STEP) and IEC 61499 [3, 4, 5] may give a solution to the interoperability issue in the reconfigurable manufacturing systems. Though the ISO 10303 standard is aimed for future work and is not part of the current research the developed software uses developed domain ontologies merged in a meta ontology which is based on the standard for integrated production systems and management IEC / ISO 62264. The ontologies are used by the software as a knowledge base for the generation of control programs based on the standard IEC 61499. The main purpose for the development of this software is to create transition between the developed ontologies which are used as a manufacturing knowledge base and the creation of control programs thus proposing approach for solving the software interoperability issue in the reconfigurable manufacturing systems. On figure 1 is presented the flowchart of the developed software. As you can see it is divided into eight sections but only sections from one to five and some part of section six are topics of the presented article. Sections seven and eight are objects of future work.

2. Graphical User Interface

As you can see on Fig.1 there are some colored elements. The green element marks the beginning of the program while the red ones mark a possible exit of the program. The blue elements mark the transition between the main graphical user interface components and the yellow ones mark areas where the user is allowed to enter data. The program starts from section one which is shown in more details on Fig.2. At the launch of the software, the program begins with an informative window that contains brief information about the software and the programmer as well the university and the faculty, and the license agreement. If the user agrees to the terms of use, he may continue by loading the *Login screen* or to terminate the program. When the *Login screen* is visualized the user may enter his username and password in the

appropriate fields and then the system will check if there are any errors. If there are any, an error message will be displayed, otherwise the system will display a message for the successful connection to the database and will visualize the *Main screen* (fig. 2).

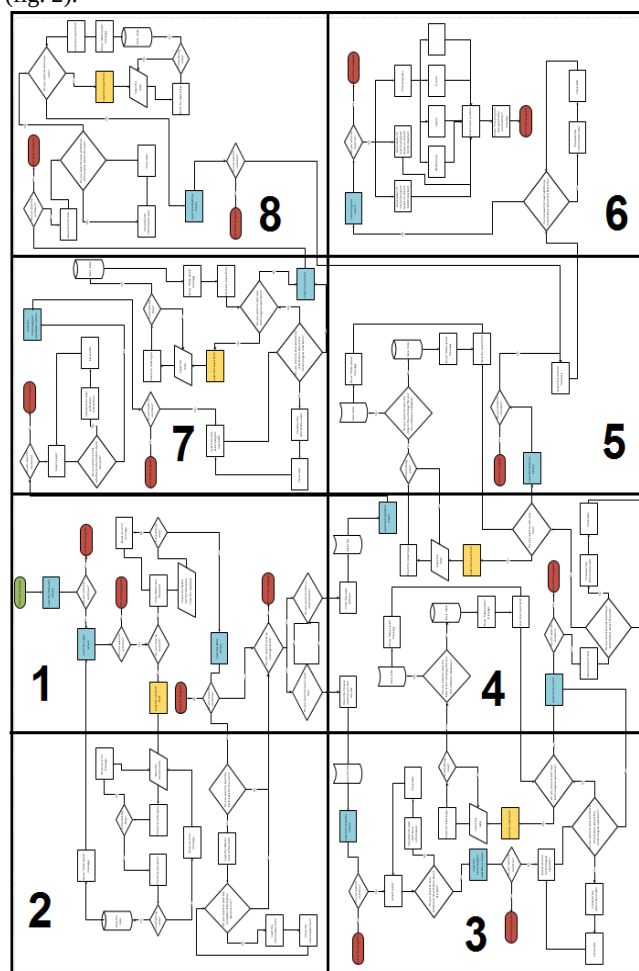
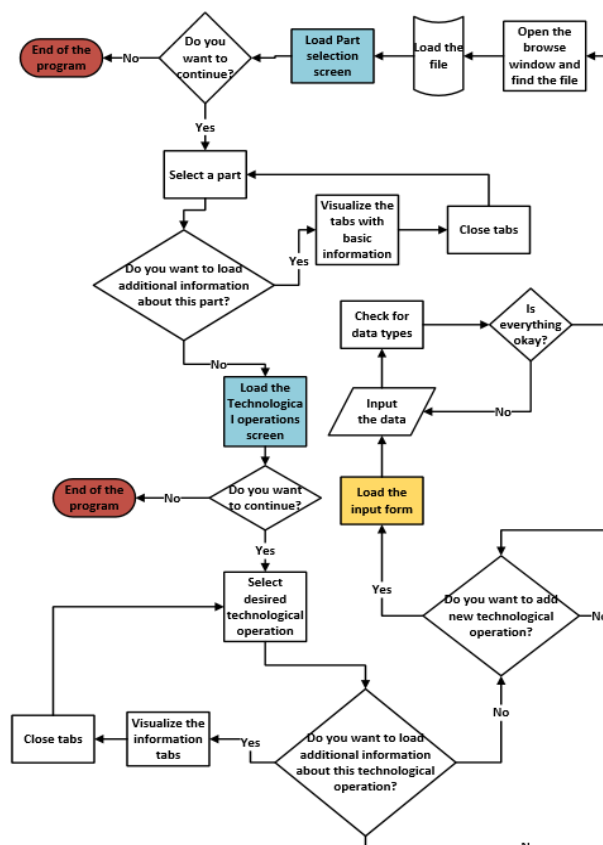
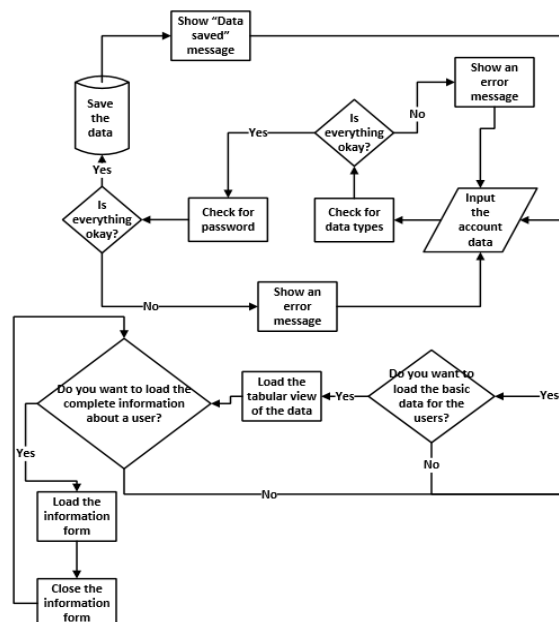


Fig. 1: Flowchart of the developed software

If the user does not have an existing account, there are two other options. The first one is to terminate the execution of the program and the second one is to create an account. The second option transfers the user to the *Account form* that needs to be filled correctly in order to create the account. The algorithm of the *Account form* is presented in Fig. 3 (section two of Fig.1). The system makes a check for the compliance of the entered data

```
graph TD
    Start([Start the program]) --> Welcome[Load the Welcome screen]
    Welcome --> Continue1{Do you want to continue?}
    Continue1 -- No --> End1([End of the program])
    Continue1 -- Yes --> Login[Load the Login screen]
    Login --> Continue2{Do you want to continue?}
    Continue2 -- No --> End2([End of the program])
    Continue2 -- Yes --> Account{Do you have an account?}
    Account -- No --> Form[Load the account form]
    Form --> Continue3{Do you want to continue?}
    Continue3 -- No --> End3([End of the program])
    Continue3 -- Yes --> Main[Load the Main Screen]
    Account -- Yes --> Enter[Enter Name and Password]
    Enter --> Check[/Check the Name and the Password from the database/]
    Check --> Okay{Is everything okay?}
    Okay -- No --> Error[Show error message]
    Error --> Continue1
    Okay -- Yes --> Main
    Main --> Continue4{Do you want to load an ontological file?}
    Continue4 -- No --> End4([End of the program])
    Continue4 -- Yes --> Local{Do you want to load a local file?}
    Local -- No --> LocalBox[ ]
    LocalBox --> LocalBox
    Local -- Yes --> LocalBox
    LocalBox --> Web{Do you want to enter a web address?}
    Web --> LocalBox
    LocalBox --> Main
```

When the *Main screen* is loaded it displays the server date and time and the user has a few options. The first one is to terminate the program. The second is to visualize a tabular presentation of the basic information about the different accounts. If the user wants he may visualize a *Business card* with detailed information for the appropriate user (Fig. 3). The third option leads the user to two different pathways of the program. The first one is to enter a web address that leads to an ontological file but that leads to section seven and eight (Fig. 1) which are not part of this paper and won't be discussed any further. The second option for the user is to open an ontological file locally. When the file is located and loaded, the system extracts all the data that the file contains and from this point on the user may continue with the generation of the control programs for reconfigurable manufacturing systems where all of the proposed decisions such as different parts, technological operations, tools, machine tools are based on the relations between classes and individuals in the opened ontology.



№	Part	Data	Drawing	Choice
1	Hydraulic Cylinder	View Data	View Drawing	☐
2	Pneumatic Cylinder	View Data	View Drawing	☐
3	Plate	View Data	View Drawing	☐

Fig. 5: Tabular presentation of all parts in the ontology

When the *Technological operation screen* is loaded the user may terminate the program or to select the desired technological operations which are presented in a tabular form. If the user is not familiar with the presented information he may load the *Technological operations form* where the desired operation is displayed in detailed view. If the desired operations are not in the presented list, the user may add them manually. To do that he loads the desired form (for drilling operations, for milling operations and so on) enters the desired data. The system makes a check for the compliance of the entered data types and if there is any mistake the system displays the appropriate error message. When all of the data is entered the user may decide how to save the data. The first option is to save the data in the software database. In that case these technological operations will be marked as additional operations and if the ontological file is loaded a second time, they won't be marked by default. The second option is to save the data in the software database and in the ontological file simultaneously. The main benefit in that case is the enrichment of the knowledge base and if the file is loaded a second time, all of the added operations will be related to the appropriate part and will be marked by default. When everything is done the user may continue by loading the *Tool screen* and the *Machine screen* (section four and section five of figure 1). Due to the fact that the work algorithms of these screens are similar to that of the *Technological operation screen* (with the exception that machines cannot be added to the ontological file and the software database) they won't be discussed in details any further. When all conditions are fulfilled (all elements that are needed for the production of the desired part) the software visualize the last of the main graphical user interfaces – the *Program screen* – presented in details on figure 6 (section six of figure 1). In the *Program screen* the user may decide the output format of the generated control program. When the IEC 61499 format is selected the user has to point the location where the XML code of the function blocks will be saved (each one of the blocks correspond to the appropriate technological operation). When the location for saving the blocks is selected, the software displays a message for the successful generation of the control program and terminates the execution of the program.

4. Future work

The development of the software will continue in the future by expanding its capabilities. For instance, the initial design of the software predicts the use of the internet, so one of the task for future development is the ability to open and extract information from ontological files that are uploaded in the internet, in compliance with all security protocols (section seven and section eight of figure 1). Another example may be made with the final output of the generated control programs. The developers wish to expand the interoperability capability of the software by adding different options for the final output – IEC 61131, CL Data files, G code and so on.

6. Conclusions

The presented approach, for software development in this study aims to present a way for solving the software interoperability issue in the reconfigurable manufacturing systems through the use of ontologies. Some of the benefits for using the software are:

- fast generation of control programs based on the standard IEC 61499;
- fast software reconfiguration in RMS;

- the software uses the developed ontologies as a source for information, so the enrichment of the knowledge of the ontologies expands the possible solutions that could be offered by the software;
- opportunity to expand the knowledge base of the ontology through the use of the software;

The software will be tested on a system of FESTO workstations, property of the Technical University of Sofia, Faculty of Industrial Technologies, Department of Mechanical Engineering and Machine Tools.

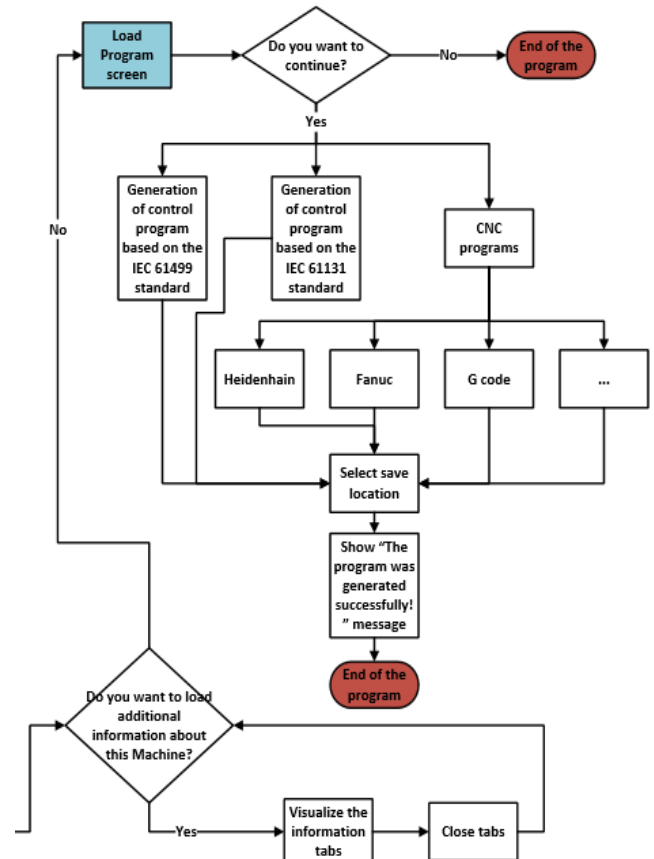


Fig. 6: Generation of control program algorithm

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DOMAIN ONTOLOGY OF THE EQUIPMENT IN MANUFACTURING SYSTEMS

ДОМЕЙН ОТНОЛОГИЯ НА ЕКИПИРОВКАТА В ПРОИЗВОДСТВЕНИ СИСТЕМИ

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Abstract: This paper presents the developed domain ontology of the equipment in manufacturing systems in order to be used in the field of reconfigurable manufacturing systems (RMS). The ontology meets the requirements of the meta-class "Equipment", which is part of the developed meta ontology based on the standard for integrated systems for the production and management IEC / ISO 62264. The article explains various properties and class restrictions of the developed ontology. Web Ontology Language (OWL 2) and Protégé 4.3 as an editor and knowledge acquisition tool are used. Special attention is given to the use of ontology reasoning to infer additional information from the facts stated explicitly in ontology - an important feature, used to perform classification, sorting and assembly operations and consistency checking.

Keywords: IT, ontologies, interoperability, IEC / ISO 62264, RMS.

1. Introduction

In the modern world the manufacturers need to satisfy the fast changing demands of the consumers in order to be competitive on the globalized market. This leads to developing new solutions in the development and manufacturing of the final product. One of the possible solutions is the development of reconfigurable manufacturing systems. These systems would allow faster implementation of the designed manufacturing systems and the result would be reduction of the time needed for the manufacturing of the final product. However, these reconfigurable manufacturing systems still have too many problems – hardware and software – that prevent their mass deployment on the world market. One of the main software problems is the interoperability issue that leads to the use of too many devices and the implementation of different software solutions in order to establish a connection and proper transfer of information between the different machines in the system. The results of this problem are increased manufacturing time and increased price for the final product. According to [1] the interoperability issue may be solved through the use of some standards such as IEC/ISO 62264, ISO 10303 (STEP) and IEC 61499 [2, 3, 4] and shared ontology. The developed domain ontology presented in this paper is one of four ontologies that are developed to match the IEC/ISO 62264 standard and merged in a developed meta ontology based on the same standard in order to work together. The purpose of the development of the four ontologies is to capture the basics of the manufacturing processes where the *Equipment* ontology is the most complex of the four because of the relations between the different individuals and classes that corresponds to different sensors, tools, machines, systems and so on. The developed ontologies will be used by specially developed software for the generation of control programs and in such way, illustrating an approach for solving the interoperability issue in reconfigurable manufacturing systems.

2. A short overview of the applied techniques

The Web Ontology Language OWL 2 [5] accepted as a World Wide Web Consortium (W3C) Recommendation from 11 December 2012 is a powerful knowledge representation language; it has been applied successfully for knowledge

modelling in many application areas [6]. As a descriptive language, OWL 2 is used to express expert knowledge in a formal way, and as a logical language, it is used to draw conclusions from this knowledge. The formal semantics allows humans and computer systems to exchange OWL ontologies without ambiguity as to their meaning, and also makes it possible to use logical deduction to infer additional information from the facts stated explicitly in an ontology [7]. Every OWL 2 ontology is a machine-processable formal description of a domain of interest and consists of the following three different syntactic categories: *Entities*, *Expressions* and *Axioms*. *Entities*, such as classes, properties, and individuals are identified by IRIs. They form the primitive terms of an ontology and constitute the basic elements of ontology. *Expressions* represent complex concepts in the domain being described: new classes as a result of *Intersection*, *Union*, *Negation*, *Existential* and *Universal Property Restrictions*, *Cardinality Restrictions*. *Axioms* are statements that are asserted to be true in the domain being described and allow relationships to be established between *Expressions*: *Subclass Axioms*, *Equivalent Classes*, *Disjoint Classes*, *Subproperties*, *Equivalent Properties*, *Disjoint Properties*, *Inverse Properties*, *Property Domain*, *Property Range*, *Inverse*, *Functional*, *Transitive Properties*, etc. These three syntactic categories are used to express the logical part of OWL 2 ontologies - that is, they are interpreted under a precisely defined semantics that allows useful inferences to be drawn [5]. The ability to infer additional knowledge (deductive reasoning [6]) is of great importance for designing and deploying OWL ontologies. A particular kind of deductive reasoning on the *ClassAssertion* axiom, the task of computing the individuals that belong to a given class (or set of classes) is called *instance retrieval*. If the task is to find out whether one particular individual belongs to the given class, it is called *instance checking*. Analogous tasks exist for *SubClassOf* axioms: computing all subclass relationships between a set of classes is called *classification*, and checking a particular subclass relationship is called *subsumption checking* [6]. Very important reasoning task is *consistency checking*, the task of determining whether a class or an ontology is logically consistent or contradictory. Instance retrieval and classification tasks can be solved by using many individual instance and subsumption checks. The concepts of *soundness* (all computed inferences are really entailed), *completeness* (all entailed inferences are really

computed) and *computational complexity* (time and resources needed for a reasoning task) are very important for the choice of suitable reasoner. Lack of *completeness* is sometimes acceptable if it allows for simpler or more efficient implementations, but the lack of *soundness* is usually not desirable [6]. Sound and complete OWL 2 reasoning is of high complexity - double exponential computational complexity - N2ExpTime. The OWL 2 new profiles (OWL 2 EL, OWL 2 QL, OWL 2 RL) restrict the used syntactic categories to improve complexity and practical performance, however with limitation of expressivity. Since the best balance between language expressivity and reasoning complexity depends on the intended application [7], and modeling of the equipment in the manufacturing systems needs more language constructions than the new OWL 2 profiles offer, we decided to tackle computational complexity using the optimized reasoning algorithm - HermiT. In [8] the performance of reasoning in HermiT is compared with that of FaCT++ and Pellet - two other popular and widely used OWL 2 reasoners. HermiT ontology reasoner supports all features of the OWL 2 ontology language, and it correctly performs both object and data property classification/reasoning tasks and is much faster than other reasoners. HermiT consists of components that together implement a sound and complete OWL reasoning system [8]. HermiT also implements a novel classification algorithm that greatly reduces the number of consistency tests needed to compute the class and property hierarchies [8].

3. Domain ontology “Equipment”

The developed ontology contains 156 classes, 1411 axioms, 34 properties, 57 different individuals. Protégé 4.3 is used as the most popular free ontology editor and HermiT 1.3.8 is used as a highly-efficient OWL Reasoner suitable for the domain of the equipment in the manufacturing systems.

3.1. Classes

The main class in this ontology is the class *Enterprise*. The complementary class *Value Partitions* is used as a “design pattern”. The class *Value Partitions* contains covering axioms used in different classifications, sorting and assembly operations using the HermiT reasoner. The class *Enterprise* follows the terminology, models and structure of a general enterprise in accordance with the world-wide accepted standard IEC/ISO 62264 for enterprise-to-control system integration [3] and has the following hierarchy – *Enterprise*, *Site*, *Area*, *ProductionLine*, *WorkCell*, *EquipmentModule* and *ControlModule* (each class is a sub class of the previous one). The class *ControlModule* is the lowest level of the hierarchy defined by the IEC/ISO 62264 standard and contains two classes - *Sensor* and *Actuator*. The *Sensor* class contains a collection of classes associated with different types of sensors. The physical object (the sensor itself) is presented via individuals described by various data properties and asserted to their appropriate class. The class *EquipmentModule* contains few additional classes except the class *ControlModule* which are *Accessory*, *Module* and *Tool*. The *Accessory* class includes a collection of classes for different accessories that could be added to the different machines such as vises, safety guards, and lamps and so on. The named *Module* class contains *CNCMachineTool_Module* and *FESTOModule* where the latter contains collection for the modules needed for the assembly of the FESTO Sorting, Processing and Handling

workstations. Similarly, to the sensors each module is described via individuals and data properties. The named class *Tool* contains a collection of named and defined classes that have restrictions and can classify different individuals by different characteristics. For example, the two defined classes *AllCarbideTool* and *AllHSSTool* will collect all tools of the ontology which are made of carbide or HSS (High Speed Steels) respectively when the ontology is inferred. Each tool is described in a similar way as the modules and the sensors. The other sub classes of the class *Tool* are *DrillingTool*, *MillingTool*, *ReamingTool* and *TappingTool*. Each one of the classes contains individuals describing different tools and asserted to appropriate tool type class. Through the use of defined sub classes, the ontology infers some sorting operations such as parting the different tools according to the material they are made of, according to preliminary defined diameter range or according to the tool size (large, medium or small). For instance, the named class *DrillingTool* contains the following named classes *DrillingTool_Diameters*, *DrillingTool_MadeOf* and *DrillingTool_Sizes* and one defined class that will sort all of the drilling tools according to preliminary defined range for the diameters of the drills when the ontology is inferred - *DrillingTool_DiametersRange*. The class *DrillingTool_Diameters* contains named classes for the different diameters of the drills and each individual is asserted to the appropriate class according to their diameter. For example, the named class *DrillingTool_Fi_1.6* contains all drilling tools of the ontology that have a diameter of 1.6 [mm]. The purpose of this classification is to create a location for the created individuals through some of their main properties. In our case this is the diameter of the tool (for cylindrical tools). From that point on it is better to create defined classes that can allocate the individuals according to their properties and the intended needs of the ontology because every single individual may have hundreds of properties and doing the job manually is nearly impossible. The *DrillingTool_MadeOf* contains two defined classes that can allocate the individuals according to the material they are made of (*DrillingTool_Carbide* and *DrillingTool_HSS*). As for the last class - *DrillingTool_Sizes* – it sorts the named classes for the diameters of the individuals into groups in a broader meaning (*Large*, *Medium* or *Small*) according to preliminary defined diameter range for each group. The classes and the operations for the other types of tools are similar to the *DrillingTool* class and will be not discussed any further. The hierarchy of the *Tool* class is shown on Fig.1.

The *WorkCell* class is equivalent to machine level. On this level sets of named and defined classes can be created and through the use of object properties different individuals from the lower levels of the hierarchy can be linked to form machines. For instance, there is a sub class of the *WorkCell* class (*FESTOWorkstations*) that when the ontology is inferred all of the appropriate sensors and modules of the lower levels of the hierarchy will be allocated to form groups of the FESTO workstations (Sorting, Handling, Processing and so on) as single machines. From this point on for the super classes of the *WorkCell* class (*ProductionLine*, *Area*, *Site*) it is better to use covering axioms for the creation of different systems, areas and sites. For example, the *ProductionLine* class contains four defined classes. These classes correspond to the level of a system (each class represent different system) so when the ontology is inferred these four defined classes form four different systems. Each system is composed of at least two FESTO workstations

that work together and that were defined on the lower level (on the level of the *WorkCell* class) as machines. There is no

limitation to the maximum number of FESTO workstations that are composing each one of the systems.

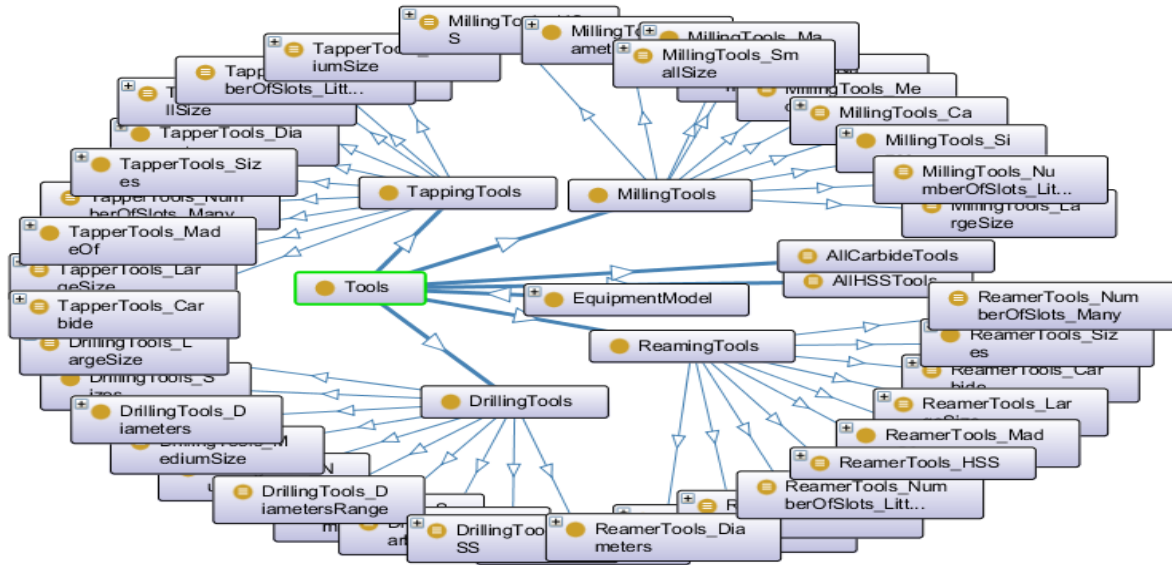


Fig. 1: Tool class hierarchy

3.2. Properties

A. Object properties

The ontology has ten object properties divided into three groups. The first one is *hasDiameter* and it is used alongside with the defined class *Tools_Size* as a covering axiom for the size of different tools. It is used as a restriction of the classes and defines three groups of sizes – *Large* for cylindrical tools with diameters larger than 10 [mm], *Medium* diameters in the range of 5 [mm] to 10 [mm] and tools with *Small* diameters which are smaller than 5 [mm]. As you can notice all of the ontology tools are cylindrical but that doesn't mean that the covering axiom is restricted to cylindrical tools only. For example, we may create another object property *hasInsertSize* and to use it to create covering axioms for prismatic tools for instance and so on. So when the class hierarchy is inferred, all of the tool classes are allocated to their places, so in this example we have allocation of classes while the second object property of the ontology is used to allocate individuals. The second object property group of the ontology is *isPartOf* and contains the sub properties *isPartOfSensor*, *isPartOfModule*, *isPartOfMachine* which are used to illustrate the relation of the different individuals among each other. As was mentioned earlier in this paper the classes *Modules* and *Sensors* hold collections of different modules and sensors. Each individual in this collection is asserted the appropriate object property. For example, the individuals that represent different sensors are related to the appropriate module via the object property *isPartOfModule*. In this way if we accept that a collection of sensors that are part of some module, and that a collection of different modules forms a machine then we can create defined sub classes of the class *WorkCell* and easily infer the knowledge for the parts that are needed to assemble a machine by allocating the different individuals to their respective defined class. This method is illustrated by three of the FESTO Workstations – Sorting station, Handling station and Processing station. Each station consists of assembly plate (in the ontology it is referred as the appropriate *Base*), modules and sensors. The *Base* is (as an individual) located in the named class of the

station, then we create defined sub classes for the available modules and sensors and by inferring the ontology all of the individuals are allocated to these classes by forming a compact description of the elements needed to assemble the appropriate workstation. The relations among the individuals are shown on Fig. 2.

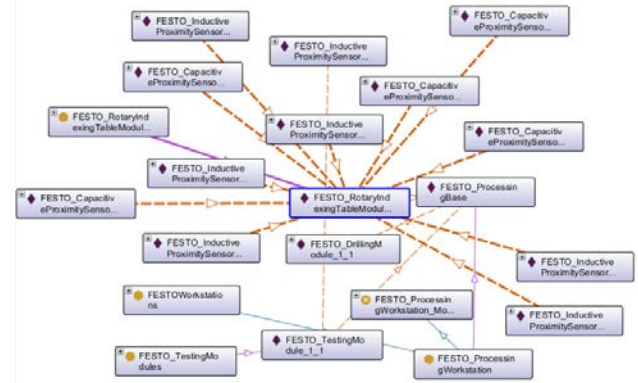


Fig. 2: Relation of individuals

The third object property group of the ontology is *consistOf* and contains the sub properties *consistOfMachine*, *consistOfSystem*, *consistOfArea*, *consistOfSite* which are used alongside the defined classes *System_Creation*, *Area_Creation*, *Site_Creation* as covering axioms for the creation of different systems and to illustrate the relation between the different classes. These properties are used in a way similar to the first and second group of properties so they won't be discussed any further.

B. Data properties

The data properties are used to describe the characteristics of the different individuals. There are 32 data properties in the ontology. As you can see from Fig. 3 the data properties are divided in some categories. The major one is *ToolsValues* which are used to describe the different properties of drills, mills, tappers and reamers and assign them values. Some of the

properties are additionally divided into groups because they are specifically reserved for only one type of tools. For example, in the *TappingToolsValue* group, the data properties are *hasPitchSizeValue* and *hasThreadValue* which are specific for the tapping tools. Some of the properties do not have groups and that is because they are universal for the ontology and each individual must have them in order to be described properly.

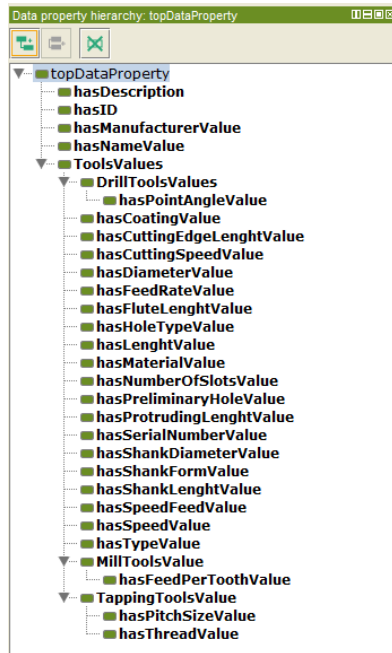


Fig. 3: Data properties

3.3. Restrictions

In this ontology the main types of restrictions that are used are *Quantifier restrictions* or more specifically *Existential restrictions* and *hasValue restrictions*. The *Existential restrictions* are used in the *Tools* section of the ontology so that the individuals could be allocated according different criteria. For example, there are two defined sub classes – *MillingTools_Carbide* and *MillingTools_NumberOfSlots_Little* – of the *MillingTool* class. The *MillingTools_Carbide* class has the *Existential restriction* *MillingTools* and *(hasMaterialValue some xsd:string[pattern "Carbide"])* and the other class – *MillingTools_NumberOfSlots_Little* – has *Existential restriction* *MillingTools* and *((hasNumberOfSlotsValue some xsd:integer[>=3]) and (hasNumberOfSlotsValue some xsd:integer[<=3]))* and *(hasMaterialValue some xsd:string[pattern "Carbide"])*. When the ontology is inferred the *MillingTools_Carbide* class is collecting all of the mill tools that are made of carbide and the second defined class *MillingTools_NumberOfSlots_Little* is collecting all mill tools that are made of carbide and have three slots. Because of the additional restriction to the second class, it is inferred as a sub class of the defined class *MillingTools_Carbide* although that these two classes are created on the same hierarchical level. In this way the sub class is going to collect two of the three mills because the third one has four slots and does not meet the specific restrictions of the *MillingTools_NumberOfSlots_Little* class. So the third mill will be inferred in the class *MillingTools_Carbide*. Another example is made by adding the *Existential restriction* *Tools* and *(hasMaterialValue some xsd:string[pattern "Carbide"])* to the class

AllCarbideTools which is sub class of the class *Tool*. The class is collecting all of the tools in the ontology that are made of carbide. So having in mind the previous example, when the ontology is inferred the group of the mill classes is allocated as sub class of the *AllCarbideTools* class.

4. Conclusions

The developed domain ontology in this study aims to represent the equipment in the manufacturing systems and the relations between the different equipment levels. The ontology, merged along with three others in meta ontology is going to be used by specially developed software for the generation of control programs thus illustrating an approach for solving the interoperability issue in the field of reconfigurable manufacturing systems. Some of the main benefits of the developed ontology are:

- the hierarchy is based on the IEC/ISO 62264 standard which defines the basic structure of the ontology;
- through the use of object properties, it is possible to create sensors, modules and machines (collections of different individuals);
- through the use of object properties and covering axioms, it is possible to create systems, areas and sites (collections of different defined and named classes);
- through the use of Quantifier restrictions and *hasValue* restrictions, it is possible to create sorting operations for the different individuals based on data properties.

Acknowledgments

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ELECTRON BEAM MELTING AND REFINING – ANOTHER POSSIBILITY FOR RECYCLING OF METAL SCRAP

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Abstract: *Electron beam melting and refining (EBMR) is one of the modern and widely used technologies which is employed industrially for melting and metal purification. Experimental investigations, computational modeling and optimization approaches are indispensable tools in the study of this ecological technology, for the development and optimization of effective technological schemes and their application to different materials as well as for reducing the price of the pure metals produced. On the basis of experimental and theoretical studies performed, data and results of practical importance for various applications of EBMR are obtained and summarized (for Cu, Ta, Hf, Ti, Au, etc.). The obtained results allow us to formulate requirements on the process parameters and are important and useful in view of studying, controlling and optimizing the quality and purity of the new materials obtained by recycling of metal scrap by EBM.*

Keywords: ELECTRON BEAM MELTING, REFINING, REFRACTORY METALS, REACTIVE METALS, ALLOYS, RECYCLING OF SCRAP, IMPURITIES

1. Introduction

Electron beam melting (EBM) in vacuum has played an important role for production of ultrapure materials and alloys, for recycling of metal wastes (including refractory and reactive metals), for purification of metallurgical-grade silicon to solar-grade silicon, etc. [1-14]. Due to a high vacuum level and superheating, the EBM provides efficient refining processes and superior refining level of gases, metals and non-metals inclusions [2]. The use of water-cooled copper crucible, where the raw material is melted, refined and solidified leads to absence of additional pollution due to the contact between the material and the refractory oxide ceramic pot, typically used in the conventional metallurgy. There are no special requirements concerning the kind of the raw (started) material which is an additional advantage of the e-beam melting method. The produced metal ingots are with homogeneous microstructure, have better performance characteristics and their weight varies from a few grams (pure metal tablets) to a few tons (large component production in aerospace industry, nuclear reactors, etc.). The production of each metal requires a successful process control, leading to decreasing the quantity of the unwanted impurities so the refined metal has to meet requirements for quality and composition, depending on the intended new applications.

The EBMR method has gained wide application in production of metals with high purity such as Cu, W, Zr, Ti, Mo, etc., and it has also an important role in recycling of metal wastes [1,12,15] containing valuable metals that have been oxidized or polluted (enriched with impurities) in their previous processing or applications. It is important to find optimal process conditions for achieving maximal level of impurities removal and minimal weight and energy losses.

There is dynamic increase in construction, implementation, and exploitation of equipment for obtaining pure metals and special alloys by EB melting in the recent years in countries like the USA - a certain leader in e-beam melting as well as in countries with developing nuclear power and space industry (China, India, etc.) which are definitely interested in this technological method. Manufacturers of refractory metals and their alloys (in the USA and in EU countries such as France, Germany, UK as well as manufacturers in Ukraine, Russia, China, India, etc.) are highly interested in developing such technologies concerning the production of wide variety of metals and alloys.

The world's recourses of many valuable metals are exceedingly limited. At the same time there are some large amounts of metal wastes collected in the country from different productions and after the laying-off of many metallurgical and metal-working manufacturing plants. Metal scrap is also collected as a result of wearing out of equipment in plants.

For countries (e.g. Bulgaria) that do not produce many metals due to the lack of ore products, the recycling of wastes of industrial use is important. As a result of studying, realized by asking the biggest industrial factories it was found that in Bulgaria there are some large amounts of metal wastes, including refractory and reactive metals and their alloys [15]. The scrap materials are mainly used catalysts, containing V_2O_5 , Mo; used capacitors, containing Ta, and chips and small pieces of Ti, Hf, W and Mo, broken knives, stale bearings and other used components from different kinds of alloyed steels. Their quantities vary from 100 tons to 10 000 tons.

The reuse of the refined metals needs to satisfy certain requirements for quality and composition that are set by the companies using these metals depending on their new applications. A major requirement to the developed refining technology is the high quality and reproducibility of the metal compliant to the corresponding standards (ASTM, BDS, etc.). The production of each metal is unique and the selective removal of impurities from the metal wastes is important. These impose the need to search for specific technological schemes and development of process regimes for different raw (initial) materials and for specific e-beam equipment [16-19].

Investigations and experiments dealing with the relations of EBM process parameters and impurities removal at EBMR of different metals, including refractory, reactive and precious ones, special alloys and scrap recycling are performed. Obtained data and results for various applications of EBMR are summarized and presented in the paper.

2. Results and discussion

Investigation was performed in the laboratory "Physical problems of electron beam technologies" at the Institute of electronics of the Bulgarian Academy of Sciences (IE-BAS). Experiments were carried out using 60 kW e-beam installation ELIT 60 (Fig. 1) with one electron gun (1), horizontal feeder (2), water-cooled copper crucible (3), and extraction system (pulled mechanism) (4).

In electron beam melting the refining processes take place mainly at the interface molten metal/vacuum [2] in three zones (Fig. 1): zone I – the front part of the started material (feeding rod), zone II – generated droplets and zone III – liquid pool (in the water-cooled crucible).

At right choice of EBM process parameters, proper thermodynamic, hydrodynamic and kinetic conditions for taking place of refining processes, concerning various impurities in each reaction zone, can be created. During the process, by changing the e-beam power and the casting velocity it is possible to control the geometry of the liquid pool, the temperature distribution in the

reaction zone and the duration of the thermal influence on the metal, which influence on the refining processes and on the quality of the obtained metal (after EBMR).

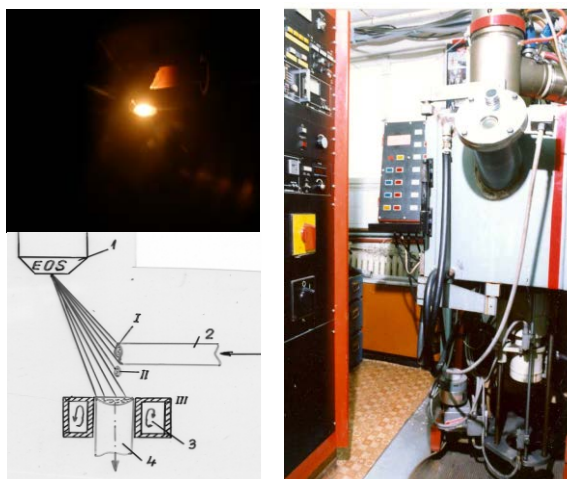


Fig. 1 ELIT 60 equipment and principal scheme of e-beam melting and refining drip process.

For development of particular technology for electron beam refining of metals it is necessary to study in details the thermodynamic limits for each chemical reaction and its rate, namely refining kinetics. Knowledge referred to the process mechanisms at e-beam refining allows more precise control the chemical composition of the obtained metals and alloys and allows obtaining alloys with given composition. This requires study of the limiting processes and factors determining the liquid pool geometry and behavior of the metals and their compounds during the refining as well as precise evaluation of the temperature field distribution.

Experimental and theoretical investigations of the processes at EBMR of various metals, including refractory, reactive and noble ones (Ti, Mo, Zr, Ta, Hf, Ni, Cu, Al, Au, Pt, etc.) and special alloys were performed and the corresponding technologies were developed. The obtained results and the various applications of EBMR method can be summarized and systemized as follows:

2.1. EBMR as a final step of the conventional metallurgical methods for production of pure metals

In many cases it is possible to involve the EBMR at an earlier stage of the conventional metallurgical process. In this way, resources such as time, funds, etc. for obtaining metals with high purity and without defects, with geometry and dimensions near to the desired ones for their application, can be reduced. In Table 1 obtained results for EBMR of titanium, zirconium, copper, molybdenum and nickel are presented. The initial material for each of these metals was material with high level of impurities' concentrations – gases, metal and non-metal inclusions (C_0 is the initial concentration, i.e. before EBM, C is the concentration after EBM, P is the e-beam power, η_i is removal efficiency of the specific impurity, Φ is the diameter of the obtained ingot after EBM).

Table 1: EBMR of metals.

Me	C_0 , %	$C_{O(O)}$, ppm	P , kW	C , %	$C_{(O)}$, ppm	η_i , %
Ti	99,86	1000	15	99,97	150	78,6
Cu	99,5	500	15	99,994	10	98,8
Zr	99,73	900	15	99,95	144	81,5
Mo	99,2		30	99,95		93,7
Ni	99,4		15	99,97		95
$\Phi = 60$ mm						

For example, in the case of EBMR of titanium and zirconium the initial material was compacted powder concentrate (titanium

and zirconium sponge); the used raw material for EBMR of copper was anode copper in which the concentrations of oxygen ($C_{O(O)}$) and of metal impurities were high. Due to the fact that there are no special requirements for the kind and the characteristics of the started (raw) material, copper from the various stages of the conventional electrolyte production – anode, cathode copper, etc. can be used as initial material. During the refining a lot of impurities serve as a gather that pulls up and combines the oxygen from the copper oxides in stable oxides, which are removed from the liquid copper through distillation. Thus both the oxygen concentration and the concentration of the metal impurities in the refined material decrease and the purity of the obtained copper (after EBMR) is higher than the purity of the electrolyte copper. For EBMR of molybdenum and nickel the initial material was concentrate or compound.

The produced metal after refining solidifies (crystallizes) in the water-cooled crucible and the ELIT 60 installation allows to obtain ingots with diameters $\Phi = 50$ mm, 60 mm, 80 mm or 100 mm and the ingot length – up to 25 cm (Figs. 1-3).



Fig. 2 Zirconium ingot obtained by EBMR of zirconium sponge.



Fig. 3 Pure metal sample obtained after EBMR.

2.2. EBMR for recycling of targets: Al, Au, Ag, Pt, Ti, Cu, Co

In many recent methods for layer deposition such as magnetron sputtering, electron beam, ion and laser evaporation etc., metal targets with high purity and strict requirements concerning the shape and the composition are used. During the process some parts of the targets are partially spent and the bigger part remains unused as expensive metal scrap with high purity.

At recycling of these used targets it is important to achieve desired geometry without changes in the chemical composition. Usually, the requirements concerning the chemical composition are connected with the concentration of gases and especially the oxygen concentration. Sometimes there are requirements about other impurities – for example at recycling of rectangular aluminum targets the requirements were connected with the removal of the alkali metal elements and their concentrations had to be less than 0,1 ppm. After EB recycling the concentration of the alkali metals decreases 10 times (Table 2).

Table 2: EBM of used metal targets with high purity.

Me	dimens., mm	P , kW	C_{i0} , ppm	$C_{O(O)}$, ppm	C , %	C_i , ppm	$C_{(O)}$, ppm
	285 x		alk Me			alk Me	
Al	160 x 15	7,5	0,1	1	99,9	0,01	1
Au	Φ 60	7,5		1	99,97		1
Ag	Φ 60	7,5		1	99,97		1
Pt	Φ 80	10		1	99,97		1
Ti	285 x 160	11		15	99,94		10
Cu	Φ 240 x 15	25		10	99,97		10
Co	Φ 60	20		10	99,9		10

EBMR method offers various possibilities concerning the geometry of the obtained materials – their shape and dimensions. Using proper equipment elements – crucibles, made with desired shape and dimensions – the obtained targets after EBMR do not need additional processing and can be used for their applications (Fig. 4).



Fig. 4 Titanium targets regenerated by EBMR.

The application of EB method in the case of precious metals recycling is especially valuable due to the fact that it is possible to minimize the material losses.

2.3. EBMR for recycling of used metals (Ta, Hf, Ti, Ni) enriched with gases

Bulgaria is not a traditional producer of many metals that are active toward the oxygen at high temperatures (such as titanium, hafnium, tantalum, nickel, etc.) due to the lack of ore products. These metals have unique physicochemical and chemical properties and that is why they are of present interest to various productions such as medical implants, artificial joints, materials for vacuum components and special equipment, electronic components, etc. (Fig. 5). At their use and processing considerable quantities of high quality metal scrap are obtained. These pure metals with unique properties were oxidized and their reuse is possible after treatment aiming to remove the oxygen and to decrease the oxygen concentration in the composition. The EBM is a proper refining method for this purpose [1,4,5,12]. The oxygen is in the solid metal scrap as oxides that pass to the liquid pool at heating. Part of them dissolves or dissociates in the liquid pool volume and another part moves and reaches the top surface (the interface molten pool / vacuum) and also dissociates due to the low relative weight. Due to the higher temperatures at the surface and the contact with the vacuum environmental, the level of dissociation of the oxides and the efficiency of the refining processes are higher (Table 3).

Ta



Hf



Fig. 5 Initial material (metal scrap) and ingots obtained after EBMR of tantalum and hafnium.

Table 3: EBMR of oxidized pure metals.

Me	C _o , %	C _{o(O)} , ppm	Φ, mm	P, kW	C, %	C _{o(O)} , ppm
Ti	99,5	1500	100	25	99,9	400
Ni	99,7		60	16	99,9	
Ta	98,9	800	100	35	99,9	400
Hf	99,6	1000	60	25	99,9	500

The obtained results show that after EB refining the oxygen concentration in hafnium can decrease up to 4 times, in zirconium – 7 times and in titanium – 10 times. Additional removal of other volatile metal impurities (such as aluminum, calcium, nickel, copper, etc.) is also possible and their concentration also decreases (up to 30 times).

2.4. EBMR for recycling of used alloys where unwanted inclusions have to be removed – Co-alloy, Cu-Ag-Ni alloy, high-speed steel and bearing tool steel

Usually, the properties of special alloys strongly depend on the proportion and the quantity of the alloyed components in the obtained composition after EBMR. Some results for recycling of: Cu-Ag-Ni alloy intended for high temperature vacuum solders, Co-alloy with low fraction of nonmetal impurities, dedicated for producing heart implants and high-speed steel and bearing tool steel are presented in Table 4.

Table 4: EBMR of alloys with special purpose.

Me	alloy comp.	C _o (O)	impur	ΔG, %	P, kW	alloy comp	C _{o(O)}	impurities
	C _o , %	ppm	ppm	%	kW	C, %	ppm	η _i , %
Cu/Ag/Ni	84,9/11,7/1,5	290				86,5/10,3/2,0	10	
P6M5	W, Mo/C, Cr, V, Co			1%	12	C = Co		
P18	W, Mo/C, Cr, V, Co		N, S	4%	12	C = Co		N=100% S=76,2%
IIIX15	Cr, Mn, Ni, Si, V				14	C = Co		
Co-alloy	Mn = 4,31 ppm	104	S=40			Mn=2,4 ppm	4	S=28ppm

The main problem at recycling of alloys is the selection of proper conditions at which the removal of the unwanted impurities takes place while keeping the proportion of the alloyed components unchanged at minimal material losses. This is very important especially in the case of alloys with special purpose and it requires process investigation leading to finding optimal conditions (process parameters) ensuring maximal level of unwanted impurities removal and creation of desired structure at minimal losses of the alloyed elements. The obtained ingots are without defects and the alloyed components are uniformly distributed in radial direction and along the sample.

2.5. EBMR for obtaining multiple metals through recycling of metal scrap

Another important application of EBMR is separation of valuable metals at recycling of wastes in which the metals present as compounds – carbides, oxides, sulfides, etc. or as impurities with high concentrations. The possibility for influencing the thermodynamic and kinetic conditions for EB refining allows pure metal obtaining from these compounds through chemical decomposition and their collection in the condensate.

When the main impurities are valuable metals with high concentrations in the raw material and have high removal efficiency, their complete removal can take place for technological conditions which are also optimal process conditions for the base metal purification. For example, at EB recycling of tungsten scrap with high level of cobalt (3,5 %) and molybdenum (1,1 %) in the initial material, high removal efficiency is seen: $\eta_{Co} = 97,1 \%$ and $\eta_{Mo} = 99,6 \%$. The provided evaluations show that the cobalt quantity generated in the condensate is more than a half of the condensate mass and the molybdenum mass is about a quarter of the condensate. In this case additional processing of the generated condensate aiming to obtain molybdenum and cobalt as pure metals is recommended and justified taking into account their characteristics and applications.

3. Conclusion

Research is conducted and technologies are being developed as the obtained applications of the electron beam method for melting

and refining of various metals and alloys with special purpose are summarized and systemized. The obtained results show a wide variety of possible applications of the e-beam method for melting, refining, and recycling of materials that contain refractory, reactive and precious metals. All of these applications are technically possible, economically reasonable, and environmentally friendly. Through each of them the most suitable and up-to-date approach is developed for processing an important category of waste materials - obtaining valuable metals, which can be used by the local economy; increasing their exploitation characteristics through refining/homogenizing of the metals/metal alloys, as well as optimizing their price when selling these materials on a local, European, or international level.

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