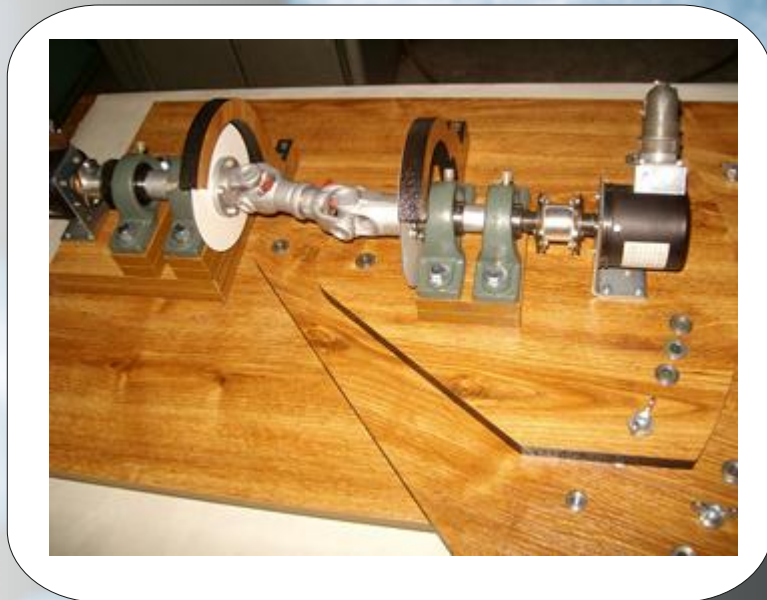


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TECHNICAL STATE IDENTIFYING OF A ROLLER BEARING WITH USING OF VIBRODIAGNOSTICS

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Abstract: The paper addresses the issue of identifying a technical state of rotating parts with the use of vibrodiagnostics. This method has been developing rapidly for recent years and is assumed to be used for predicting failure occurrence. In this paper we focus on monitoring a technical state of a medium truck bearing box where we simulate different field conditions and their dependence on the RMS – root mean square. A measuring device DEWE 50/8 including the DEWEsoft software product of the Dewetron company have been used for the actual measurement. The aim of the work is to calculate the values of root mean square acceleration up to the moment a failure occurs. In the next step we will put the values into a graph and try to determine a gRMS limiting value. In the future this enables us to change the bearing before a failure occurs otherwise it would increase the related cost.

KEYWORDS: ROOT MEAN SQUARE, ROOT MEAN SQUARE OF ACCELERATION, VIBRATION, VIBRODIAGNOSTICS.

1. Introduction

Vibrodiagnostics is one among many methods of technical diagnostics which has been continuously monitoring a technical state of a device by observing the level of a mechanical oscillation in a real time. The mechanical oscillation is the manifestation of a device during its operation. Certain parts become vibration exciters, others, depending on excitation, react specifically.

The vibrodiagnostics is one of the most important methods used in technical diagnostics for identifying a technical state. With the use of vibration diagnostics we are able to detect an incipient failure, locate the place of an incipient failure and predict the length of time during which a device is going to work before a failure occurs or a preventive action is performed. The proper application of vibrodiagnostics can prevent from undesirable damaging machines, thereby saving money spent on a repair and a device in a disabled state.

Experimental vibrodiagnostics measurements have been performed while obtaining primary signals. Primary results of measurement are systematized and its analysis is done. Dependence of work characteristics between rotary systems with bearings of sliding friction and of roll is ascertained. Generalization of research results is done and conclusions are formulated [1][2][3].

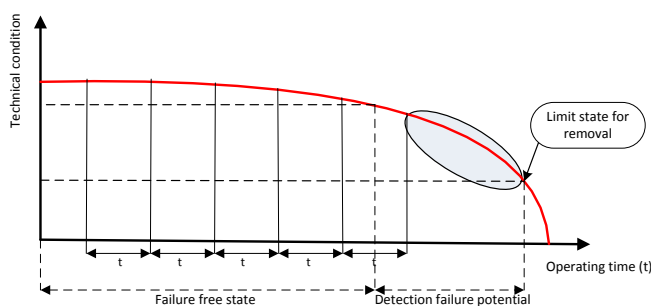


Fig. 1 Dependence of the wear of machine parts on operating time [5]

Two kinds of excitations can produce noise in rotating machinery; excitations due to primary sources, and excitations due to manufacturing defects. It is difficult to act on the primary sources or functional loads as they are specific to a machine. These defects are inherent in both the manufacturing quality and the configuration of the machine. They are caused by the machine's rotating parts (rotors, disks, bearings, gears ...) and create concentrated or distributed loads that produce vibrations and noise. These vibrations depend on the machine itself through the transfer function while the noise is a function of the machine environment [4].

A lot of companies spend a big amount of money on the preventive maintenance of machines and technical equipment

despite the fact that at that particular moment there is no need to perform a preventive action. This leads to big financial losses mainly during the machine unavailability. Therefore it is desirable to perform preventive maintenance at the time when it is really necessary (Fig. 1). Determining a preventive action or replacing a part based on a real technical state with the use of a mathematical model describing a machine technical state during its life leads to proactive maintenance. The aim of our article is to describe the technical state of a vehicle bearing box using vibrodiagnostics.

2. Main characteristics of vibrations

Vibrations occur as a result of rotating or straight-line moving bodies. The course of vibrations is influenced mainly by a technical state of single machine components such as shafts, gear boxes, crank mechanisms, cam mechanisms, antifriction bearings, and also by the imbalances of rotating parts, backlash in friction bearings, wear, material fatigue, occurring cracks, corrosion and other parameters affecting a smooth machine run. The vibration itself is defined then as a dynamic phenomenon when particles or solid bodies move around a zero equilibrium position. They are given by a combination of six movements, namely by a shift in an orthogonal coordinate system x, y, z and a rotation about these axes. We can describe them by amplitude and a phase at a certain period of time. Depending on the time variations of values, the vibrations are of a periodical, non-periodical or random character. As for periodical vibrations, a time course of vibrodiagnostic values repeats. A harmonic vibration which has a sinusoidal waveform is based on these vibrations. For harmonic vibrations we need to set only one determining value and the other ones can be calculated.

The basic way of describing oscillations is to determine their displacement x , velocity v , acceleration a , maximum amplitude X_{max} , a root of mean square X_{RMS} , and a mean absolute value X_{ave} .

The measurement of displacement x is convenient for low-frequency events such as measuring backlashes, etc. which might be calculated the following way [6]

$$x = X_{max} \sin \alpha t \quad (1)$$

$$\omega = 2\pi f \quad (2)$$

where: X_{max} - maximum amplitude (maximum displacement); ω - angular frequency; f - frequency (oscillation); t - time.

Velocity can be expressed as the characteristics of motion which informs us about the way of changing the position of a body (particle) in time. Velocity is a vector physical value, because it defines both the change magnitude and its direction. Velocity might be determined as the time derivation of trajectory (displacement) using the equation below

$$v = \frac{dx}{dt} = X_{\max} \omega \cos \omega t \quad (3)$$

Acceleration can be expressed as the characteristics of motion which shows the way the velocity of a body (particle) changes in time. The acceleration is a vector physical value, since it gives both the change magnitude and its direction. It is possible to calculate momentary acceleration and average acceleration. The acceleration might be also determined as the time derivation of velocity using the formula below [6]

$$a = \frac{dv}{dt} = -X_{\max} \omega^2 \sin \omega t = X_{\max} \omega^2 \sin(\omega t \pm \pi) \quad (4)$$

If the acceleration is in counter-motion, it is called deceleration and has a minus sign.

The International Standards Organization (ISO) which establishes internationally acceptable units for the measurement of machinery vibration suggested velocity – root mean square (RMS) as the standard unit of measurement. This has been agreed on in order to derive criteria that would determine an effective value for the varying function of velocity. The RMS velocity tends to provide the energy content in the vibration signal, whereas the velocity peak corresponds better with the intensity of vibration. Higher RMS velocity is generally more damaging than a similar magnitude of velocity peak [6].

The calculation of the mean value A_{ave} and RMS effective value was based on acceleration and therefore the effective value is marked as g_{RMS} . For the calculation we have used the following equations.

The mean absolute value A_{ave} can be expressed as follows

$$A_{ave} = \frac{1}{T} \int_0^T |a| dt \quad (5)$$

where T – a period expressed by the formula $T = \frac{1}{f}$.

The root of mean square can be calculated by the equation below [6]

$$g_{RMS} = \sqrt{\frac{1}{T} \int_0^T a^2 dt} \quad (6)$$

3. Characteristics of vibration sensors for measuring

Vibration sensors are used for measuring physical values (displacement, velocity and acceleration) and their transforming into an electric signal which is later worked with. There is a great variety of different vibration sensors which are used for achieving results as accurate as possible. We have the sensors of acceleration, velocity and displacement. The principle of a vibration sensor function is the motion of seismic matter of mass m towards an object of mass M whose vibrations are measured. For the calculation the formula below is used

$$ma_h + bv + ky = -ma_0 \quad (7)$$

where y – displacement; v – velocity; a_h – acceleration of seismic matters motion; a_0 – object acceleration; m – seismic matters mass; k – spring stiffness; b – damping coefficient [7].

For the measurement we have used the full equipment of the Dewetron company including evaluation software DEWESOFT. We have used the device DEWE-50-USB2-8 which is an 8-channel measuring system where eight slots might be connected for modules DAQ and PAD.

For the measurement we used two tri-axial acceleration sensors which are at present basic vibration sensors used for measuring mainly on fixed parts of rotating machines like in this case. We

used the sensors KS943B.100 which are placed in a duralumin case, measuring range ± 60 g, measuring sensitivity 100 mV/g, frequency range 0.5 Hz – 22 kHz.

If the measurement is to be accurate, it is necessary to select the right place to measure and the right way of attaching sensors. Sensors are placed on clean surfaces and if possible as close to the place where vibrations occur as possible. If the sensors are attached inappropriately, the measured data may be completely devaluated, or the applicable frequency range of a sensor can be significantly limited. When attaching acceleration meters, the following methods may be used: (Fig. 2):

- by a contact probe – applicable only for preliminary measurement to about 0.6 kHz,
- by a magnet – a frequent and quick way of attaching a sensor to ferromagnetic materials, but used only for common operating measurement to a frequency of about 7 kHz,
- by beeswax or a thin bonding tape – a quick way of anchoring a sensor which is used mainly for laboratory measuring and for smaller sensors. It is applicable only at the temperatures of up to 40 °C and sensor frequency of about 10 kHz,
- by adhesive – if the surface suits the needs of a sensor and the applicable frequency of the sensor is kept at about 10 kHz,
- by a screw – it is the most reliable way to anchor objects which decreases only slightly the applicable frequency of a sensor which is about 15 kHz. The surface under the sensor base should be clean and even, the sensor should be in full contact with the surface, the screw hole should be perpendicular to the measured surface and sufficiently deep, and the right screw thread should be used. This way of attaching was used during our measurement.

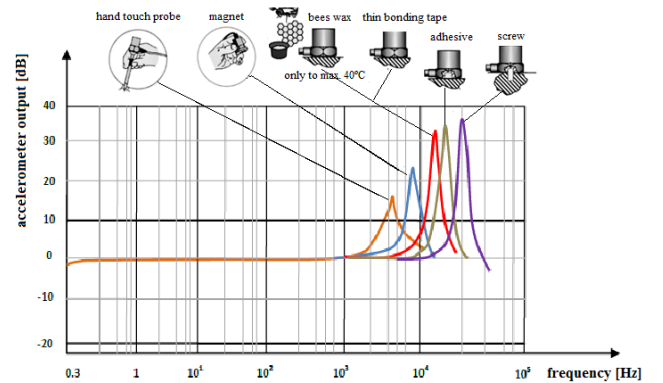


Fig. 2 Ways of attaching measuring sensors and their frequency ranges [8]

4. Description and results of the bearing housing vehicles

The measurement was performed on a testing stand shown in Fig. 3 Testing stand for vibrations measurement. The main parts of the stand are a frame for anchoring measured equipment (1), an asynchronous motor with engine speed control in 10 – 3000 rpm (2), a propeller shaft with a flange (3), a frequency converter MOVITRAC MCLTE B0040-5A3-4-00 (4), measuring equipment DEWE-50-USB2-8 (5), a notebook with software DEWESOFT X2 (6), two pieces of tri-axial acceleration sensors KS943B.100 (7), and measured equipment (8). We have used a bearing box of the PV3S vehicle

The aim of the measurement was to identify a technical state of two conical bearings. Therefore the sensors were placed on a bearing box body directly above the bearings (7). The contact surfaces for attaching acceleration meters had to be prepared so that the meters could be anchored according to the set requirements.

4.1 Determining of the technical condition of bearings based on gRMS

In the bearing box there are conical bearings labelled as FAG 31308A. The bearing 1 is close to an electromotor flange. This bearing was not a subject to any failure during all the period. The bearing 2 is placed in the gear part of the bearing box and it worked without failures up to 122500 km. We disassembled the bearing and

performed technical specification and analysis. As part of this experiment we also measured the gRMS values at all three levels. Then we summed all these values and expressed the gRMS dependence on the mileage in graphs 1 and 2. In graph 1 we were observing the bearing 2 where the artificial failure had been made during the mileage 122500 km. The values gRMS were being observed at 1200 and 2200 revolutions.

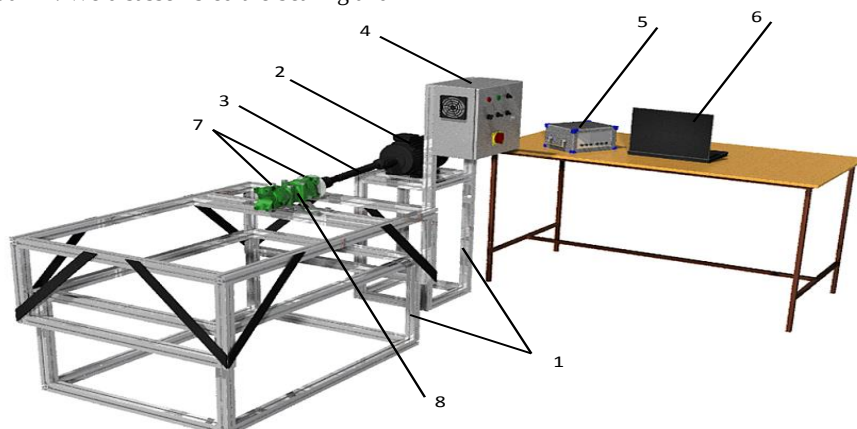
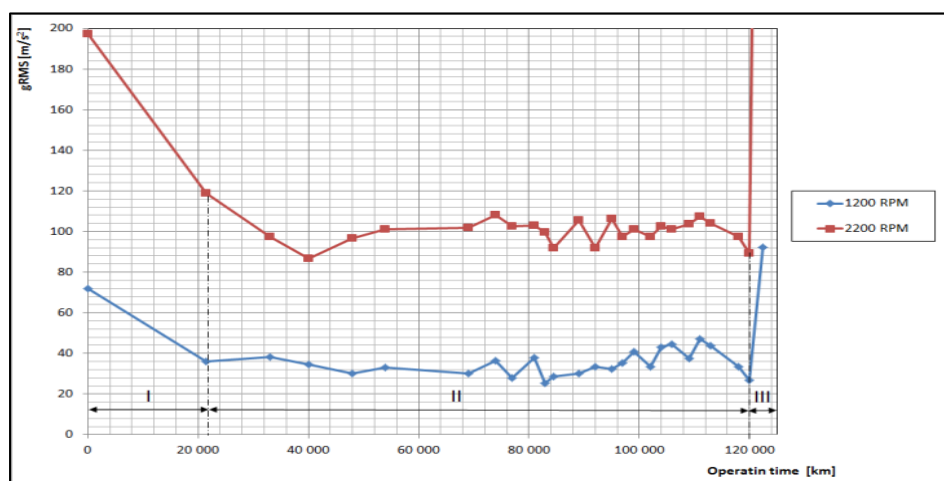


Fig. 3 Testing stand for vibrations measurement [8]

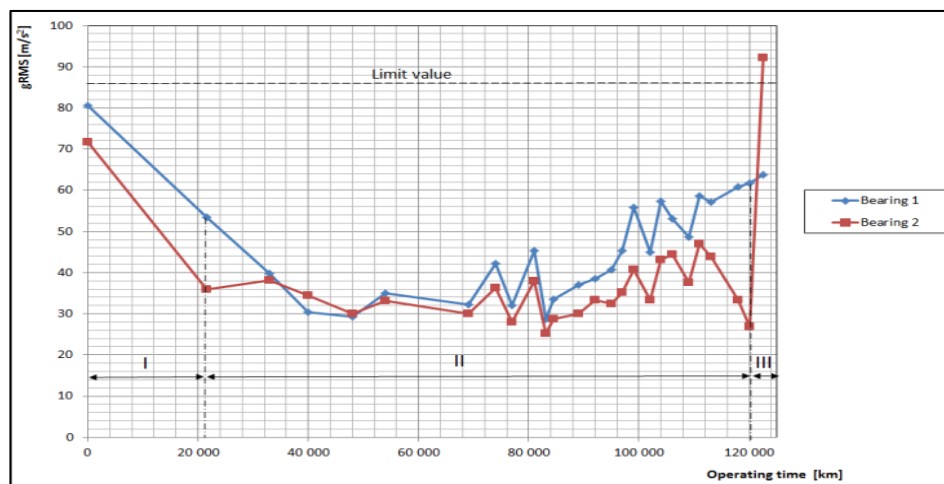
In graph 2 there are the values of gRMS for the bearings 1 and 2 during the mileage 122500 km at 1200 RPM. These graphs show that at first there is a period of running-in and positioning bearings against each other with the gRMS value going down. During another period characterized as operating the gRMS becomes more or less constant. In the third period of an object life when the object becomes considerably worn we made, as it has been mentioned

before, the artificial bearing failure. This led to a significant increase in gRMS which had been expected.

Based on the measurements we determined in graph 2 the gRMS limiting value 85 ms^{-2} for both bearings at 1200 RPM. The Figure 1 shows that this limiting value will differ depending on RPM.



Graph 1 Damaged bearing 2 – expressing gRMS dependence on mileage

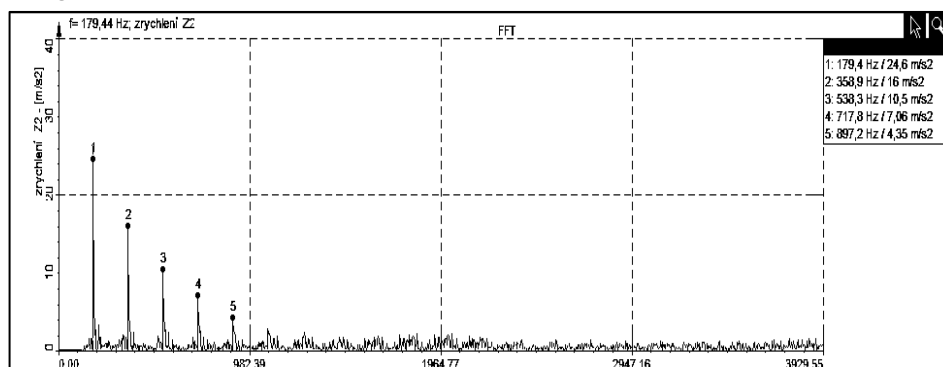


Graph 2 gRMS dependence on mileage at 1200 RPM for the bearings 1 and 2

4.2 Artificially created defect - defect in an outer ring

In order to verify whether it is possible to use frequency values for specific failures calculated in advance, we gradually created defect in the second bearing.

As for the first mechanical damage to the bearing, we chose an outer ring in which a groove parallel with a rotation axis and perpendicular to the route of rolling elements was cut. This ensured that the rollers would be made to roll over the groove.



Graph 3 Frequency spectrum record of the damaged outer ring

For the analysis we selected the measurement 1600 RPM on a shaft and the axis “Z2” record, but also the same can be observed in the other axes. In the right upper corner we can see that these values are really within a given range. Minimum deviations can be caused by the inaccurate measurement of bearing parameters.

Table 1 - The values calculated for bearing fault frequencies labeled FAG 31308A

Designations of fault frequency	f_r frequency 20 [Hz]	f_r frequency 26,66 [Hz]	f_r frequency 36,66 [Hz]
Snap ring defect - FTF	8,42	11,22	15,43
Bearing defect - BPF	107,22	143,72	194,63
Outer race - BPFO	134,64	179,48	246,80
Inner race - BPFI	185,36	247,08	339,76

In order to illustrate the frequencies of our interest better, we used a broadband filter where the lower filter limit was six times the amount of rotation frequency which was in our case 160 Hz, and also we applied the envelope. After the application of the filter and envelope we achieved a clear spectrum with the required frequencies.

No visible signs of wear were detected. In order to verify the calculation of failure frequencies, we notched the outer ring of the bearing 2. On the basis of the measurements we managed to verify the calculated value validity Outer race – BPFO, see Table 1.

The presented work has been prepared with the support of the Ministry of Defence of the Czech Republic, Partial Project for Institutional Development, K-202, Department of Combat and Special Vehicles, University of Defence, Brno.

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SURFACE ROUGHNESS EVALUATION OF ALUMINUM MATRIX COMPOSITES AFTER DRY SLIDING WEAR TESTS

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Abstract: Aluminum matrix composites composed of Al, Al-5,6 wt.% Cu (Al5.6Cu), Al-7 wt.% of alpha brass α -Cu_{0,8}Zn_{0,2} (Al7CuZn) and Al-9 wt.% of nickel brass Cu_{0,64}Zn_{0,31}Ni_{0,05} (Al9CuZnNi) as the matrix and 15 vol.% of TiC and synthesized Al-Ti-C master alloy (MA) as the reinforcement were successfully fabricated by hot forging. Sliding wear tests were conducted at different velocity and loads using a pin-on-disc apparatus and under dry conditions. The results of the investigations indicate that the coefficient of friction significantly lower in composites with Al-Ti-C master alloy then that reinforced with TiC, while the wear rates are lower in composites with Cu additions. The post-test analysis of the material damage mechanisms were examined by optical profilometer.

KEYWORDS: MASTER ALLOY, HOT FORGING, WEAR TESTS, ROUGHNESS, 3D PROFILOMETRY MEASUREMENTS

1 Introduction

The tribological behavior characteristics of aluminum matrix composites (AMC) strengthened with various ceramic particles (TiC, B₄C, TiB₂, Al₂O₃, SiC) have been extensively studied to determine the effect of different combinations of matrix and reinforcement on wear behavior [1] whilst the AMC with synthesized master alloys (MA) as a reinforcement has not been systematically investigated so far.

The master alloy is an intermediate material of finely-dispersed second phase (mostly ceramic phase) in the metallic or intermetallic matrix, in the form of porous mass or sponge, [2;3] prepared by in-situ processing techniques involving a chemical reaction resulting the formation of thermodynamically stable reinforcing ceramic phase. Therefore in our work, master alloy was prepared from elemental powders of Al, Ti and C to subsequently application for producing hot forming composites mixed with aluminum powder. It is assumed that, as a result of in-situ reaction in the synthesized master alloy the grain boundaries between the particles of the strengthening phase TiC and aluminum will be free of oxides, which greatly increases the interfacial strength, titanium carbide particles themselves are of submicron size and homogeneously distribute in the volume, which increases mechanical properties of AMC, provides in effective load transfer and decreases the wear rates. [4]. However, presence of brittle titanium aluminides particles in such composites has a deleterious effect on the mechanical properties, which is why to investigate a wear behavior of such composite materials especially compared with Al/TiC composite materials is in great interest. [5-7]

Studying the topographical features of the worn surfaces morphologies (craters, cracking, transfer layer, plastic deformation, fatigue, shear fracture, etc.) also one of the important investigation subject for many decades, because it helps to evaluate wear conditions, predicting wear behavior and controlling wear processes. Wear quantification techniques are based on mass or geometric measurements. The widely used technique to calculates the wear volume loss is gravimetric wear measurement, but this method is not very useful when the wear damage involve both abrasive and adhesive mechanisms. Usage of stylus or optical profilometers could be good additional method to evaluate not only the wear volume or depth, but also the local development of the wear damage on the sample surface due to standardized roughness parameters calculated from 2D or 3D profiles [8-10].

Thus, the aim of the present work is to study the wear behavior of aluminum matrix composites after dry sliding tests under different conditions of applied load and speed, in order to determine their effect on friction coefficient, surface roughness and clarify the damage mechanisms.

2 Experimental procedure

AMC composed of Al, Al-5,6 wt.% Cu (Al5.6Cu), Al-7 wt.% of alpha brass α -Cu_{0,8}Zn_{0,2} (Al7CuZn) and Al-9 wt.% of nickel

brass Cu_{0,64}Zn_{0,31}Ni_{0,05} (Al9CuZnNi) as the matrix and 15 vol.% of TiC and previously synthesized master alloy (MA) of composition 20Al-64Ti-16C (wt.%) as the reinforcement, were prepared as follows: raw powders of matrix material and reinforcement additives were ball milled in planetary mill for 7,5 minutes, then compacted at 500 MPa, heated in a furnace under argon atmosphere at the temperature of 600 °C and hot forged. Throughout the text, abbreviations of the following type will be used: Al-TiC, Al-MA represents samples containing 15 vol.% of reinforcement phase with aluminium matrix and Al5.6Cu-MA, Al7CuZn-MA, Al9CuZnNi-MA – samples with alloyed matrix. Table 1 shows the values of Brinell hardness, density and ultimate tensile strength for test materials after hot forging.

Table 1: Mechanical properties of aluminium matrix composites

Materials	HB, MPa	Density, g/cm ³	UTS, MPa
Al-15TiC	319	2,647	156,6
Al-15MA	615	2,896	187
Al5.6Cu-15MA	958	3,036	151,1
Al7CuZn-15MA	927	2,849	140,6
Al9CuZnNi-15MA	879	2,946	145,7

Cylindrical samples were examined under dry sliding condition against a counterface of G51320 steel having a hardness of 63-65 HRC using a pin-on-disk machine at different applied loads (10, 20 and 30N) and speed (1 – 4 m/s), for a constant sliding distance of 1 km. The mass loss of the specimens was measured with an analytical balance. Sliding surface was examined under optical microscopy XJL-17AT and roughness parameters were identified by optical profilometry to explore the possible wear mechanism.

3 Results and discussion

Fig. 1 shows the microstructure of the composites materials after hot forging. The grey phase corresponds to Al, the dark phase – master alloy (Fig. 1, a, b), which is consist of two main phases, i. e. TiC, Al and weak additions of titanium aluminides [7]. In composite with alloyed matrix (Fig. 1, c, d, e), could be seen white phase corresponds to Cu, alpha and nickel brass.

Fig. 2 represents the wear rates of Al-15TiC and Al-15MA. It was found; those tested materials maintain only 10 N load and work properly at 1 m/s and 2 m/s sliding speed, where mass los the highest for Al-15TiC, but further increasing of sliding speed results to adhesion between the composite materials and the steel counterface.

It can be seen from the abrupt raise of wear rate values at 3 m/s (fig. 2), from the formation of transferred layer on the counterface surface (fig. 3) and the visible traces of extensive plastic deformation – presents of numerous voids, cracks and

delimitation in worn surface of Al-15TiC, Al-15MA composite materials (fig. 4 a, c).

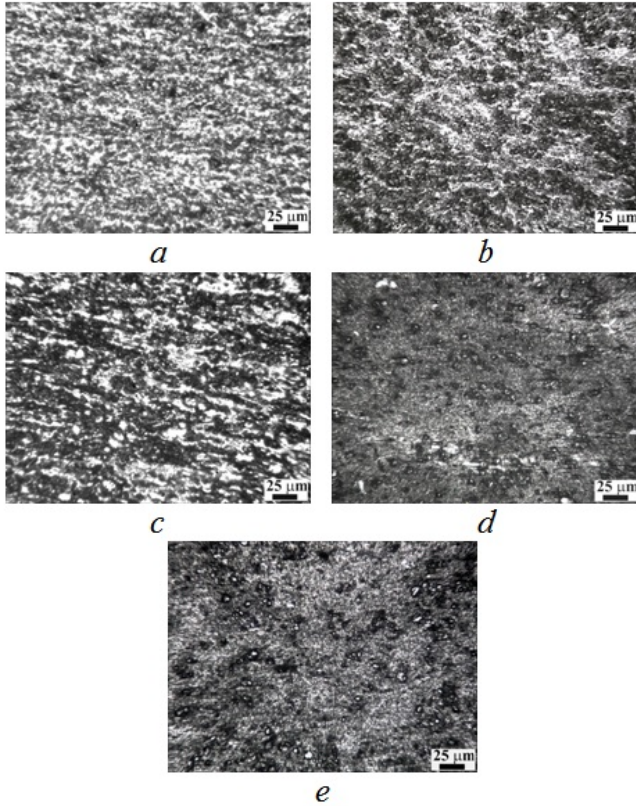


Fig. 1 Microstructures of ACM: a) Al-15TiC, b) Al-15MA, c) Al5.6Cu-15MA, d) Al7CuZn-15MA, e) Al9CuZnNi-15MA

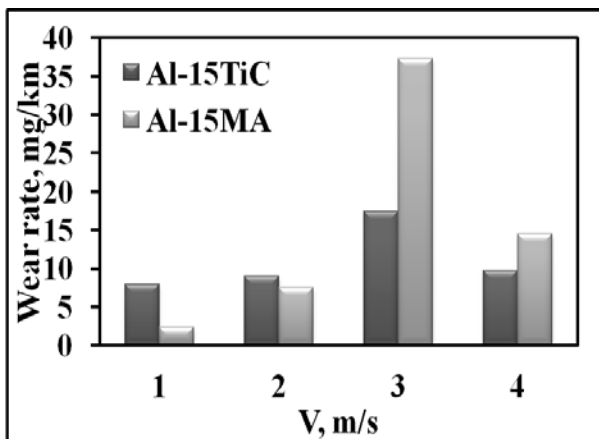


Fig. 2 Variation of wear rate of ACM, reinforced with TiC and master alloy at 10 N load with sliding speed

3D profiles of Al-15MA indicates (fig. 4 d), that a layer of material has been removed as debris from these areas and that the debris is in the form of thin sheets. The examination of the Al-15TiC 3D profiles (fig. 4 b) reveals the plastic flow of the matrix material and hard particles spalling. All this assumption is in good correlation with increasing of surface roughness parameters, especially in maximum valley depth R_v and maximum peak height R_p (Table 2).

The results of the investigations shows that the coefficient of friction lower in composites with Al-TiC master alloy (0,2-0,3) then that reinforced with TiC (0,4-0,38), probably because of better mechanical properties of the Al-15MA.



Fig. 5 The photograph of the G51320 steel counterface worn surface. The applied load is 10 N, and the sliding velocity is 4 m/s.

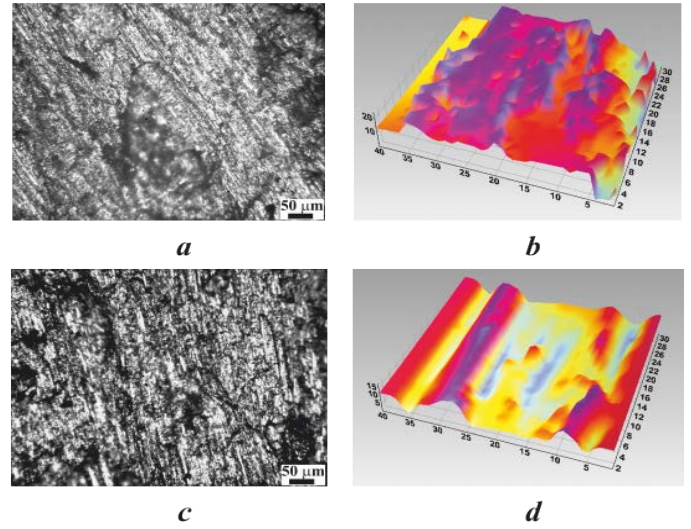


Fig. 4 The microstructure of the worn surfaces of a) Al-15TiC, b) Al-15MA and their 3D surface profiles respectively. The applied load is 10 N, and the sliding velocity is 4 m/s.

To improve the wear resistance of AMC were decided alloyed matrix material with 7 wt.% of alpha brass $\alpha\text{-Cu}_{0,8}\text{Zn}_{0,2}$ and 9 wt.% of nickel brass $\text{Cu}_{0,64}\text{Zn}_{0,31}\text{Ni}_{0,05}$, which noticeably increase hardness of the composites compared to Al-15TiC, Al-15MA and decrease tensile strength (table 1).

Table 2: The surface roughness parameters of AMC after wear tests

Materials	R_a , μm	R_z , μm	R_p , μm	R_v , μm
Al-15TiC	3,708	11,44	8,105	-13,31
Al-15MA	4,837	6,639	16,14	-4,827
Al5.6Cu-15MA	1,815	4,787	5,944	-4,954
Al7CuZn-15MA	2,105	5,897	4,014	-4,97
Al9CuZnNi-15MA	3,936	6,667	12,64	-5,213

There are grooves and ridges running parallel to one another in the sliding direction on the worn surface of the composites with alloyed matrix as shown in Fig. 5 (a, c e). It seems, that grooves are deeper in the Al5.6Cu-15MA and Al7CuZn-15MA then Al9CuZnNi-15MA, but the lower surface roughness parameters from the table 2 indicate that Al5.6Cu-15MA more wear-resistant. The 3D profiles after friction tests (Fig. 5 b, d, f) has rather smooth surface, unlike uneven surface with traces of extensive plastic deformation in the case of Al-15TiC and Al-15MA. The variation of were rate and coefficient of friction with sliding speed exhibit a load dependence and illustrated in Fig. 6 and Fig.7.

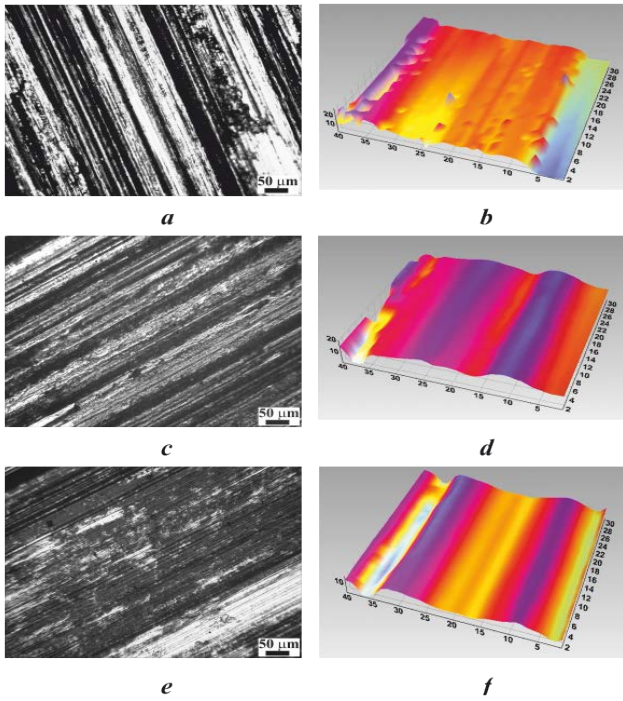


Fig. 5 The microstructure of the worn surfaces of a) Al5.6Cu-15MA, b) Al7CuZn-15MA, c) Al9CuZnNi-15MA and their 3D surface profiles respectively. The applied load is 30 N, and the sliding velocity is 4 m/s.

The variation of wear rate and coefficient of friction with sliding speed exhibit a load dependence and illustrated in Fig. 6. With an increase of the sliding speed and applied load wear rate of the samples increase and coefficient of friction decrease. Under 10 and 20 N all materials have close wear rate values, but load and speed extension to 4 m/s and 30 N respectively leads to significant loss of mass in Al7CuZn-15MA, Al9CuZnNi-15MA composites. It is clear from the obtained dates, that Al5.6Cu-15MA exhibits the lowest value of coefficient of friction, wear rate and roughness parameters.

Conclusion

According to the microstructural and 3D profile analysis, friction coefficient, wear rate and roughness parameters measurements of aluminum matrix composites, the best wear behavior exhibits samples of Al reinforced with 15 % of Al-Ti-C master alloy compared to Al-15TiC composite and composites with Cu addition due to better mechanical properties.

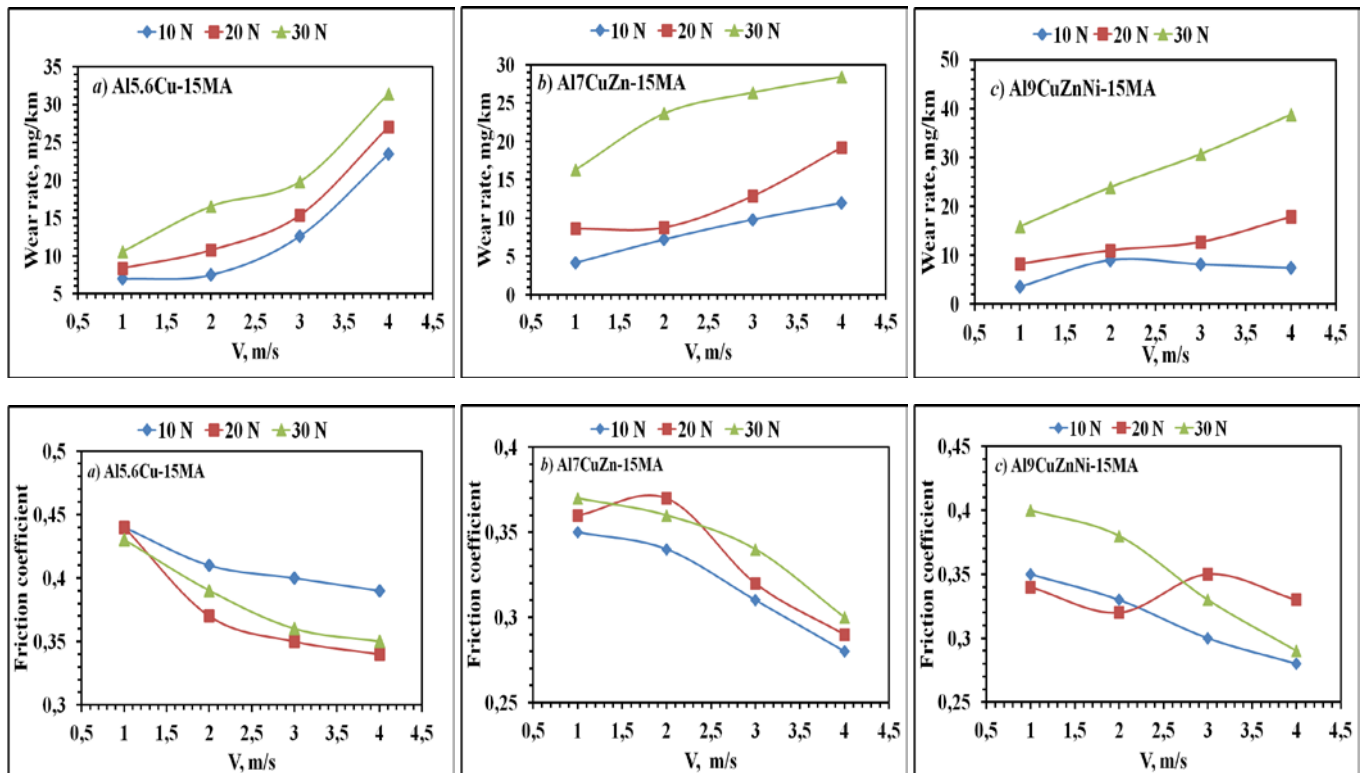


Fig. 6 Wear rate and friction coefficient of AMC, alloyed with Cu, alpha and nickel brass and with 15MA as a function of sliding speed and applied load

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EFFECT OF FIBER ON PROPERTIES OF SELF-REINFORCED PHENYLONE

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Abstract: Now there are a number of important scientific and technical problems of producing fibers with a specified set of properties and high quality indicators, process optimization and efficient processing of their applications. In this context, the aim of this work was the possibility of creating new self-reinforced polymer composites based on aromatic polyamide phenylone reinforced with organic fibers. The properties of self-reinforced composites based on aromatic phenylone are presented. It is shown that the optimum fiber content are 5-10 wt.% in the polymer matrix.

Keywords: AROMATIC POLYAMIDE, ORGANIC FIBERS, ORGANOPLASTICS

1. Introduction

Composite materials have been a synonymous to technological progress for a long time and its prospects are doubtless. Currently, a large number of synthetic polymeric materials with a valuable set of properties are received. If the first synthetic polymers were only replacing natural materials, but further high-molecular compounds of new types which were significantly different from the natural, which have in some cases, specific unique properties have been synthesized [1].

Progress in many areas of technology certainly dependent on the production of synthetic fibers with specific properties. However, organic filaments as fillers for composites have been recognized recently [2]. But their appearance suggests an organic composites as the most promising and indispensable structural materials [3]. The use of synthetic fibers in the composite contributes to further development of aviation and rocket and missile engineering etc. For example, in aircraft applications organic composites enabled to reduce the mass of the aircraft on 30% [4].

In connection with the foregoing, the aim of this work is to develop a process of getting samples of self-reinforced organic plastics with high strength characteristics. The main stages of the method developed by us are as follows. Selected components are aromatic polyamide - phenylone C-1 and organic fiber – phenylone.

2. Methods and subjects of investigation

Phenylone aromatic polyamide C-1 (TS 6-05-221-101-71) was used as a binder; this represents finely divided pink powder with a bulk density of 0.2 - 0.3 g / cm³ and a specific viscosity of 0.5 % in dimethylformamide solution with 5 % of lithium chloride not less than 0.75, characterized by the following properties: density of 1.35 g / cm³, toughness of 20 kJ / m², hardness of 18 HRB, the tensile breaking stress of 100 MPa.

Table 1. Compound press-composition

Filler	Content, mass. %	Based	Content, mass. %
Fibers phenylone	-	Aromatic polyamide phenylone C-25P	100
	5		95
	10		90
	15		85

For the reinforcement of phenylone C-1 heat resistant organic fiber were selected from aromatic polyamides phenylone fiber (2-3 mm long, the strength of 69 kgf / mm², an elongation of 15-20%, the elastic modulus of 900 - 1200 kgf / mm², density of 1.37-1.38 g / cm³).

Press-composition of the compound: C-25P phenylone +5-15 mass % of organic fibers (Table 1) was prepared by mixing the

components in a rotating electromagnetic field in the presence of ferromagnetic particles. The tablets were charged in a mold preheated to 523K, heated to 593-598K and maintained at this temperature for 10min, 10min without pressure and under pressure of 30 MPa. To fix the shape of a product, the goods were cooled under pressure to a temperature of 523 K and pushed out of the mold later.

Physical-mechanical properties: strength ($\sigma_{\text{compr.}}$), relative deformation (ϵ) and elastic modulus (E) under compression were determined by a device SANS (according to NSS of China GB/T 2569-1995) on loading 10 ton and at speed 2 mm/min. Operational speed range – 0,05-500 mm/min. Samples 10 mm in diameter and 12 mm in height were used for researches.

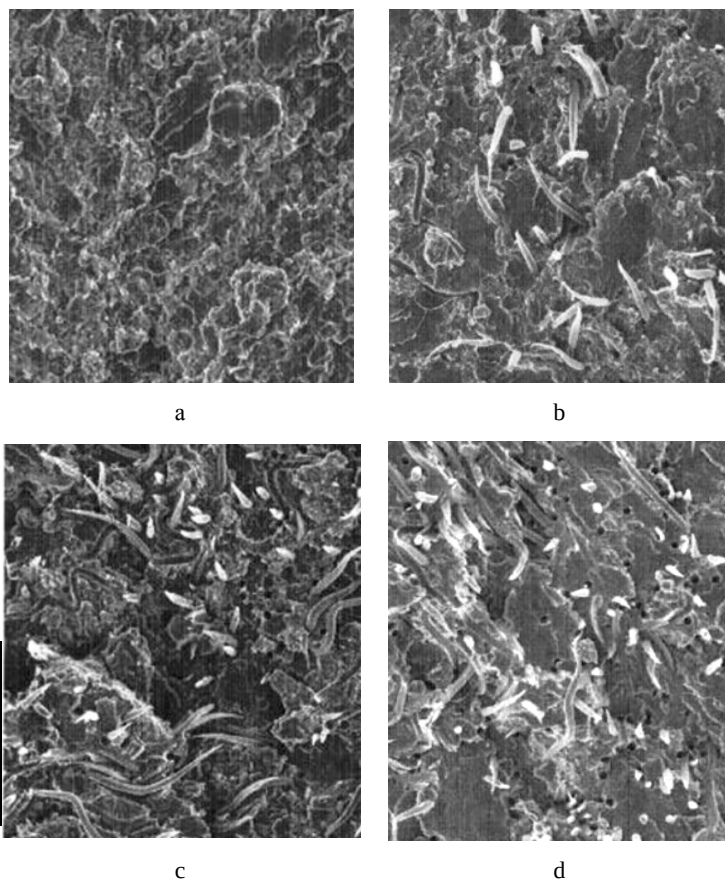


Fig.1. The distribution of fibers in a polymer matrix with filler content: a - 0; b - 5; c - 10; d - 15 wt.%

Electron microscopic studies were carried out with samples of materials that can withstand 3 minutes in liquid nitrogen and then were subjected to brittle fracture. On freshly prepared fracture in vacuum (10-4mm.merc.st.) the carbon film of 500-700 Å thick was

deposited by thermal evaporation on a VUP-2K at 24. Then, a carbon film was deposited into a 20% solution of gelatin in water. After drying gelatin carbon film was frustrated with the sample surface. Carbon film was washed in hot distilled water from the gelatin, washed in alcohol and placed on a copper grid. To enhance the image contrast carbon film by thermal evaporation in vacuum. Shielding platinum at an angle 250 thus prepared film was seen in the electron microscope UEMV-100K at an accelerating voltage in the range of 75 kVt increase from 3.000 to 30.000 times. IR-spectrum analysis was made on spectrometer VERTEX 70 (Germany, Bruker Company).

The microstructure of the surface and friction were studied with an optical microscope NEOPHOT 32 at 100 magnification.

3. The results and their discussion

Considering the fact that machinery is one of the main branches where developed organic fiber-reinforced plastics are used, in particular – details of movable connections. Special emphasis during studying of its physical-mechanical properties got compression strength, because this factor allows to predict load-bearing capacity of friction knot completed with details from organic fiber-reinforced plastics.

As a result of mixing the starting components, it was obtained a uniform distribution of the organic fiber organoplastics (fig.1).

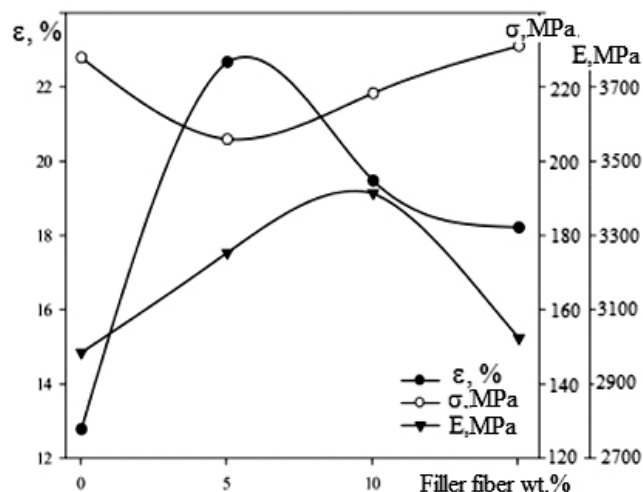


Fig.2. Physical and mechanical properties of phenylone and organic plastics and on its basis

These organoplastics have high compressive strength - more than 200 MPa, elastic modulus at a content of 5-10 wt.% reaches values in excess of 3.1 GPa, and an increase of relative deformation. It is established that compression limit of initial aromatic polyamide phenylone increases directly proportional to organic fibers content (by 1,2 – 1,5 times). Especially significant compression strength improvement is observed in injection of 5-10 mass. % of organic fibers. As to elastic modulus, it increases only by 5-10 mass% percentage content, further it starts decreasing (fig.2).

This increase can be explained by inter-compound filling effect, when fiber particles are placed on the boundaries of super moleculars in drawback sections and influence on macromolecules flexibility. Nearby filler surface there is limitation of supermolecular structures mobility, which doesn't depend on polymer and filler nature. It leads to a certain change of material elasticity [5,6]. For phenylone globular structure with traces of intense destruction is characteristic. The mutual arrangement of the globular structures is different from the original one, which is characterized by denser packing. The improving of strength properties of organic plastics based on phenylone can be explained by good adhesion of the polymeric binder with the fiber and converting the globular structure into fibrillous one.

Macromolecules of phenylone degrade less intensively than in aliphatic polyamides [7]. No significant changes at the molecular level are confirmed by the results of infrared spectroscopy. Spectrogram of base phenylone and that of wear particles are identical, except for a slight displacement of the absorption band in the frequency range 1500-1550 cm^{-1} , which is proof of the rupture of hydrogen bonds.

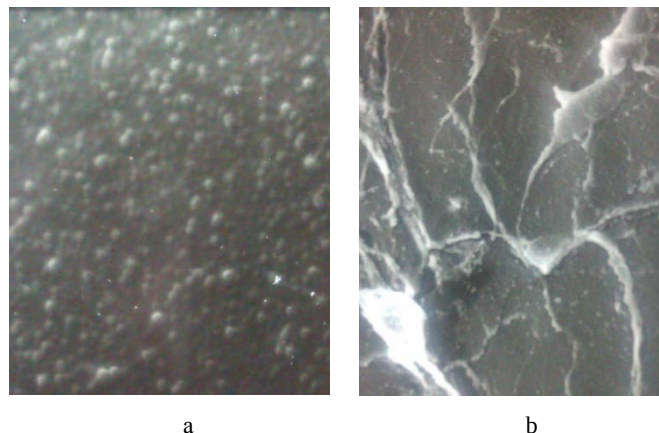


Fig. 3. The structure of the starting polymer and organoplastic (magnification $\times 8000$)

Analyzing the test conducted earlier [8,9], it was revealed that the optimum content of the fibers in the polymer matrix is: phenylone - 5 wt%. The results indicate the prospects for further research in this area and provide a basis to recommend organoplastics for the manufacture of construction materials.

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EFFECT OF THE MARBLE POWDER AND WOOD POWDER CONTENT ON THE TECHNOLOGICAL PROPERTIES OF THERMOPLASTIC COMPOSITES

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Abstract: The waste powder produced during the manufacture of marble, which is presently mostly discarded in landfills, has the potential for higher-valued usage. Recycling marble waste powder will contribute to the protection of nature as well as economic gain. The goal of this study is to investigate the potential use of marble waste powder as filler in the thermoplastic composites with wood. Thermoplastic composites were manufactured by adding marble factory waste powder and wood powder in different ratios to polypropylene (PP). Maleic anhydride grafted polypropylene (MAPP) were used as coupling agent to improve interfacial adhesion between hydrophilic wood-fibers and hydrophobic polypropylene. The waste marble powder and wood powder were mixed by weight of with polypropylene in the percentage of 0%, 10%, 20%, 30%, 40%, and 50%. Physical and mechanical tests were performed on the specimens prepared from the thermoplastic composites. Although mechanical properties of the composites decreased with increasing content of the marble powder, the water absorption of the composites significantly decreased with increasing content of the marble powder.

KEYWORDS: THERMOPLASTIC COMPOSITES, TECHNOLOGICAL PROPERTIES, WOOD POWDER, MARBLE POWDER,

1. Introduction

Studies of polymer composites mixing with organic or inorganic fillers have steadily increased due to the advantages of the fillers in economic and environmental aspects. Organic wood fibers have characteristics of low density, biodegradability, and sustainable productivity [1, 2], and inorganic fillers have attracted great attention because of their cost efficiency, abundance [3]. The fillers (organic or inorganic materials) generally increase stiffness, strength, and hardness of polymer composites by hybridization [4, 5, 6]. Inorganic and organic fillers have long been considered as a future candidate to replace glass fiber or carbon fiber in thermoplastic composites, and thus, it can help resolving environmental issues and taking economic advantage over those artificial fibers [7].

Marble, used frequently in construction applications, is utilized by an industry that produces a significant amount of solid waste during the cutting process. Recycling the marble powder produced during cutting is an important issue because of the current development of environmental awareness and costs for filler [8]. It is estimated that approximately 2.2 million tons of marble blocks are processed in Turkey annually, of which 660,000 tons of marble powder is thrown out without being recycled. If that potential material is evaluated in industry, it is provided significant gains to the economy [9]. The unused marble powders have significant effects, not only economically, but environmentally as well. The large number of marble processing facilities in the world is the cause of the intensification of marble waste areas, which negatively affect the environment and natural beauty, especially in the regions where these facilities are located [10].

When studies on the economic use of marble wastes were examined, it was observed that they reported on the construction sector in general, such as using marble powder wastes in filler processes, the manufacture of light construction blocks, improving floors with marble powder, and as an additive substance in the manufacture of cement [9, 11, 12, 13, 14, 15, 16, 17]. Excluding the use of wastes from marble processing facilities as construction materials, it was observed that they are used as powder wastes reduced to different dimensions as a raw material decoration in architecture, a filler material, and as an additive substance for agricultural purposes [18, 19].

The use of organic wastes of wood industry and agricultural industry as an additive substance in the manufacture of thermoplastic composites has drawn a lot of attention in recent years. In previous studies, in addition to waste wood fibers, some

other natural fibers such as kenaf [20], jute [21], sisal [22], flax [23], hemp [24], coir [25], pine cones [26], walnut shell [27], and sunflower stalk [28] have been investigated, and positive results have been obtained. Although some inorganic fillers such as talc [29], kaolin [7], clay [30], boron-nitride [31], and zinc-borate [32] have widely been adopted in thermoplastic composites with wood fiber, to our knowledge, there are no reports on the utilization of marble waste powders as a filler in thermoplastic composites.

The objective of this study was the manufacture of thermoplastic composites by adding marble powder and wood powder in different ratios to polypropylene and studying their physical and mechanical properties. We aimed to investigate the effect of marble powder content on the density, water resistance and mechanical properties of the thermoplastic composites.

2. Materials and methods

2.1. Materials

The waste marble powder were obtained from the collected liquid precipitation ponds at a factory manufacturing travertine marble powders in Denizli, Turkey. The technical compositions of the travertine marble are given in Table 1. The marble powders were passed through a mesh screen and retained on a 0.25-mm mesh screen (Fig.1). The marble powders were then oven-dried to a moisture content of 0 to 1% using a laboratory oven at 100 °C for 48 h, and then stored in a sealed container.

Wood particles were obtained from beech (*Pinus nigra* Arnold var. *pallasiana*, oven-dry $\rho = 0.490 \text{ g/cm}^3$) lumbers by using laboratory type disc chipper with three knives. The moisture content of the wood particles, as determined by oven-dry weight, was found to be 40–50% prior to the treatment. The wood particles were ground in a laboratory Wileygrinder. The wood powder passing through a US 35-mesh screen was retained by a US 80-mesh size. The wood powder was dried in a laboratory oven at 102 °C for 24-h to a moisture content of 0–1% based on the oven-dry weight of wood ant then stored in a polyethylene bag.

Polypropylene (PP) (melting temperature = 160°C, density = 0.9 g/cm³, melt flow index at 230°C and 2.16 kg = 6.5 g/10 min) produced by Petkim Petrochemical Co. (Izmir, Turkey) was used as the polymeric material. MAH-grafted PP [MAPP-OPTIM-415 with the reactive modifier MAH (MAH content = 1 wt %)] was supplied by Pluss Polymers Pvt., Ltd. (New Delhi, India).

Table 1. Technical Properties of the Marble (Test report of Demirkayalar Marble Company, Denizli, Turkey, 2009).

Property	Unit	Travertine Marble
Hardness	Mohs	3 to 3.5
Unit Weight	g/cm ³	2.44
Density	g/cm ³	2.66
Particle Size	µm	<250
Water Absorption in Atmospheric Pressure	By weight (%)	1.62
Water Absorption Under Pressure	By weight (%)	3.94
Porosity	%	3.94
Compressive Strength	N/mm ²	54.4
Compressive Strength After Freezing	N/mm ²	50.8
Degree of Pores	%	3.94
SiO ₂	%	1.91
F ₂ O ₃	%	79.10
MgO	%	1.15
CaO	%	2.43



Fig. 1. Waste marble powder

2.2. Composite Manufacturing

The marble powder, wood powder, PP, and MAPP granulates were pre-blended in a mixer and then processed in a 30- mm conical, co-rotating, twin-screw extruder (Aysa Instrument Com., Istanbul, Turkey) with a length to diameter ratio of 30 : 1. The raw materials were fed into the main feed throat with a gravimetric feed system. The barrel temperatures of the extruder were controlled at 170, 180, 190, and 190°C for zones 1, 2, 3, and 4, respectively. The temperature of the extruder die was held at 200°C. The extruded strand passed through a water bath and was subsequently pelletized. These pellets were stored in a sealed container and then dried for about 3–4 h before they were injection-molded. The temperature used for the injection-molded samples was 170–190°C from the feed zone to the die zone. The WPC samples were injected at an injection pressure between 45 and 50 kg/m² with a cooling time of about 30 s. Finally, the samples were conditioned at a temperature of 23 ± 2°C and a relative humidity of 50 ± 5% according to ASTM D 618-08.12. The formulations of the composites are given in Table 2.

2.3. Mechanical properties

The flexural properties, modulus of rupture (MOR), and modulus of elasticity (MOE) were measured in three-point bending tests with a standard material testing system at a crosshead speed of 1.3 mm/min in accordance with ASTM D 790-03. The MOR and MOE values of the samples with dimensions of 127 × 12.7 × 3.2 (thickness) mm³ were determined at ambient conditions of 23 ± 2°C and 50 ± 5% relative humidity according to ASTM D 618-08. The tensile tests were conducted according to the ASTM D 638. Tensile specimens [dogbone shape (Type III)] were tested with a crosshead speed of 5

mm/min in accordance with ASTM D 638. Seven specimens were tested for the tensile and flexural properties of each composite formulation.

Table 2: The raw material formulations of the WPCs.

WPC code	Wood powder (%wt)	Marbel powder (%wt)	Polypropylene (PP) (wt%)	MAPP (wt%)
A	50	0	47	3
B	40	10	47	3
C	30	20	47	3
D	20	30	47	3
E	10	40	47	3
F	0	50	47	3

2.4. Water resistance

Thickness swelling (TS) and water absorption (WA) tests were carried out according to ASTM D 570-05 specifications. The test samples were in the form of disks 50.8 mm in diameter and 3.2 mm in thickness. Ten replicate samples were tested for each WPC formulation. The conditioned samples were placed in a container of distilled water maintained at a temperature of 23 ± 1°C. The weights and thicknesses of the samples were measured at different time intervals during the long period of immersion. At the end of 24, 168 (7 days), and 672 (28 days) h of submersion, the samples were removed from the water one at a time, all surface water was wiped off with a dry cloth, and the samples were weighed to the nearest 0.001 g and measured to the nearest 0.001 mm immediately. The value of WA as a percentage was calculated as follows:

$$WA(t) = \frac{W(t) - W_0}{W_0} \times 100$$

The value of the TS as a percentage was calculated as follows:

$$TS(t) = \frac{T(t) - T_0}{T_0} \times 100$$

where TS(t) is the thickness swelling at time t (%), T₀ is the initial thickness of the sample, and T(t) is the thickness at time t. The density of the sample was measured on the TS sample.

3. Result and discussion

3.1. Mechanical properties

The mechanical properties of the WPCs are presented in Table 3. The MOR of the WPCs decreased with increasing content of the marble powder. In particular, the MOR more decreased as the amount of marble powder was above 30 wt% (Figure 2). The addition of 10 wt% marble powder improved the MOE considerably. Further increment in the marble content up to 50 wt% decreased the MOE of the composites but still it was higher than that of the control group without marble powder (Table 3, Figure 3).

Table 3: The results of the mechanical properties of the composites.

WPC code	MOR (N/mm ²)	MOE (N/mm ²)	Tensile Strength (N/mm ²)	Tensile Modulus (N/mm ²)
A	55,3 (3,49)*	3616,0 (648,16)	31,0 (3,39)	3842,3 (159,08)
B	55,0 (0,93)	4843,2 (514,06)	29,4 (1,34)	3800,3 (87,38)
C	54,0	4763,3	28,9	3622,8

	(2,36)	(645,10)	(0,95)	(241,24)
D	52,0	4549,1	22,8	3218,0
	(0,76)	(743,09)	(2,26)	(193,52)
E	45,2	3965,1	21,2	2863,9
	(2,44)	(610,99)	(1,52)	(247,95)
F	44,8	3813,5	20,0	2755,0
	(1,18)	(743,82)	(1,81)	(220,00)

* Standard deviations

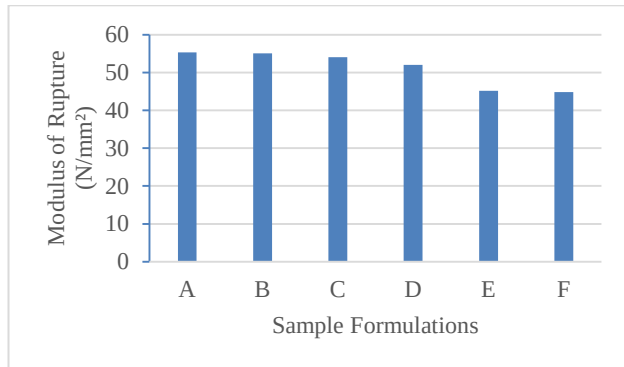


Fig. 2: The MOR of the composites

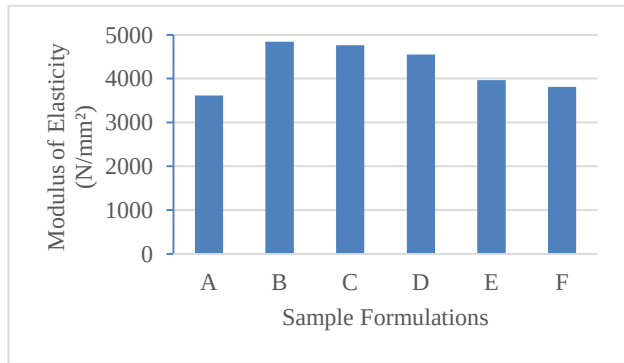


Fig. 3: The MOE of the composites

The tensile strength and tensile modulus of the composites are shown in Figures 4 and 5, respectively. As increased the marble content of composites, both the tensile strength and the tensile modulus decreased. Specifically, as the amount of marble content was above 20 wt%, the tensile strength and modulus decreased remarkable when compared to the composites having 20 wt% and below. The decreament ratio in the tensile strength was more pronounced than the decreament ratio in the tensile modulus.

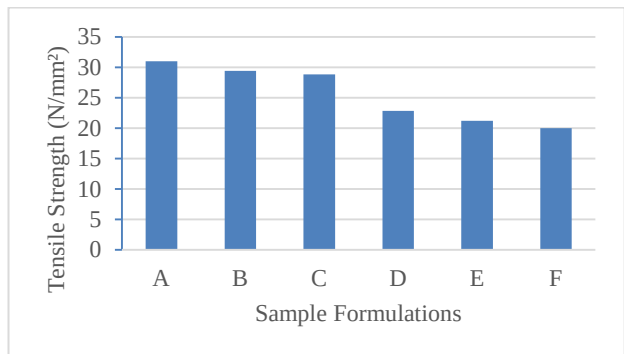


Fig. 4: The tensile strength of the composites

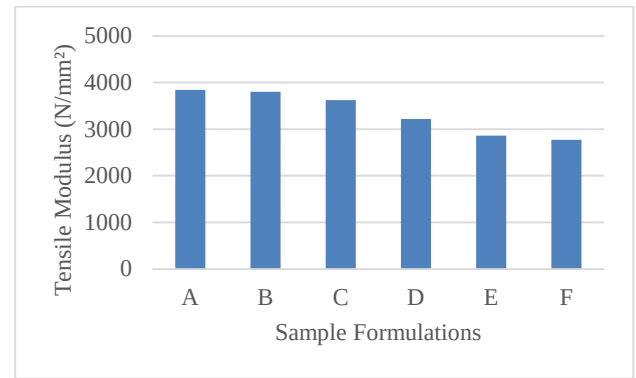


Fig. 5: The tensile modulus of the composites

3.2. Water resistance

The results of water resistance are presented in Table 4. In general, the water absorption and thickness swelling decreased with increasing amount of the marbel powder and decreasing amount of wood powder (Table 4, Figures 6 and 7). The water absorption and thickness swelling of composites sharply decreased when the amount of marble content reached to 30 wt%. The highest water absorption and thickness swelling values were found in the specimens produced with 50 wt% wood powder while the lowest values were found in the specimens produced with 50 wt% marble powder as seen Figures 6 and 7.

Table 4: The results of water reistance of the composites.

WPC code	Water Absorption (%)			Thickness Swelling (%)		
	One day	One week	Four week	One day	One week	Four week
A	0,21 (0,08)*	0,56 (0,08)	1,30 (0,15)	0,40 (0,18)	0,85 (0,25)	1,53 (0,35)
B	0,19 (0,03)	0,47 (0,08)	1,24 (0,16)	0,30 (0,12)	0,66 (0,17)	1,45 (0,23)
C	0,17 (0,07)	0,47 (0,08)	1,10 (0,14)	0,26 (0,08)	0,63 (0,14)	1,43 (0,18)
D	0,12 (0,05)	0,32 (0,14)	0,65 (0,16)	0,24 (0,10)	0,58 (0,14)	0,93 (0,22)
E	0,11 (0,09)	0,18 (0,06)	0,25 (0,08)	0,19 (0,06)	0,35 (0,13)	0,64 (0,23)
F	0,09 (0,06)	0,09 (0,05)	0,14 (0,05)	0,13 (0,07)	0,22 (0,13)	0,42 (0,22)

* Standard deviations

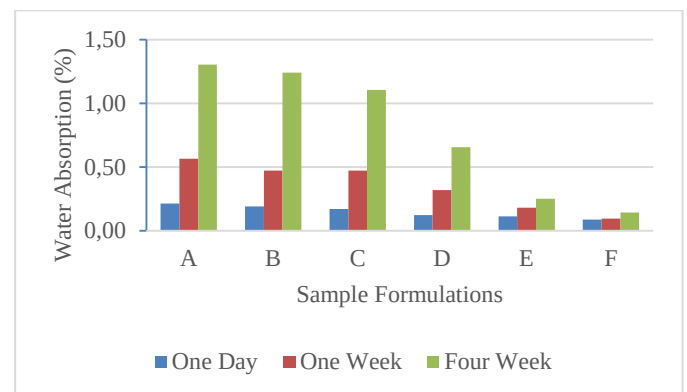


Fig. 6: The water absorption ratios of the composites

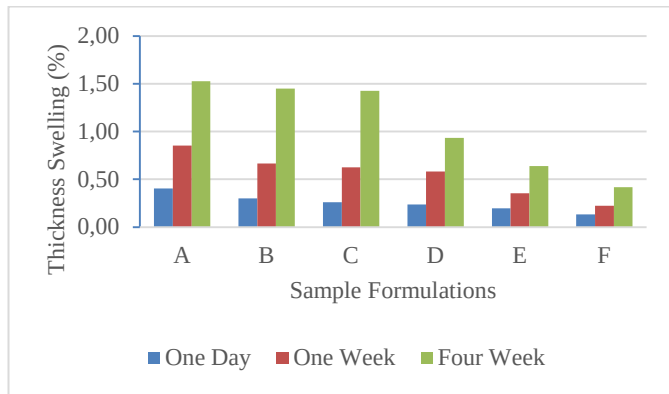


Fig. 7: The thickness swelling ratios of the composites

4. Conclusions

The results of the research revealed that the increase in the amount of the marble powder in the composites had a negative effect on the mechanical properties of the composites while the increase in the amount of the wood powder had a positive effect. One exception of this was observed in the MOE values where the MOE of composites improved considerably with the addition of 10 wt% marble powder and then decreased again with the further increment in the marble content up to 50 wt%. The decrease in the mechanical properties of composites was more remarkable when the marble content in the composites was over than 20 wt%. The water absorption and thickness swelling decreased with increasing amount of the marble powder and decreasing amount of wood powder.

5. Acknowledgement

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METHOD FOR THE DETERMINATION OF THE ROTATIONAL VARIABILITY OF CARDAN DRIVE

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Abstract: The paper justifies the importance of the experimental determination of rotational variability of cardan drives and couplings. The objective of the authors' team was to elaborate a new automated test machine for the determination of this variability. The principle design of this new automated test machine is described in details. The advantages of the application of electronic measuring equipment in combination with PC for the automation of the measuring and experimental data processing are pointed out. The test machine gives opportunities for changing of the angles between the driving and the driven shaft and for regulating the rotational speed of the driving shaft. The other functions of the electromechanical test machine are described in details in the paper. Conclusions are made: the methodology for experimental research of rotational variability of cardan drives is improved; the application of electronic test machine verifies the advantages of the usage of high sensitive and precise sensors of new generation; contemporary approaches are applied.

Keywords: CARDAN DRIVE, ROTATIONAL VARIABILITY, AUTOMATED TEST MACHINE, ENCODERS, DATA PROCESSING

1. Introduction

The cardan coupling is applied for transmitting torque between shafts with intersecting axes. The main disadvantage of the single cardan coupling (joint) is the fact that by constant angular velocity of the driving shaft ($\omega_1 = \text{const}$), the driven shaft is rotating with periodically changing angular velocity ω_2 . This specific feature causes dynamic loadings, which have unfavorable impact upon the driving characteristics.

The relation between the angles of rotation of the driving shaft φ_1 and the driven shaft φ_2 can be observed through the angle γ (the angle between the axes of both shafts) in the following way:

$$\tan \varphi_2 = \frac{\tan \varphi_1}{\cos \gamma}$$

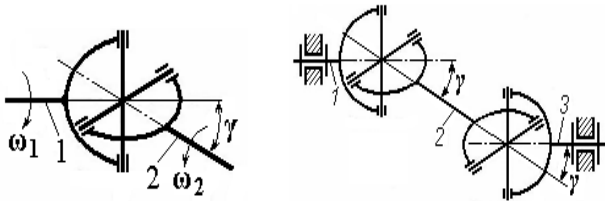


Fig. 1 Scheme of a single and a duplicate cardan coupling

Differentiating the indicated analytical expression concerning the time t , the following relation between the angular velocities of the shafts: ω_1 (for the driving shaft) and ω_2 (for the driven shaft) is obtained:

$$\omega_2 = \frac{\cos \gamma}{1 - \sin^2 \gamma \cos^2 \varphi_1} \omega_1$$

The variable angular velocity ω_2 leads to changes of the torque T_2 (torque of the driven shaft) within one full rotational movement. These changes cause dynamic loadings which do not have positive influence upon the exploitation characteristics of the driven machine. The irregularity δ depends upon the value of the angle γ (the angle between the axes of both shafts) and it is to be determined by the analytic expressions: $\delta = \sin \gamma \cdot \tan \gamma$.

The influence of this irregularity is not a positive phenomenon. Therefore, this specific parameter has to be investigated more thoroughly.

2. Prerequisites and Means for Solving the Problem

Different methods and test devices for the determination of cardan drives' irregularity and variability are described in [1], [2] and [3]. The considered devices possess a variety of disadvantages: mechanical scales for reading data; not quite perfect coupling encampment; options for personal errors by reading the angular displacement, etc. Aiming to avoid errors and to ensure precise results, a new method for automated measuring the variability and irregularity of cardan drives is elaborated.

It is envisaged that the experimental measuring is to be carried out with the help of experimental test machine, in which the cardan drive possess very good bearing system. Besides, a registering system is to be also a component of the test machine. In order to achieve this objective a new test machine is designed. It will give the opportunities to register and analyze the existing irregularity of a cardan drive.

Measuring of rotational angles for different values of the angle of the intersection between the driving and the intermediate shaft and the angle between the intermediate and the driven shaft is envisaged. The experimental measuring will also be done by different rotational speeds of the driving shaft.

One possible method for reading the results is the application of electronic encoder. The design layout includes the data processing to be done automatically, with the help of device for collecting data (USB produced by the company National instruments).

The practical solution of the problem was based upon the professional experience of the authors' team.

3. Solution of the Examined Problem

Fig. 2 shows the scheme of the test machine for automated data acquisition and for analysing the irregularity of cardan drives by transmitting motion.

The electronic encoders, item 1 on Fig. 2, are intended for measuring the rotational angle of the relevant shaft. The compensating couplings, item 2 on Fig. 2, form the connection between the driving and the driven shafts and the relevant electronic encoder.

The angular rotation φ_1 (of the driving shaft) and φ_2 (of the driven shaft) is to be converted by the corresponding electronic encoder in a signal sequence N_1 and N_2 . The number of the signals in the relevant sequence is a function of the angular rotation: $N_1=f(\varphi_1)$; $N_2=f(\varphi_2)$.

The exact expression of the function is to be determined by the characteristics of the electronic encoders. Particularly, this function depends on the resolution capacity: number of signals per rpm (revolutions per minute) – $[i/R]$.

The electronic encoders used in the test machine possess resolution capacity 1024 i/R. This kind of encoders ensures the necessary preciseness of the experimental research. Besides, if changes are to be envisaged these encoders can be replaced with other devices – from a higher class. It is especially important the parameter resolution capacity to be included in the software programme. Taking into account that the design of the applied encoders makes possible to realize and to convert a certain position, then the full resolution capacity is to be multiplied by four. The existence of zero pulse/signal (zero position of the shaft of the encoder) is to be used for starting the measuring.

The circular scales, item 4 on Fig. 2, ensure the opportunity for direct visualization of the shafts' rotation.

The generated signal sequence by the electronic encoders is designated respectively: **INPUT DATA** (φ_1, ω_1) and **INPUT DATA** (φ_2, ω_2). The signals enter the USB devices, item 6 on Fig. 2. Then, the number of signals gives information about the rotational angle φ_1 and the frequency of the signals carries data about the angular velocity ω_1 . After registering these parameters in the relevant USB device, they are to be transmitted to a personal computer PC, item 7 of Fig. 2.

The created files and records are to be processed by specialized programs. The USB modules are also special and they are used to convert the measure parameters and to read them. Their function includes also assigning control commands and modes to all other units in the program environment LabVIEW, which is installed on the PC – item 7.

The results' visualization in real time is displayed on the monitor of the PC, item 7, with the help of special software of the programme system LabVIEW.

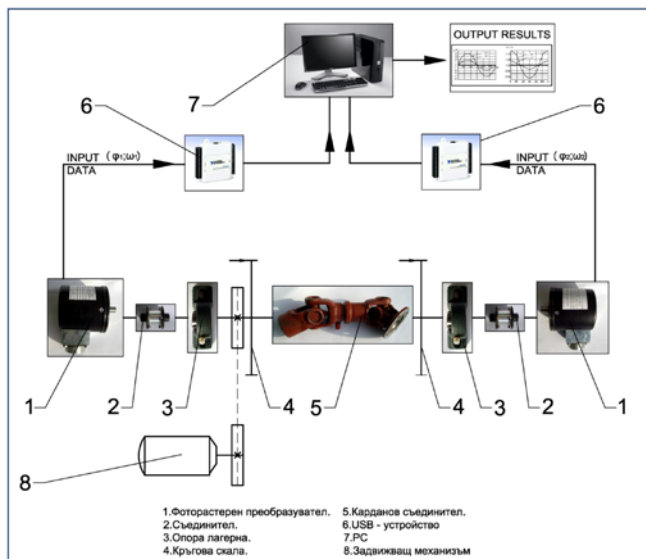


Fig. 2 Scheme of the test machine for the experimental research of cardan drive

The following methods for experimental research with the system are possible:

1. The experiment is started by manual driving of the input shaft, through crossing the zero position by the electronic encoder. The number of the signals (which is generated by the electronic encoder of the driving shaft) is reported through the N signal of the driving shaft.

Based upon this working approach, the relationship $\varphi_2=f(\varphi_1)$ is recorded over the angular interval $\Delta\varphi$. Such method of working with the system requires the opportunity for setting the parameter $\Delta\varphi$ and its relevant transformation in a number of impulses N .

The impulses, which are generated by the rotation in a reverse direction, are not to be reported by the designed system. In this case, the angular velocity ω_1 is not constant.

2. Rotating the input shaft with constant angular velocity ω_1 , it is possible to carry out the measurements over a time interval Δt . This parameter has to be considered together with the magnitude of the angular velocity ω_1 in order to reach the necessary preciseness.

In this way of working with the system, the relation: $\omega_2=f(\omega_1)$, is determined.

The application of the described methods and the designed test machine makes possible the achieving of the following positive results:

- The personal errors by recording the data during the implementation of the experimental measuring are avoided;
- Special registering system is applied aiming to increase the measuring preciseness;
- The registering system reports the values of the rotation of the driving and driven shaft with high accuracy in real time;
- The applied specialized software processes the results and gives the opportunity for their graphical visualization.

4. Results and Discussion

In order to ensure the successful functioning of the test machine, special software product has been elaborated. This application converts data and makes possible the results' visualization in the environments of LabVIEW. The special features of this software application are described in details in [4].

The front panel of the developed (in the environment of LabVIEW) virtual instrument is shown on Fig. 3. It presents in a graphical way the relation between the ratio of the angular velocities and the values of the rotation of the driving shaft. Besides, the dependency between the difference of the rotational angles $\Delta\varphi$ and the same parameter: rotation of the driving shaft is also visualized. The obtained graphical functions, Fig. 3, correspond to 2 different values for the angle between the driving and the driven shaft of the cardan coupling: $\gamma = 15^\circ$ and $\gamma = 30^\circ$.

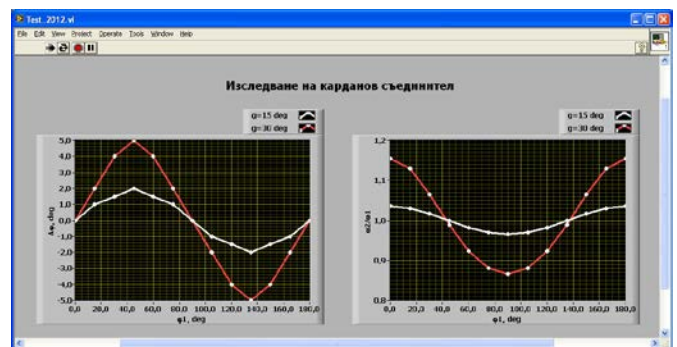


Fig. 3 Front panel of the virtual instrument with visualization of the results from the experimental research

The structure of the software application of the virtual instrument is presented through the block diagram, Fig. 4. This product has been developed especially for the designed automated test machine.

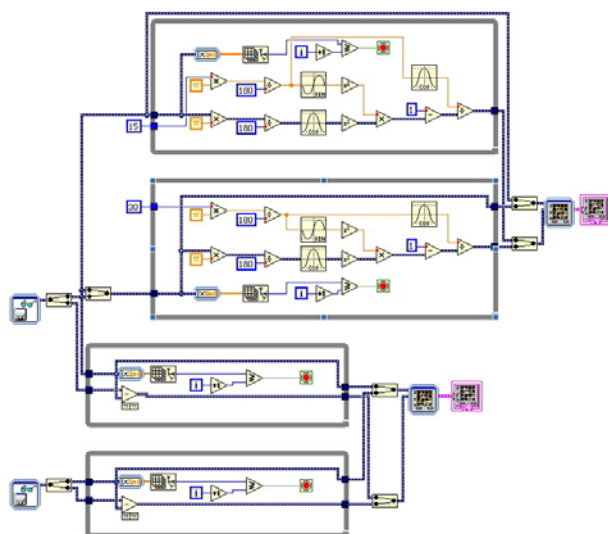


Fig. 4 Block diagram of the virtual instrument, [4]

The product LabVIEW has been selected due to the following reasons:

- The programmes, which are developed with the help of LabVIEW, can be regarded as virtual instruments. Their way of functioning is comparable to real devices;
- The virtual instruments consist of interactive user interface, diagram of data flow (program code – block diagram) and icons with links, which gives the opportunity to the virtual instruments to be accessed as a subprogram from other software instruments;
- The interactive user interface of the virtual instruments is characterized by a front panel, which can include (Fig. 5 and Fig. 6) keys, sliders, graphical display and other input areas and indicators.

The front panels, shown on Fig. 5 and Fig. 6, include a “button” for starting the program and another “button” for ending it.

One of the main advantages of the innovative test machine is that the experimental research can be implemented for different angles γ between the driving and the driven shaft.

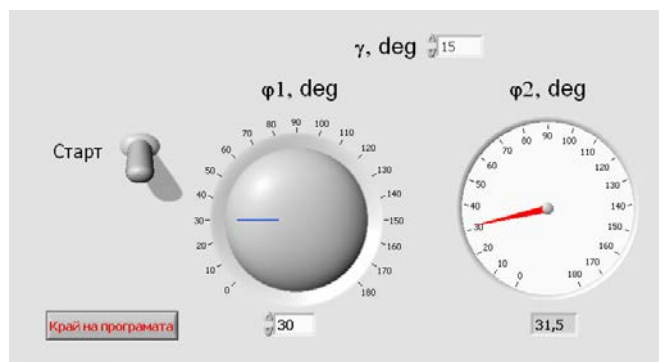


Fig. 5 Front panel showing measuring results by $\gamma = 15^\circ$

Fig. 5 shows a front panel, which visualize in real time the experimental values of the investigated parameters for angle γ (between the driving and the driven shaft), equal to 15° .

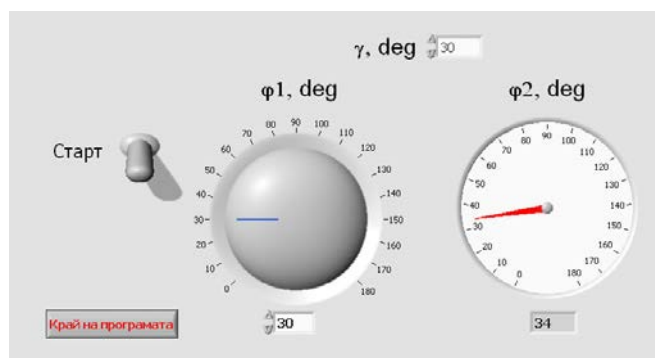


Fig. 6 Front panel showing measuring results by $\gamma = 30^\circ$

Fig. 6 shows a front panel, which visualize in real time the experimental values of the investigated parameters for angle γ (between the driving and the driven shaft), equal to 30° .

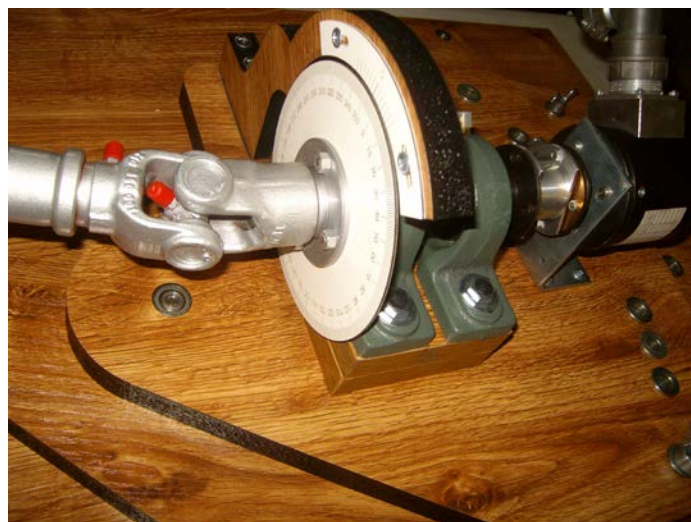


Fig. 7 Photograph of the designed and produced test machine

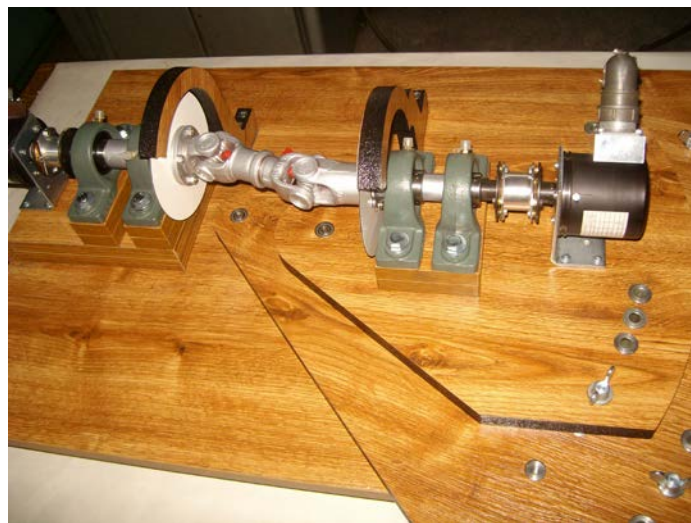


Fig. 8 Photograph of the designed and produced test machine

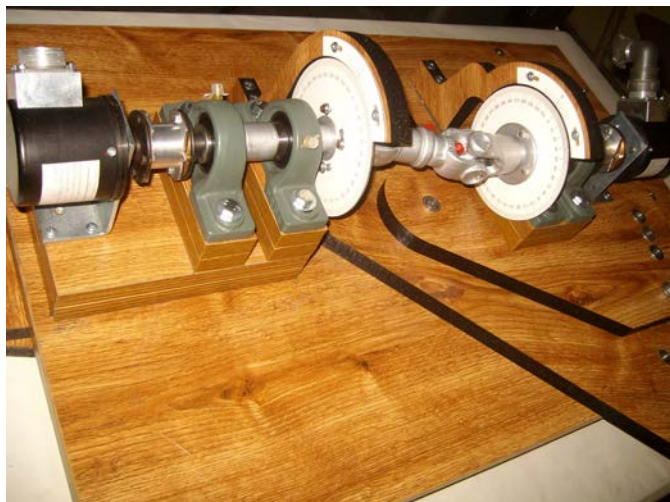


Fig. 9 Photograph of the designed and produced test machine



Fig. 10 General view of the innovative test machine

Several photographs of the innovative test machine for cardan drives are shown on Fig. 7, Fig. 8, Fig. 9 and Fig. 10.

5. Conclusions

1. The determination of the irregularity during the transmitting of motion in cardan drives is carried out through an innovative method. It has been developed by the authors' team based upon improved methodology for the investigation of the variability and the loading during the process of motion transmission by cardan drives;

2. The processing of the input and output parameters is carried out automatically. The designed and produced mobile automated test machine with electronic measuring equipment works in the environment of LabVIEW. Special software for converting and controlling of signals and a program application for the obtained results' visualization has been developed;

3. The measuring of the rotational angles is implemented directly with electronic encoders;

4. The obtained results are visualized in real time on a monitor. This feature of the innovative test machine presents one of the main advantages of the developed method for the determination of the variability of the cardan drive based upon contemporary tools;

5. Significantly greater accuracy by the processing of the experimental data has been achieved.

The designed and produced automated test machine for cardan drives applies a new way of processing input and output parameters. Besides, it is able to work in the environment of LabVIEW and with the corresponding to this product specific hardware.

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COMPARATIVE ANALYSIS OF MODELS DSAT-16 AND MOTP_VTU TO CALCULATE THE PROPERTIES OF THE LAYER IN THE WELDING AREA

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Abstract: The paper presents the characteristics of a modern software system for modeling and optimization of technological processes MOTP_VTU. It outlines the possibilities also to use the system at the design stage. A comparative analysis is performed of three characteristics to apply the new software system MOTP_VTU related to a similar existing one – DSAT-16. via similar systems it is possible to expand the basis of constructions and of functional materials in low technological level during exploration of the set of properties of these materials. This process of realization of scientific and technical ideas is a process to search via multi criteria support of decision making between the project task and the actual possibility, determined by the chemical composition and the processing-mode parameters.

Keywords: DSS, MCDM, MODELING, OPTIMIZATION, TECHNOLOGICAL PROCESSES

1. Introduction

The realization of technical solutions via *Informatics Science & Materials Science* is among prioritized scientific elaborations marked by the absence or a limitation of the possibilities of constructive and functional materials and also by an insufficient technological level in the research of the set of properties of these materials. This process of realization of scientific and technical ideas is a process to search a reasonable compromise between the required in the project and the possible reality; it is proved by the rapid development of these two branches of science and the adjacent industries after the convergence of *Informatics Science & Materials Science*. In this regard, modeling and optimization may be treated as methods of knowledge from the real life, forming the so called information society linked to the intelligent core of rapidly developing technologies [Samarsky, A. A., A. P. Mikhailov] [1].

Modern computer systems allow to create (to collect) huge data arrays to solve problems of processing, analysis and optimization algorithms of data related to materials. In this regard, the improvement of similar approaches, methods and software tools are directly connected to the improvement of the explored technologies via the obtained technological solutions with specific benefits for the materials for aerospace engineering up to biomaterials that save lives

2. Aim and Specifics of the Proposed research

The present research is goal-oriented at a comparative analysis between the already present computational system DSAT-16 and the new one MOTP_VTU created in the University of Transport “T. Kableshekov” [2] and on this basis to identify the possibilities provided to their users.

The stage of preparation of the numeric solution includes the elaboration of the algorithm and also of a software/system for the direct determination of the solutions. The solutions of models with increased numbers of parameters are always of a multivariate nature. The research of various numeric methods can significantly supplement the results from the analytical research; for lots of models this turns out to be the only realizable solution. The analysis of the numeric results and their usage are related to the adequacy of the models. The mathematical methods for testing/verification can determine if a model is built incorrectly and also they can determine the class of potentially robust models.

All this comprises elements of the system to support the decision making in the domain of analysis and multi criteria optimization of different selected indicators for control, and the optimization of quality parameters of metal-processing technologies.

A validated algorithm is applied. It is associated with the following two classes of problems:

- *Informative with a predefined threshold;*
- *Operative – analytical.*

The system (the software) allows work with a data base with full information for the decision maker about the analysis of the investigated multi parameter space and also the effective solutions for a series of quality indicators in this multidimensional research area. The data base itself is a set of tables that store the data grouped as rows and columns. Part of the data in the rows represent various combinations of the technological parameters that together with other data from the row determine the relation of this combination with the research quality parameters.

The main part for the final decision is quantitative information (as a level of detail and as a degree of reliability) formed at the stage of experimental testing and processing. There is a need to increase the accuracy of such calculations compared to already existing ones. They must provide a reasonable choice of alternatives at the initial stages of the design and the formulation of quantitative data of the criteria (mechanical properties or other indicators) for structural and parametric optimization.

3. The main idea of the proposed software in the field of metallurgy

At the design stage, the process of selection or synthesis of properties of compositions and processing materials gives the sense of the most important field of materials science. Solving problems regarding the relation “structure-properties” is always associated with resolving the contradictions that formulate the complex /set/ by certain characteristics. A good example in this regard is the production of alloys that overcome the contradiction between “strength and plasticity elongation”. Deciding such contradiction, as an innovation in the field of steels there have been created TRIP-steels, which in addition to high strength, possess higher plasticity, e.g. more than 6-10% and also more than the ones compared to Mart-steels. The traditional strategy for development of alloys consists of producing numerous samples of varying composition, and variations of elements and mode of treatment for a particular alloy with optimal properties. This approach leads to high costs for experimentation.

That is why within the group of methods for directed search, the “trial and error” method is the least preferred and it stands lowest in the hierarchy of methods.

An alternative and effective approach is to use data from previous experience, processed up to a statistical model, based on a

large amount of data related by composition, processing and properties.

The design of the alloy composition and the optimization of the technological-process parameters are directly related to the resolution of the compromise between the measured values related to certain selected indicators of the quality of a set of materials for a test group or a class [1]. The most characteristic for these approaches is that they do not use the principles of metallurgy and metal physics. It is relied mainly only on an a priori information about the relation "composition and processing and their influence on the properties". Compared with physical models, the advantage of statistical models is their ability to explore a complex of properties and to obtain information in a timely and effective manner, even when there are no well-established physical theories and models. These approaches are created for ease of the DM. After determining the composition such that they meet the formulated requirements, an expert and experimental verifications carried out.

Metallurgical design is not only the design on a base with alloying elements by type, number and amount of the elements, but it includes taking into account also their synergistic effect. It is necessary to select such a synergistic effect by the combination of elements in which the more expensive elements must be in lesser amounts.

Along with the execution of this task, the metallurgical design must meet also the sought compromise between the properties of the product, depending on the processing parameters. These several groups of parameters should form the general parameters of the metallurgical design. The complexity of the so defined problem consists in the large number of input parameters, and the fact that the chemical composition is involved implicitly by the synergistic effect in the system "composition-structure-processing-properties-price". Multicriteria genetic algorithms (MCGA) have proven to be effective in finding Pareto-optimal solutions of multicriteria optimization problems.

There are many MCGA capable of approximating Pareto - fronts with a set of points. One of the biggest difficulties in implementing MCGA to solve the described problem is the large amount of calculations of the computing functions of the criteria, because the order is several thousand. Reducing the number of these calculations is an important issue. Finding good approximation methods is particularly difficult due to the number of criteria and the possible interactions between them. The goal of this study is to propose an approach by which to determine optimal compositions corresponding to the precisely specified properties, a priori defined by the user, in accordance with the system "composition-structure-processing-properties-price."

The main goal of the research is to apply the approach to a specific task.

In this work a solution is proposed, based on the use of software model with applied techniques from the field of multi-criteria analysis and optimization, and the establishment of regressions between the mechanical properties of the alloy and its chemical composition based on neural models.[4]

4. Mathematical Model MOTP_VTU

General Characteristics of the Model

Data processing for an experiment begins with its formation into a table (matrix). The result from experiment "Y" we call output data (*data functions*). The values of "Y" depend on a series of other values "X" which we shall call input data (*factors*). These names are specified because the programs contain questions and guidelines for them. Every matrix is characterized by its number of rows and by its number of columns. It is accepted in the elaborated software that the number of factors cannot exceed 10 and that the output values cannot exceed 200, but there are no constraints like the ones for the number of factors. The matrix must be refined at messages for

shortage of memory ("out of memory") for the problem to find the model coefficients.

For example, the case with 5 numbers "X" and 3 numbers "Y" needs the following form of matrix formulation: $X_1, X_2, X_3, X_4, X_5, Y_1, Y_2, Y_3$. We begin with the factors and we end with the outputs.

We remember the meaning of every "X" and "Y". The so formed matrix is used for a further processing and search of solutions.

Data Input

Data input is the next stage of processing the results from the experiment. The input must be performed in rows, starting from the first and ending with the last line. There will be questions about the number of the rows, the number of the factors and the number of the outputs. The sum of the number of the factors and the number of the outputs determines the number of the columns in the matrix.

Programming language BASIC used for the realization of the algorithms operates with numbers with seven significant digits but it allows use also numbers with sixteen significant digits (*double precision*). There will be a question about this detail. This is particularly important for processing huge matrices. In our case of limitations this means a matrix with big number of rows. Numbers with up to seven significant digits (*single precision*) require half of the memory. The data input may be aborted at any time followed by an exit from the program for data input. At the end of the input there is a possibility to correct the detected errors. The matrix obtained in this way is saved as a .DAT file with a specific name.

After the end of the input a primary analysis is provided. At this stage, for every column there will be determined the estimates of the mathematical mean, the variance, the minimal and maximal values. These estimates are also saved and they are used later.

Processing and Internal Links

The further processing of entries may continue to search for linear and non-linear relationships between them. It allows each column of the matrix to be presented as a function of another column in the form:

$$(1) \quad Y = A_1 + A_2 \cdot X \text{ to } Y = A_1 + A_2 \cdot X + A_3 \cdot X^2 + \dots + A_{11} \cdot X^{10}$$

It is possible in this way to establish relations for every column, regardless of the "X" or "Y" with other columns and to draw respective conclusions for further processing.

To relieve the further work there have been elaborated two programs for interpolation: Newton interpolation with unequally spaced nodes, and Eitken interpolation with up to 6 nodes. They can be used to obtain missing table values.

Forming a Mathematical Model

As it has been already said, the number of factors is limited to 10. For every specific case from 2 to 10 factors, there have been elaborated separate programs, because in the case with 2 factors in the mathematical model there are 6 coefficients, in the case with 3 factors they are already 10 coefficients and for 10 factors they are 66 coefficients.

For example for the case with 4 factors the mathematical model has the form:

$$(2) \quad Y = A_1 + A_2 \cdot X_1 + A_3 \cdot X_2 + A_4 \cdot X_3 + A_5 \cdot X_4 + A_6 \cdot X_1 \cdot X_2 + A_7 \cdot X_1 \cdot X_3 + A_8 \cdot X_1 \cdot X_4 + A_9 \cdot X_2 \cdot X_3 + A_{10} \cdot X_2 \cdot X_4 + A_{11} \cdot X_3 \cdot X_4 + A_{12} \cdot X_1^2 + A_{13} \cdot X_2^2 + A_{14} \cdot X_3^2 + A_{15} \cdot X_4^2.$$

This is the complete and best operating model of mathematical form. After finding the coefficients, the program shows the results from the statistical estimate of the model and the estimate for its ability to predict.

Digital Optimization

In the case with a positive assessment of the adequacy of the mathematical model to predict, there can be sought a desired extremum – min or max.

This problem is solved with 3 programs for digital optimization:

1. Method of Hook and Dzhivs – the configuration method (for up to 10 factors);
2. Method of Nelver and Mid – the deformable-polyhedron method (for up to 6 factors);
3. The method of golden section to find an extremum of functions of a single variable.

The extremum is sought calculating the function value without using derivatives. The optimization is performed within the factor constraints. It is possible to find the extremum with these 3 programs for each case determined by the number of factors. Within the organization of the calculations every program “calls” internally the model coefficients, then it “asks” for min and max factor values and other necessary values.

Taguchi Assessments

The calculation of Taguchi assessments starts with calculating matrix (27.*) where “*” is the number of rows of the input matrix. This is done by the first program of the two programs. The calculated matrix is saved in a file. Though that the effect from Taguchi estimates is manifested for greater number of factors, this program is designed for versions from 2 up to 10 factors. The second program calculates Taguchi estimates from the already calculated (27.*) matrix.

Entering the Coefficients of a Model and Calculation of the Model

In cases with multi criteria problems, it is necessary to calculate a function based on the results from the extremum of another problem. This program makes it possible to enter the coefficients of the mathematical model and the values to calculate with. The program is elaborated in the version from 2 to 10 factors.

Sorting in Ascending Order

It is possible to sort a set of values with this program. Sorting is performed in ascending order: after the sorting is over, then the first value is the smallest, and the last value is the greatest one.

5. Analysis of the results obtained via the two software systems for a concrete example in the domain of welding

This analysis was necessary after the originally formulated problem to find the extremum of obtained mathematical models from DSAT for HRC, the “carbon equivalent and cost” for weld metal. The obtained mathematical models are of second degree with interactions on four factors: X_1 – carbon, X_2 – silicon, X_3 – chromium, X_4 – tungsten. The mathematical models can predict.

When the results were obtained then it was decided that this problem must be solved again with new mathematical models and programs developed in the University of Transport (see pt.4). The statistical analysis of the models shows the following properties:

DSAT Model

HRC	Carbon Equivalent	Cost
R = 0,6635	R = 0,9990	R = 0,9298
F = 2,3032	F = 1456,21	F = 18,6973

MOTP_VTU Model

HRC	Carbon Equivalent	Cost
R = 0,7828	R = 1.0	R = 0,9213
F = 4,6327	F = 14,771 E+11	F = 18,6973

In the cases with mathematical models for carbon equivalent and cost, both programs give approximately the same result, because they are analytically calculated values and there is no randomness.

The results from both models are very good: the coefficient of multiple correlation R is near to 1.

As noted, the mathematical models are able to predict, because the calculated value of Fisher criterion is greater than the value in the table for the case of F with (0,05, 14,41) = 1.9465.

This is not so for HRC. The VTU model has a greater coefficient of multiple correlation $R = 0,7828$ related to $R = 0,6635$ for the model DSAT. This difference is not small; it shows that the VTU model gives a better approximation to the experimental data.

The desired extrema of the mathematical models are: for HRC – maximum, for carbon equivalent and cost – minimum. The extrema are sought with the method of Hook and Dzhivs; in all cases the starting point is: $X_1 = 1$, $X_2 = 1$, $X_3 = 1$, $X_4 = 1$.

Results

HRC (max)

DSAT Models	MOTP_VTU Models
Ye = 11338,05	Ye = 11638,74
$X_1 = 3,5$	$X_1 = 2,0$
$X_2 = 4,0$	$X_2 = 4,0$
$X_3 = 0$	$X_3 = 6,15$
$X_4 = 8,1$	$X_4 = 9,5$

The MOTP_VTU model gives a little bit greater value for the obtained extremum.

Carbon equivalent (min)

DSAT Models	MOTP_VTU Models
Ye = 3,59	Ye = 8,00
$X_1 = 8,00$	$X_1 = 0,00$
$X_2 = 0,00$	$X_2 = 0,00$
$X_3 = 0,00$	$X_3 = 0,00$
$X_4 = 0,00$	$X_4 = 8,00$

In this case, the model DSAT gives a smaller value.

Cost (min)

DSAT Models	MOTP_VTU Models
Ye = - 42434,89	Ye = 5,71
$X_1 = 8,00$	$X_1 = 0,08$
$X_2 = 4,00$	$X_2 = 1,83$
$X_3 = 30,00$	$X_3 = 0,00$
$X_4 = 9,50$	$X_4 = 3,31$

In this case, DSAT gives as an extremum a negative number which is unacceptable as value whilst MOTP_VTU gives an acceptable value.

The second problem was to formulate HRC, the carbon equivalent and the cost as one-dimensional functions of the given X_1 , X_2 , X_3 , X_4 . This was achieved building mathematical models from 2nd to 10th degrees. Then a statistical analysis was performed and the best choice was related to R , the coefficient multiple correlation [3].

- Model HRC – the best performance is with variable X_3 with a polynomial of 8th degree, $R = 0,8406$.
- The carbon equivalent model – the best performance is with a variable X_1 with a polynomial of 4th degree, $R = 0,9847$.
- The cost model – the best performance is with a variable X_4 with a polynomial of 9th degree, $R = 0,8606$

The obtained results show that HRC, the carbon equivalent and the cost of weld metal may be represented as single-factor models; in them the better models are in the beginning, taking into account the simultaneous influence of 4 factors.

6. Conclusion

The realization of specific technical solutions with modern tools expands the possibilities at the design stage.

This was demonstrated by the comparative analysis of three characteristics during the application of the new software system MOTP_VTU.

It is possible to expand the basis of constructs and the functional materials for a low technological level of research for the set of properties of these materials.

This process of realization of scientific and technical ideas is a process to search a reasonable compromise between the design goal and the possible reality.

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INVESTIGATION OF ZINC COATED PANELS Nylofor® 2D Super

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Abstract: Zing galvanized panels were ordered and delivered for the fencing of the factory yard. But immediately after receiving the panel from the deliverer, it was concluded that their quality is suspicious. These panels must fulfil strict standards requirement concerning their quality. To confirm this purchaser engaged the team from the Faculty of Technology ad Metallurgy in Skopje to perform investigation and to check if the panels satisfy quality requirement. The performed investigation consists of the following testing's: chemical composition of base metal (wire), wire diameter and tolerances, tensile test, weld shear strength test, mesh size and tolerances, coating, visual inspection of panels. Performed investigation confirmed that delivered panels didn't fulfill necessary requirement for this type of fencing.

Keywords: ZINC COATING, PANEL, S NYLOFOR, WHITE RUST, ELECTRO RESISTANCE WELDING

1. Introduction The Nylofor 2D & 2D Super system is, because of the high rigidity and security, recommended for professional fencing of schools, play grounds, parks, public buildings, factories and workshops, airports and military sites. The extra heavy horizontal wires make Nylofor 2D Super particularly suitable for the security of sport grounds too. The panels are extremely rigid due to the use of heavy welded mesh in conjunction with double horizontal wires. The coating technology should guarantee a long lifetime. The system includes panels in different mesh apertures and heights, posts with adapted fixing systems and a large range of mesh and gates. All components guarantee a fast and professional installation. As can be seen from the formerly presented things, the quality of the panels is result of entirely performing of the quality requirement [1-8].

So the main task in this research work is to checks the quality of the delivered panel's trough the mechanical and visual testing and to compare results with the standard requirement,

2. Material and investigations

The subject of investigations in this research work are Panels Nylofor® 2D Super intended for fencing of factory yard - according with appropriate standard. The panels are produced by electrical resistance spot welded galvanized wires in accordance with EN 10223-7. The vertical wires have a barb at one side of the panel. The panel is reinforced by means of a horizontal double round wire at both sides of the vertical wire.

3. Results of the investigation

Chemical composition of base metal (Wire rods)

This test was performed according EN 10016-2 (ISO 16120). The designation of the wire rod is C9D, and its WNo is 1.0304 – wire from unalloyed steel. Chemical composition of the welding wire according standard requirement and values obtained by chemical testing are presented in table 1.

Table 1. Chemical composition of welding wire according EN 10016-2 (ISO 16120) and performed chemical analyze.

Element, %	C	Si	Mn	P	S
Max. value	0.16	0.300	0.600	0.0350	0.035
Hor. wire	0.070	0.140	0.500	0.0179	0.008
Ver. wire	0.070	0.138	0.498	0.0182	0.008

As can be seen from the table 1 obtained value for chemical composition is beneath max values from standard requirement. It generally means that chemical composition fulfill the standard requirement. But, it has to be point out that measured values for carbon and silicon are much lower than values prescribed in standard.

Wire diameter and tolerances

Measured outer wire diameters for Nylofor 2D super panels were compared with values given in European standard EN 10218-2. Obtained values are given in table 2.

Table 2. Outer wire diameter and tolerances

EN 10218-2 Diameters and tolerances	Horizontal wire, [mm]	Vertical wire, [mm]
Nylofor 2D Super	8.00 ± 0.20 mm	6.00 ± 0.20 mm
Measured values	7.45, 7.49, 7.48, 7.45, 7.48, 7.49, 7.46, 7.46, 7.49, 7.46,	5.52, 5.53, 5.52, 5.55, 5.53, 5.52, 5.53, 5.54, 5.55, 5.54

As can be concluded from table 2 measured values are beneath values for the outer diameters of Nylofor 2D and Nylofor 2D Super. It means they don't satisfy standard requirement.

Tensile test

The tensile strength of horizontal and vertical wires should be 500 to 700 N/mm². Results from tensile testing of horizontal and vertical wire are given in the table 3.

Table 3 Tensile testing of horizontal and vertical wire compared with standard requirement

Vertical and horizontal wire, min, [N/mm ²]	500	
Horizontal wire, [N/mm ²]	473	467
Vertical wire, [N/mm ²]	564	568

Results from performed tensile testing showed that vertical wire fulfills the standard requirements, but obtained results from tensile testing of horizontal wire are beneath the minimum values given in standard and don't satisfy.

Weld shear strength test

Weld shear strength test was performed in accordance with EN 10223-7. Four randomly taken specimens (welds) were prepared and tested. According this standard, average shear strength shall not be less than 50% of the breaking load of the vertical wire. Obtained results are given in the table 4.

Table 4 Weld shear strength test

50% of the minimum breaking load of the wire, [N] 5939					
Meas. value, [N]	1	2	3	4	Average value
	3125	3124	3765	3624	3410

As can be seen from the table 4, 50% of the minimum breaking load is 5939 N. Average value from four test measurement is 3410 N. It means that shear strength test didn't fulfill standard requirement.

Mesh size and tolerances

Mesh size and tolerances are determined by EN10223-7 standard. Randomly chosen fields were tested. Requirements of the standard and measured values are given in table 5.

Table 5 Mesh size and tolerances

Mesh size and tolerances Nylofor 2D super	Standard requirement	Measured values
Distance between horizontal wires	200 ± 2 mm	198, 203 , 197 , 202, 201, 199, 200, 198, 200, 201
Distance between vertical wires	50 ± 2 mm	48, 49, 50, 50, 49, 50, 48, 50, 49, 48, 49, 49

Comparison between measured and obtained results showed pretty good results. Only too values didn't satisfy standard requirement (horizontal wire bolded values).

Zinc Coating

Raw material i.e. steel wires are previously galvanized. Minimum zinc coating according with Betafence recommendation for the horizontal and vertical wires is 40 g/cm². Results from coating measurements are given in table 6. Obtained results from measurements were compared with requirement from ISO 1461 standard for zinc galvanized coating.

Table 6 Zinc coating requirement for steel wires according ISO 1461 standard

ISO 1461	Coating min, [g/m ²]	Coating min, [μm]
Standard requirement	505	70
Measured values (horiz. wire)	711	100
Measured values (vertical wire)	1069	150

Obtained results show that zinc coating is much thicker compared with ISO 1461 standard requirement. Measured thickness value for vertical wire is two times higher than standard request.

Visual inspection

Inspected Nylofor 2D Super panels were laid on the wooden pallets in the factory yard. Every pallet with galvanized panels was separately inspected, and different types of defects were detected. As can be seen from the figure 3, pallets were protected with nylon coverage during transportation and storage. But this protection was generally damaged. General conclusion is that almost all panels have many different types of surface defects. From the most characteristic defects detected in the inspected panels were taken photographs which are given below. Photographs given in figure 1(a and b) concern to the white rust. White rust is type of surface defect which can appear on the surface of the fresh galvanized parts. The main reason for its appearing is presence of water (moisture) in contact with part and appropriate temperature. White rust is in fact Zn(OH)₂. Process of rust formation last until the last drop of water is present in contact with galvanized surface. Figures 2 refers to excess zing coating on the galvanized bars. The reason can be improper temperature of molten zinc during galvanization. Figure 3 concerns to defect i.e. corrosion attack as result of mechanical damaging of the galvanized layer or bed surface preparation before galvanization start. Panels with defects like dross, flux, peelings and sapling are presented at figure 4. Vertical ribbed bars are not allowed for these panels (Figure 5), but they are used for panel's production. Mechanically damaged panels during transport or

storage can be seen at figure 6. Figure 7 show bed spot welds. It means that there is not strong connection between the bars.



a



b

Figure 1(a and b) white rust



Figure 2 excess materials (zinc coating) on the surface



Figure 3 Corrosion attack on the coated bars



Figure 4 Panels with dross, flux, peeling and spaling



Figure 5 Vertical ribbed bar



Figure 6 Mechanically damaged panels



Figure 7 Bed welding spot

4. Discussion

Chemical composition of welding wire is lower than max value prescribed by standard, but it is indicative that measured values of carbon and silicon are much lower from these values. For manufacturing Nylofor 2D Super panels, horizontal wire with diameters of 8 mm and vertical wire with diameters of 6 mm were used. Performed investigations confirmed that tensile strengths of tested horizontal wire are 467 and 473 N/mm² which is beneath lower value of 500 N/mm² given by standard.

As can be seen from table 2 measured diameter of wires is beneath tolerances prescribed by standard. As was noted by visual inspection, outer surface of some wires are not flat but ribbed figure 4(a-c)) which is not prescribed for the Nylofor 2D Super panels. Thickness of the zinc galvanized layer satisfy standard request. But measured thicknesses are much higher from the values determined by standard. Weld shear strength test showed that obtained values are lower than standard request. It means that welding parameters like: welding current, welding time, pressure of copper thorns is not properly chosen. Besides, welding of galvanized is more difficult than bare steel wires. From the figure 6a is visible that there is no strong penetration between the wires in the resistance spot. It is the main reason for bed result of weld shear strength test. Visual inspection of panel's surface showed that many types of surface defects are present. Some of them just show influence to the aesthetic view of panels, but the other ones are important because they lower corrosive protection of panels. As can be seen from the figures 3 corrosion process, at some panels already started. Noticed defects were compared with literature dates and information's. Some standard which determine exactly which defects are allowed and which not can't be found. Mainly it is determined with contract. But the white rust and rust can't be allowed on the new panels.

However, the role of zinc coating is to protect the panel surface from corrosion. It's a fact that galvanized coating normally has to be smooth, continuous and free from gross surface imperfections and inclusions. The surface of the steel wires should be completely covered with a uniform zinc coating whose thickness depend principally by the thickness of the steel being galvanized. During the visual control and measurement was found that zinc deposits are too thick and not uniform.

White rust (figure 1(a and b)) is a white powdery deposit formed from a natural corrosion process that can occur on any new zinc coated steel product. Zinc is a very durable coating for the purposes of providing sacrificial protection to the underlying steel substrate but, because it is reactive to water, great care must be taken in storing it correctly. That is why it is often referred to as "wet storage stain." The white powder is actually zinc hydroxide – the substance formed when zinc reacts with water and air - and it gradually consumes the zinc coating; this process is most likely to happen in wet conditions with inadequate air circulation (improper packing of panels).

The actual thickness of galvanized coating achieved varies with steel section size, surface profile and surface composition. Actual coating weights are often much more than the minimum specified in the standard. Thicker coatings than those set out in EN ISO 1461 can give additional protection for use in particularly aggressive environments. For most applications, thicker coatings are rarely necessary.

The service life for the coating is determined by two factors, the environment and the coating thickness. Recent studies on the life of a galvanized coating show that a coating in an industrial environment will have 60% of the life of the same coating in a rural environment. In the neighborhood of company yard there is no such severe conditions.

Defects on the surface of zinc coating (figure 3) are influenced by many factors quality of raw material (wire), preparation of wires for galvanization, purity and temperature of zinc in bath, welding techniques and technology and many others. Molten zinc has to contain about 95 % Zn. Presence of impurities during the galvanization can be harmful for quality of the coating. Such localized places with defect are potential sites for rust formation.

Proper packing and transportation to the purchaser is very important too. As can be seen from the figure 5 (a-c) there is mechanical damaging of the some panels.

5. Conclusion

In this investigation (technical report) of Nylofor 2D Super panels were investigated. Investigation consists of mechanical testing of panels (according with appropriate standards) and visual inspection of panels (quality of zinc coating). The main conclusions are the following:

1. Results of mechanical investigation showed tensile strength of horizontal wire is lower than 500 N/mm² which is beneath standard requirement. Weld shear test didn't satisfy too, because obtained values are lower than 50% of the minimum breaking load. (EN10223-7). Outer surface of some coated wires is not flat.
2. During visual examination many types of the surface defects on the coatings were detected. Some of them influence only aesthetic view of the surface but the other ones like (white rust, rust, dross, peeling, spalling...) can show significant influence to the predicted service time of the panels.

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- [2] EN 10016-2:Non-alloy steel rod for drawing and/or cold rolling – Part 2: specific requirements for general purposes rod.
- [3] EN 10218-2: Steel wire and wire products – General – Part 2: Wire dimensions and tolerances.

[4] EN 10223-7: Steel wire and wire products for fences – Part 7 : Steel wire welded panels – for Fencing.

[5] EN 10244-2: Steel wire and wire products - Non-ferrous metallic coatings on steel wire - Part 2: Zinc or zinc-alloy coatings on steel wire,

[6] *ISO 16120-4:2011 Non-alloy steel wire rod for conversion to wire -- Part 4: Specific requirements for wire rod for special applications*

[7] EN 10245-1: Steel wire and wire products - Organic coatings on steel wire - Part 1: General rules.

[8] ASTM F 2453 / F 2453M: Standard Specification for Welded Wire Mesh Fence Fabric (Metallic-Coated or Polymer Coated) for Meshes fo 6in.² [3871 mm²] or Less, in Panels or Rolls, with Uniform Meshes

WEAR AND CORROSION RESISTANCE OF Ni-P COATING ON AA7075 ALUMINUM ALLOY

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Abstract:

This study was initiated to compare the wear and corrosion performances of an AA7075 quality aluminum alloy after electroless Ni-P process. The characterization of the coating was made by microscopic examinations, thickness, surface roughness and hardness measurements. Wear and corrosion performances of the uncoated and coated samples were investigated by using a reciprocating wear tester and a Potentiodynamic Polarization Scanning (PDS) technique, respectively. Formation of Ni-P layer on AA7075 aluminum alloy accompanied not only by remarkable increase in the surface hardness, but also caused significant improvement in wear and corrosion resistances.

Keywords: COATING, CORROSION, ELECTROLESS, WEAR.

1. Introduction

Aluminum and its alloys belong to the most important lightweight engineering materials [1]. Nowadays, lot of research work was done on aluminum and its alloys because of their exclusive properties such as high strength to weight ratios, high thermal conductivity and good corrosion protection [2, 3]. However, several drawbacks restrict the application of unprotected aluminum alloys, especially their low hardness and limited wear resistance. To improve the practical usage of aluminum alloys, many researchers have attempted to develop high wear-resistance strategies [4, 5]. Among different surface techniques, electroless deposition appeared as an attractive surface modification technique generating a micro-scale amorphous Ni-P layer to enhance wear and corrosion resistance of aluminum and its alloys [6, 7]. In order to assess the wear and corrosion behavior of this coating, the wear and corrosion experiments were carried out, and the results were compared with those of the 7075 aluminum alloy substrate.

2. Methods and Procedures

AA7075 disc-shaped samples with 25 mm diameter and 5 mm thickness were used as the substrate for the preparation of electroless NiP coating. This grade was chosen because it is very popular in aeronautics. The aluminum attracts easily with oxygen, hence the fine layer is allow to form on the surface. Therefore, it is difficult to coat the aluminum substrates covered with a very thin and impervious oxide film, so suitable surface preparation (mechanical grinding and polishing, alkaline cleaning with acetone and methanol, acid pickling and pretreatment) is required [8]. The commercial Ni-P electroless solution (DURNI-COAT DNC 520-9) containing 5 g/L nickel, 40 g/L NaH₂PO₂ and suitable amounts of additive and stabilizer were used. The stirring rate of plating bath was about 250 r/min, using a magnetic stirrer and a polytetrafluoroethylene (PTFE) coated magnet with 2 cm length and 5 mm in diameter. The deposition was carried out in a 100 ml thermostated double wall beaker at 90 °C and pH 4.6 for 1 h to achieve a thickness of 13 µm.

Cross-sectional morphology of the electroless Ni-P coated sample was characterized by using an Optical Microscopy (OM). Mechanical properties of the uncoated and coated samples were examined by microhardness measurements and dry sliding wear tests. Microhardness tests were conducted on polished samples from cross section of the coating with a Vickers indenter under a load of 10 g for a dwell time of 10 s. Three microhardness measurements were obtained for each sample, and the average value was recorded. Dry sliding wear tests of the uncoated and coated samples were performed on a reciprocating wear tester operating in ball-on-disc configuration at room temperature. In this configuration, an Al₂O₃ ball with a diameter of 10 mm was sliding forward and backward against the coatings with a sliding speed of 1.7 cm s⁻¹. Normal load

of the test, sliding amplitude (wear track length) of the reciprocating motion and overall sliding distance were 2 N, 10 mm and 50 m, respectively. During the wear tests, the temperature and the relative humidity were maintained as 20±5 °C and 40±5 %, respectively. The friction coefficient force was continuously recorded during the tests. Width and depth of the wear tracks were measured by a surface profilometer (SurfTest SJ 400) to calculate wear performance of the samples. Following the wear tests, wear tracks were examined by an OM.

The electrochemical corrosion tests were performed utilizing a typical three electrode potentiodynamic polarization test unit in the corroding media of aerated solution of 3.5 wt. % NaCl at room temperature. Before potentiodynamic polarization measurements, an initial delay of 45 min. was employed in order to measure the open circuit potential between working and reference electrodes. Potentiodynamic polarization curves were generated by sweeping the potential from cathodic to anodic direction at a scan rate of 1 mVs⁻¹, starting from - 0.25 up to + 0.25 V. Corrosion potentials (E_{corr}) and corrosion current densities (i_{corr}) were calculated using a Tafel type fit in the software. Finally, the surface images of the corroded samples were examined using an OM.

3. Results and Discussions

The cross-section morphology of the Ni-P coating detected by OM is illustrated in Fig. 1. Micrograph of the coating deposited on top of the aluminium alloy revealed that the coating has a good adhesion to the substrate and there is no discontinuity at the coating/substrate interface. Additionally, profilometry measurements indicated that the Ni-P coating has a roughness value $R_a = 0.17 \pm 0.01 \mu\text{m}$.

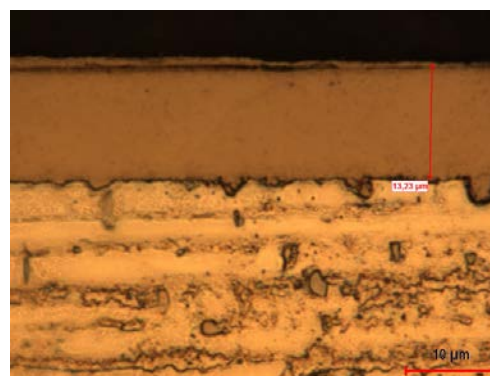


Fig. 1 Cross-section micrograph of Ni-P coating.

The microhardness value of the Ni-P coating is 204 HV_{0.01}, while the microhardness of the uncoated sample is about 35 HV_{0.01}. Thus, the electroless Ni-P coating caused to about a 5.8 fold increase in the hardness.

The results of wear tests for uncoated and coated samples are given in Table 1. It is seen that the Ni-P coating has lower friction coefficient and lower wear rate than those of uncoated sample. Comparing with uncoated sample, the Ni-P coating possesses both better friction-reducing ability and better wear resistance. By taking into account the wear rates, it is quantified that wear resistance of the Ni-P coating is ~11 times higher than that of the uncoated sample.

Table 1: Friction coefficients and wear rates of uncoated and coated samples.

Sample	Friction coefficient	Wear rate $\times 10^{-4}$ ($\text{m}^3 \cdot \text{N}^{-1} \cdot \text{m}^{-1}$)
Uncoated Sample	0.5–0.75	111.5
Ni-P coating	0.44	9.89

The images of the wear tracks on the uncoated and coated samples along with the friction curves presented in Fig. 2 confirm the above findings. The images show the intensification of damage and roughness in the wear track, which is considerably lower for the Ni-P coating than for the uncoated sample (Fig. 2 a, b). Friction coefficients for the uncoated and coated samples used in the above experiments are shown in Fig. 2 c. The friction coefficient obtained for the Ni-P coating stabilizes after 30 number of cycle and shows a steady value of 0.44, whereas the friction coefficient for the uncoated sample shows a variable regime and a higher value (0.5–0.75).

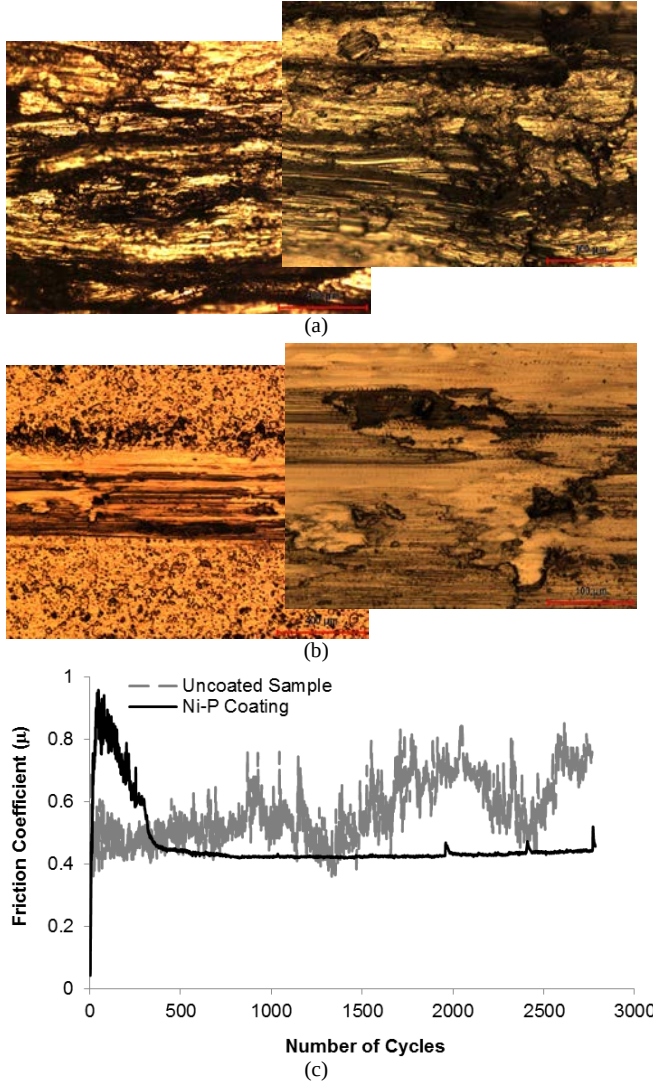


Fig. 2 Low and high magnification OM micrographs of wear tracks generated on the (a) uncoated, (b) coated samples and (c) friction coefficient curves recorded during wear tests.

The Ni-P coating shows great positive shift in corrosion potential and evident decrease in corrosion current density in comparison with the uncoated sample (Fig. 3). The corrosion potential E_{corr} of the Ni-P coating is -767 mV and the corrosion current density i_{corr} is $23.5 \times 10^{-6} \text{ A/cm}^2$. Meanwhile, the corrosion potential E_{corr} and corrosion current density i_{corr} of the uncoated sample are about -1050 mV and $47.9 \times 10^{-6} \text{ A/cm}^2$, respectively. Besides, an improved anticorrosion efficiency (IE) of the Ni-P coating than the uncoated sample could be calculated by Eq 1 [9]:

$$\text{IE (\%)} = 100 \times (I_B - I_A) / I_B; \quad (\text{Eq 1})$$

where I_A and I_B are I_{corr} of the Ni-P coating and uncoated sample, respectively. According to Eq 1, an enhanced anticorrosion efficiency (IE %) of the Ni-P coating is 50.9 % compared with the uncoated sample. The high corrosion resistance of the Ni-P coating is because of its amorphous characteristics; the absence of the defects in crystalline alloys such as grain boundaries, dislocations, stacking faults and other surface defects [10].

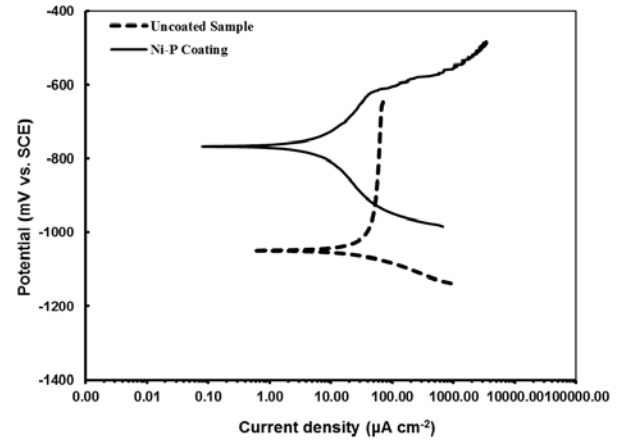


Fig. 3 Polarization curves of the uncoated and coated samples.

Figure 4 shows the OM images of the uncoated and coated samples after the corrosion tests. As shown in figure, the main failure mechanism for the uncoated sample was the pitting corrosion (Fig. 4 a). Many pits were seen on the uncoated sample, but the pits on the Ni-P coating did not formed (Fig 4 b).

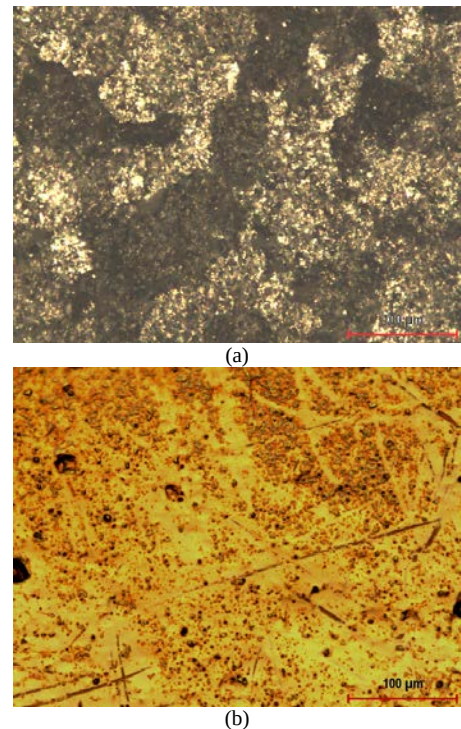


Fig. 4 Corrosion surfaces of the (a) uncoated and (b) coated samples.

4. Conclusion

The behavior of the substrate coated with electroless Ni-P was compared to that of the uncoated AA7075 aluminum alloy. Analyzing the properties of the uncoated and coated samples applied to the tests, one can conclude that:

1. Ni-P coating on AA7075 alloy is prepared by electroless deposition. The cross-section view of the Ni-P coating reveals that the coating is uniform, crack free and adherent metallic coating.
2. The hardness, wear and corrosion resistances of the Ni-P coating generated by electroless deposition are remarkably higher than those of the uncoated sample.

Acknowledgements

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THE SYNTHESIS AND CHARECTERIZATION OF GRAPHENE OXIDE (GO) AND REDUCED GRAPHENE OXIDE (RGO)

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Abstract: In this study, graphene oxide (GO) was synthesized from graphite by using the Hummer method. GO was reduced using hydrazine hydrate to achieve reduced graphene oxide (RGO). GO and RGO powders synthesized by these methods can be used as fillers in the production of polymer matrix composite. These synthesized powders was examined in detail using the Zeta Potential (ZP) measurements, Ultraviolet Visible Spectrophotometer (UV-VIS), X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) equipped with Energy Dispersive Spectroscopy (EDS) analyzer and Thermogravimetric-Differential Thermal Analysis (TG-DTA). All analysis results confirmed the GO and RGO considered as fillers in the production of polymer matrix composite can be prepared successfully.

Keywords: FILLERS, GRAPHENE OXIDE, REDUCED GRAPHENE OXIDE.

1. Introduction

Graphene, a single layer of carbon atoms densely packed in a honeycomb crystal lattice, is considered as promising versatile filler, due to its specific and unique structural, mechanical, and electronic properties [1-3]. However, graphene is hydrophobic and tends to agglomerate irreversibly [4], thus it does not disperse well in polymers and has a tendency to form phase separated composites [5]. To overcome these shortcomings, Graphene Oxide (GO) is prepared from oxidation of Graphite (GF) powder by Hummers method and Reduced Graphene Oxide (RGO) is synthesized from the reduction process of GO. GO is hydrophilic and contains epoxides, alcohols, lactols, ketones, and carboxyl groups, which can significantly affect the van der Waals interactions between the graphene layers (Fig.1) [6]. Easy synthesis and solution processability of GO as an inexpensive filler material encourage the production of polymer composites [7]. Also, the RGO sheets are usually considered as one kind of chemically derived graphene, just like GO [8, 9]. Stankovich et. al (2007) have examined the chemical reduction of exfoliated graphene oxide sheets with several reducing agents and found hydrazine hydrate ($\text{H}_2\text{NNH}_2 \cdot \text{H}_2\text{O}$) to be the best one in producing very thin graphene-like sheets [10]. The RGO became less hydrophilic due to the removal of oxygen atoms and thus precipitated. Hydrazine takes part in ring-opening reaction with epoxides and forms alcohols (Fig.1) [11].

In this study, GO and RGO powders were synthesized and the obtained powders were studied by ZP, UV-VIS, XRD, SEM, and TG-DTA analysis. The objective of this work is to synthesis graphene based fillers for polymer composites. Recently, attention has been renewed for producing graphene based materials because of its excellent thermal, mechanical, electrical and optical properties [12].

2. Experimental Details

GF powder, concentrated sulfuric acid (98%), potassium permanganate, 30 % H_2O_2 solution, hydrochloric acid and hydrazine hydrate were of reagent grade and purchased from Merck. All the reagents were used without further purification. All solutions were prepared using deionized (DI) water. GO was prepared from natural graphite (45 μm nominal particle size) by the Hummers method [13]. Graphite (1 g) was mixed with 69 mL of concentrated H_2SO_4 and the mixture was stirred in an ice bath for around 30 min. After homogeneous dispersion of the graphite powder in the solution, KMnO_4 (8 g) was added slowly to the solution in an ice bath and the reaction mixture was stirred for 15 min. under a reaction temperature of 20°C. Then the ice bath was removed and the mixture was stirred at 35°C overnight to form thickened paste. Afterward, 70 mL of DI water was added slowly into the reaction solutions to avoid the reaction temperature rising to a limit of 98 °C. After 2 h of vigorous stirring, 12 mL of 30 % H_2O_2 was added and the color turned golden yellow immediately. Finally, the mixture was then filtered and washed several times with 3 % HCl and DI water until pH 7 and dried at 65°C for 12 h to obtain

GO powder. The obtained GO has a plenty of oxygen-containing functional groups in its graphitic backbone: carboxyl (COOH) and carbonyl (C=O) groups at the sheet edges and epoxy (C-O-C) and hydroxyl (-OH) groups on the basal plane (Fig. 1) [14]. To prepare RGO, 0.1 g of GO was dispersed in 100 mL of DI water. Then 1 mL of hydrazine hydrate was added to the mixture and heated at 95°C for 12 h. After that, the mixture was filtered and the RGO was obtained as a black powder. Thus, the product obtained was washed with DI water several times.

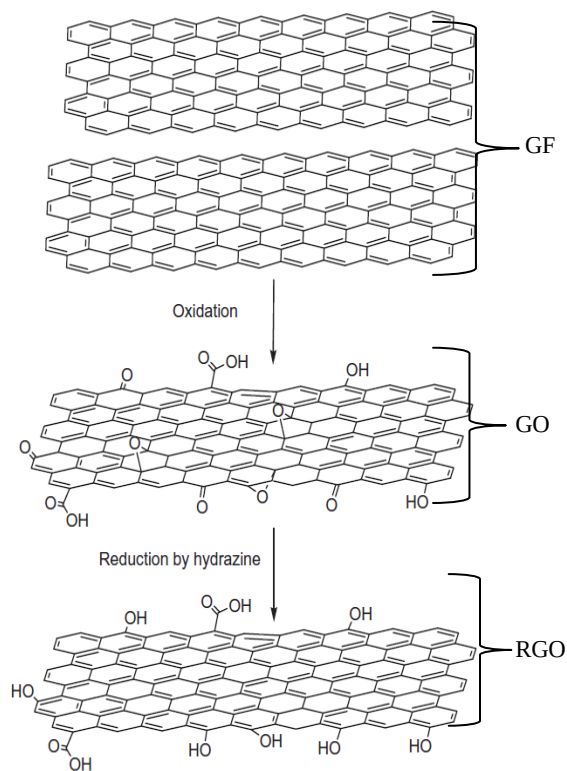


Fig. 1 Oxidation of GF to GO and RGO [11].

Zeta potentials of powders dispersed in water using ultrasonic bath were measured by Zetasizer- NANO-ZS (Malvern Instruments Ltd., UK). Electronic absorption spectra of the powders were recorded in water solvent in the wavelength range of 200–400 nm at room temperature by using Lambda 25 UV-VIS spectrometer (Perkin Elmer, USA). The analyses of the powders were carried out by X-Ray Diffraction (XRD, PAN analytical, Empyrean) in the range of 5–50°. The surface morphology was examined by a Scanning Electron Microscopy (SEM, Supra 40VP, Zeiss). EDS analyses were performed on the same instrument. TG-DTA analysis (LABSYS evo, Setaram) was performed by heating the samples from 25°C to 600°C at a rate of 20°C min^{-1} in a nitrogen atmosphere.

3. Results and Discussion

Zeta potential is an important indicator to determine the surface charge of the sheets and to characterize the stability of dispersions [15]. The zeta potential of GO and RGO dispersions was shown in Fig. 2 a, b.

Zeta potentials in Fig. 2 a, b were -41,3 and -3,81 mV for GO and RGO, respectively. The zeta potential of GO was high due to the presence of negatively charged OH and COOH groups [16]. The zeta potentials value of RGO was -3,81 mV due to a decrease in oxygen functional groups [17]. As shown in Fig. 2 b, the zeta potential distributions of RGO were more regular than GO's. High negative charge of GO and very low negative charge of RGO demonstrated excellent oxidation and reduction processes respectively.

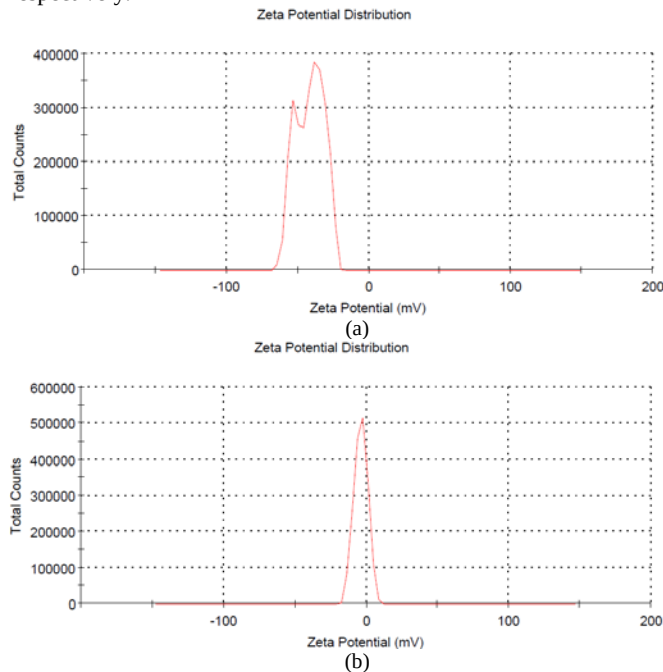


Fig. 2 Zeta potentials of (a) GO and (b) RGO.

The oxidation and reduction progress were monitored by UV-VIS spectroscopy. As shown in Fig. 3 a, GO showed a maximum absorption peak at 291 nm which could be attributed to the $n-\pi^*$ transitions of C=O bonds [18]. As shown in Fig. 3 b, the UV-VIS spectrum of the RGO dispersion possesses one absorption peak at 323 nm. The absorption peak of GO at 291 nm red shifted into wavelengths around 323 nm due to the reduction progress [17].

Figure 4 showed XRD patterns of the GF and prepared GO and RGO powders. In addition, 2θ values and d-spacing data of the same materials are given in Table 1. The crystalline GF had a sharp characteristic peak at $2\theta=26.4^\circ$. The corresponding interlayer distance was observed to be 0.33 nm. After oxidation, the diffraction peak shifted to $2\theta=9.95^\circ$ and the interlayer space increased to 0.88 nm (Table 1) [19]. The increase in the interlayer distance from 0.33 nm to 0.88 nm was due to oxygen-containing functional groups intercalated within the layered structure (Table 1) [16]. RGO exhibited a broader diffraction peak as shown in Fig. 4. This indicated that the GO is completely exfoliated to a single layer of graphene [16].

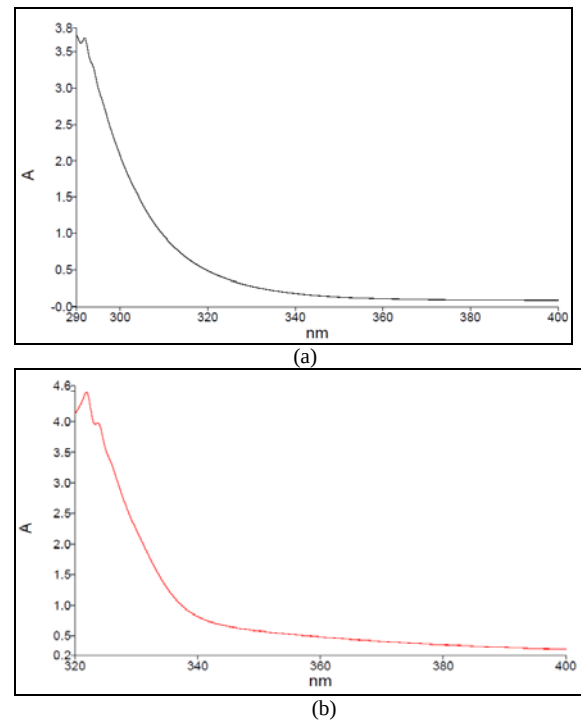


Fig. 3 UV-VIS spectra of (a) GO and (b) RGO.

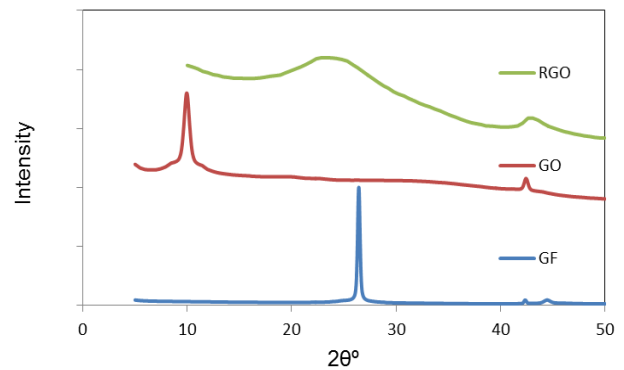


Fig.4 X-ray diffraction patterns of GF, GO and RGO powders.

Table 1: 2θ values and d spacing data obtained from XRD results

Samples	$2\theta^\circ$	d (nm)
GF	26,4	0,337
GO	9,95	0,888

The SEM images of the GF, GO and RGO powders are shown in Fig. 5. It could be seen clearly from the SEM image of Fig. 5 a that GF had a thin plate stacked structure [20]. GO presented a worm-like structure randomly aggregated [21] (Fig. 5 b). According to EDS results of the GF and GO, oxygen content increased from 22.59 % to 47.95 % (Table 2). As shown in Fig. 5c, the SEM image of the RGO showed that wrinkle-like structure due to the rapid removal of oxygen-containing functional groups in GO [2]. According to EDS result of RGO (Table 2), only 14.28 % oxygen content remained which illustrated successful reduction of GO.

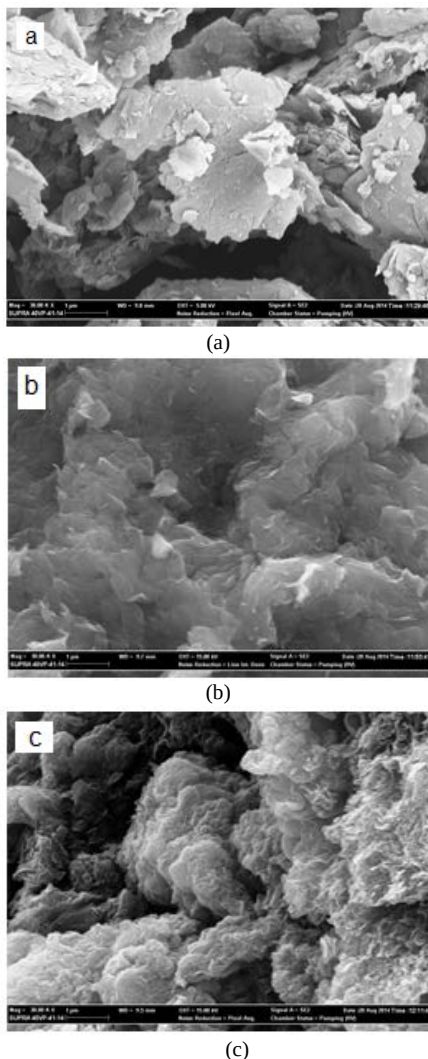


Fig.5 SEM images of (a) GF, (b) GO, (c) RGO (magnification 30.000 KX).

Table 2: EDS results of GF, GO and RGO.

Samples	Oxygen Content (atom %)
GF	22,59
GO	47,95
RGO	14,28

TGA and DTG graphs for the GO and RGO powders were given in Fig. 6 a, b and thermal parameters were summarized in Table 3. As shown in Fig. 6 a, GO showed two steps of decomposition. The first weight loss for the GO was observed in 78°C corresponding to the loss of water molecules. GO showed a major weight loss at the temperature range of 170–200°C which can be attributed to the removal of most of the oxygen-containing functional groups. The step at 558°C was related to pyrolysis of the remaining oxygen-containing groups as well as the burning of ring carbon (Fig.6 a and Table 3) [9 - 22]. GO exhibited about 13% residual weight at 600°C. This demonstrated its excellent thermal stability [2]. As shown in Fig. 6 b, RGO exhibited two steps degradation; the first step commencing at 51°C was due to the loss of water molecules. The second step degradation at 491°C involved the pyrolysis of the hydroxyl, epoxy functional groups, yielding CO, CO₂, and steam [10]. RGO exhibited only 56 % weight loss at 600°C, which was much lower than that of the GO (Table 3), indicating a significantly decreased amount of oxygenated functional groups [18].

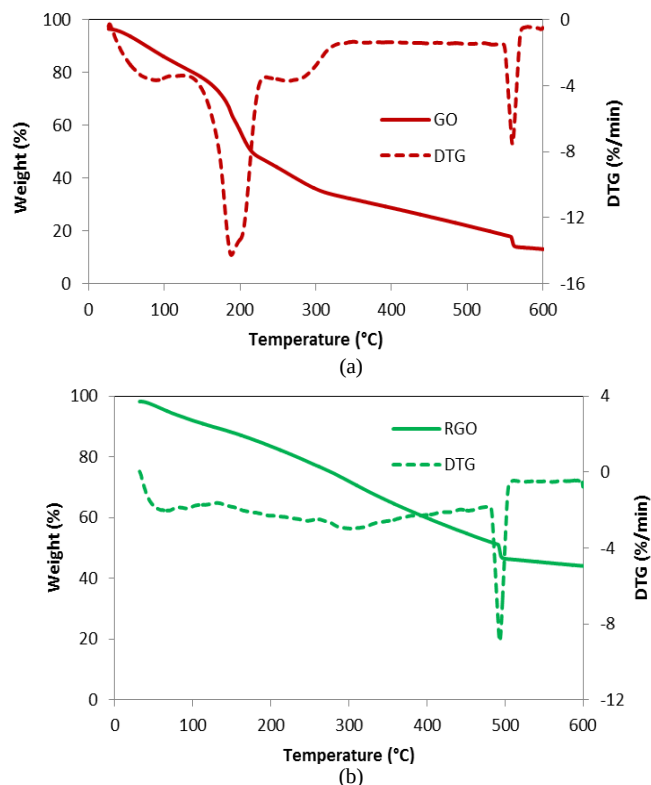


Fig.6 TGA and DTG curves of (a) GO and (b) RGO

Table 3: Thermal parameters for the GO and RGO powders. (20 °C/min heating rate, under nitrogen atmosphere).

Sample	T (°C) range			Weight loss at 600°C (%)	Residue at 600°C wt. (%)
	T ₁	T ₂	T ₃		
GO	78	185	558	87	13
RGO	51	-	491	56	44

4. Conclusion

In summary, GO powders were successfully produced by Hummer's method and chemical reduction of GO using hydrazine hydrate was characterized using various techniques. Analysis results indicated that GO could be prepared and reduced into RGO successfully. GO and RGO powders synthesized by these methods can be used as fillers in the production of polymer matrix composites.

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CALCULATIONS AND VERIFICATIONS OF SHREDDING CHAMBER OF TWO-SHAFT SHREDDER FOR CRUSHING OF CONCRETE, RUBBER, PLASTIC AND WOOD

ИЗЧИСЛЕНИЯ И ПРОВЕРКИ НА РАЗДРОБЯВАЩА КАМЕРА НА ДВУВАЛОВ ШРЕДЕР ЗА РАЗДРОБЯВАНЕ НА БЕТОН, ГУМА, ПЛАСТМАСА И ДЪРВО

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ABSTRACT. The article is devoted to the calculation and verification of the shredding chamber of a two-shaft shredder for crushing of concrete, rubber, plastic and wood. In this work a model study of the shredding chamber of such type of shredder has been done. The studies of the mechanical load and behavior of the shredding chamber have been conducted through solving the equations describing the mechanical processes under operating conditions by the finite element method. For this purpose, a three-dimensional geometric model of the bottom of the chamber has been generated, which is discretized to a planned network of finite elements in the programming environment of ANSYS MECHANICAL APDL.

Keywords: STRESSES, DEFORMATIONS, TWO-SHAFT SHREDDER.

1. Introduction

Shredders are machines, shredding the secondary and waste materials. This is a group of relatively new machines, which are classified mainly according to the number of working shafts (Abadzhiev, Tonkov, 2007) to: single-shaft, two-shaft and four-shaft.

Shredders are configured according to each unique application of theirs, with selection of different thicknesses and number of cutting teeth, shaft diameter, thickness of spacing collars, power of drive, productivity (Vatzkicheva, Grigorova, 2015).

According to the technology of shredding, there is a choice between single-shaft, two-shaft, three-shaft, four-shaft, five-shaft shredders, with varying degree of automation and control of the key parameters, different level of noise, different speed of rotation, supply, degree of pressurization, etc. (Borshtëv, 2004).

The advantage of the two-shaft shredders is their high productivity. The disadvantages are related to the high price and the high cost of maintenance of the machines.

The hydraulic two-shaft shredder consists of feeder-conveyor, (receiving) hopper, shredding chamber, output belt (strip), discharging belt, and belt for separation of metal particles (Vatzkicheva, Valkov, 2013).

In the present work a model study of the shredding chamber of such type of shredder has been done.

2. Object of Study

The shredding chamber consists of a receiving hopper and crushing shafts.

The receiving hopper is constructed of hot-rolled sheet steel with extra ribbing. The depth of the hopper is 1000 mm, and the width at the top - 2400 mm. The volume of the bunker is 3.0 m³. These dimensions are consistent with the sizes of recycled wastes and the possibility of their wedging (seizure) when placing in the hopper.

The crushing shafts are parallel, with length 900 mm, wheel-base 350 mm, and hexagonal cross-section. On the shafts there are mounted the crushing discs. Between the discs, to the chamber body, there are mounted counter-knives for cleaning the space between the separate discs.

The construction of the chamber is verified for general strength, by applying the loads from the weight of the shafts, the chamber elements, the input hopper, as well as the support reactions at the bearings of the shafts (Tavakoli, Mohtasebi and Jafari, 2008). The studies have been conducted through the mathematical models and numerical procedures described below.

3. Concept for model study.

The studies of the mechanical load and the behavior of the shredding chamber have been conducted through solving the equations describing the mechanical processes under operating conditions by the finite elements method. For this purpose, a three-dimensional geometric model of the bottom of the chamber has been generated, which is discretized to a planned network of finite elements in the programming environment of ANSYS MECHANICAL APDL (Braess, 2007).

The boundary conditions, reflecting the mechanical load during operation of the steel structure, include the following parameters:

- input power: $P_{vh} = 90 \text{ kW}$;
- revolutions of the working shaft: $n_v = 25 \text{ min}^{-1}$;
- frequency of rotation of the working shaft: $\omega_v = (\pi \cdot n_v) / 30 = 2,62 \text{ rad / s}$;
- torque of the working shaft: $M_v = P_{vh} / (\omega_v \cdot \eta) = 35 \text{ kN.m}$, where $\eta = 0,98$ is efficiency factor of the transmission ;
- failure stress of concrete: $\tau_s = 60 \text{ MPa}$;
- shear force by one knife: $F_s = M_v / (3,0,175) = 66,7 \text{ kN}$;
- resisting moment of shredding by 1 knife: $M_{s1} = F_s \cdot l_s = 11,67 \text{ kN.m}$.

The mechanical load during operation of the structure is presented in Figure 1 (FAG Spherical roller bearings E1, 2011).

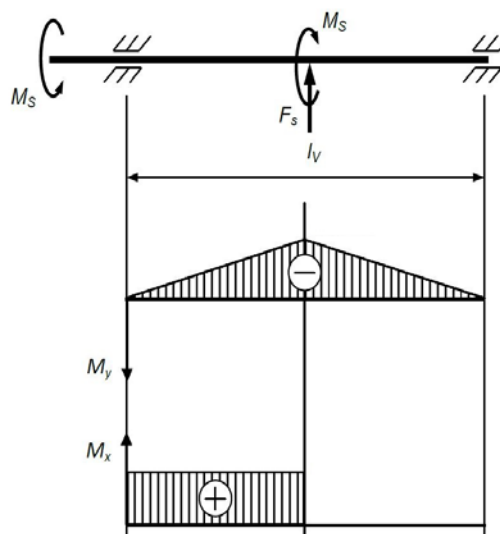


Fig.1. load

The system of equations is solved with parameters of the steel presented in Table 1.

4. Numerical results

Table 1 summarizes the results of the verification of the strength of the chamber with the accepted mechanical properties of steel :

Table 1: Results of the verification

Name	Steel	
General	Mass Density	7,85 g/cm ³
	Yield Strength	207 MPa
	Ultimate Tensile Strength	345 MPa
Stress	Young's Modulus	210 GPa
	Poisson's Ratio	0,3 ul
	Shear Modulus	80,7692 GPa
Stress Thermal	Expansion Coefficient	0,000012 ul/c
	Thermal Conductivity	56 W/(m K)
	Specific Heat	460 J/(kg c)

The figures below present a visualization of basic parameters characterizing the state of stress of the steel structure.

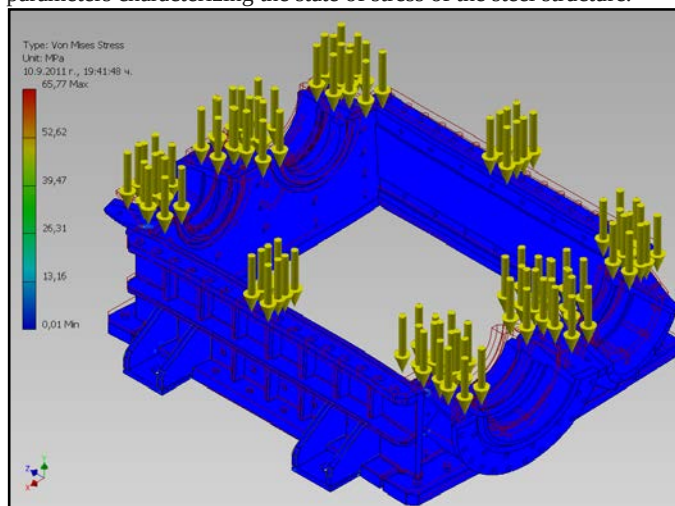


Fig.2 . Summarized stresses

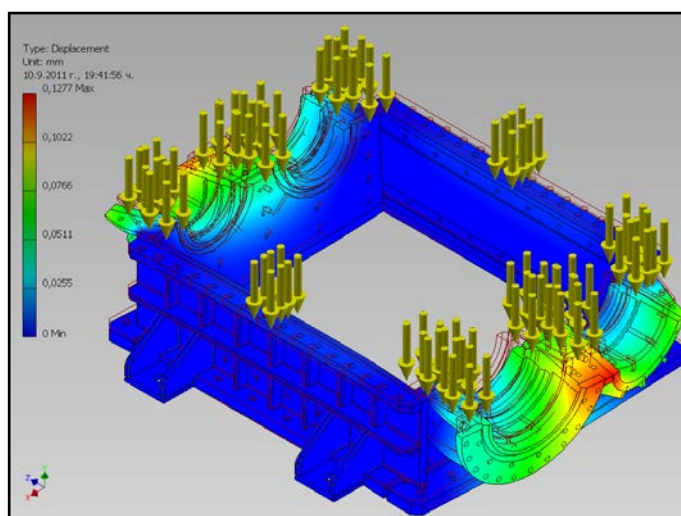


Fig.3 . Deformations

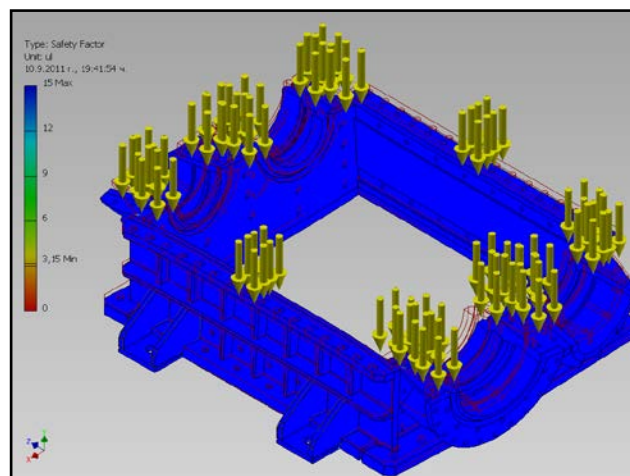


Fig. 4 . Safety factor

Table 2 summarizes the maximum and minimum stresses and deformations.

Table 2: Maximum and minimum stresses and deformations.

Name	Minimum	Maximum
Volume	39292300 mm ³	
Mass	308,444 kg	
Von Mises Stress	0,00548071 MPa	65,7722 MPa
1st Principal Stress	-15,6595 MPa	28,8686 MPa
3rd Principal Stress	-83,2857 MPa	4,36874 MPa
Displacement	0 mm	0,127705 mm
Safety Factor	3,14722	15

The conducted study shows that the maximum stresses for the examined structure do not exceed the admissible values for the material of the chamber.

5. Conclusions

The conducted model studies show that the examined structure of the shredding chamber can be used for shredding machines of type shredders .

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ANALYSIS OF COMPLEX PLANETARY CHANGE-GEARS THROUGH THE TORQUE METHOD

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Abstract: An alternative method for kinematic and power analysis of compound gear train is presented, which uses the torques and lever analogy of a given gear train. The method combines the accuracy of the Willis analytical method with the clarity of the graphic method of Kutzbach. Unlike these methods, the torque method allows determining not only the gear ratio, but the magnitude and direction of power flows, and hence the determination of efficiency of a given compound planetary gear train. The application of the method is illustrated with example of complex change-gear (gear-box).

Keywords: KINEMATIC ANALYSIS, POWER ANALYSIS, RATIO, EFFICIENCY, PLANETARY GEAR TRAINS, CHANGE-GEARS

1. Introduction

There are various methods for analysis of planetary gear trains (PGT) at all. Two, however, are most commonly used. One is the analytical method of Willis, the other is a graphical method of Kutzbach. Both methods have proved their worth over many years. The method of Willis (1841) [19] is used for almost two centuries and the method of Kutzbach (1927) [12] is there nearly a century.

The main advantage of analytical method is the accuracy. Moreover it is universal. However, it lacks any clarity, the volume of calculations, especially for the complex compound PGTs, is not small, which allows and there is no simple way to check the results, but the most careful repeating of the calculations.

Undoubtedly the main advantage of the graphical method is the clarity. However, it is lost for complex compound planetary gear trains because of the tangle of lines obtained. Frankly in graphical methods we cannot speak for high accuracy.

The importance of accurate analysis of all gear trains is determined by the fact that errors in defining the correct transmit ratio or in the direction of rotation of the output shaft of the train in some cases may be fatal.

The two main methods at use have advantages and disadvantages. This determined the need of proposed another method – **torque method** – more suitable for the practice that combine their advantages and avoid the disadvantages [1, 3, 4, 5, 6, 7, 8, 9, 10]. The following properties are desired:

- accuracy;
- simplicity;
- maximum clarity;
- easy usability (relevance);
- easy check of the results;
- generally the opportunity to achieve more goals than with previous methods, namely - not only determining the gear ratio, but the presence or absence of internal division or circulation of power, determining the efficiency and, in particular in gearboxes, determining the load spectrum of the elements of gear train (wheels, shafts, bearings), as a prerequisite for their reliable load capacity calculation;

The aim of this paper is illustrate the advantages of torque method in analysis of complex planetary change-gears (gear-boxes).

2. Essence of the Torque Method

Unlike the methods of Willis and Kutzbach using angular velocity ω (or rotational speed n) and the peripheral velocities v , at the presented here method the torques T are used. The method is based on the following well-known principles of mechanics, illustrated with the simplest case of elementary (single-carrier) gear train with three external shafts that has a very good lever analogy (Fig. 1):

a.) Equilibrium of ideal (with no account of losses) external torques acting on the three shafts

$$\sum T_i = T_{Dmin} + T_{Dmax} + T_{\Sigma} = 0 \quad (1)$$

where

T_{Dmin} and T_{Dmax} are the unidirectional external ideal torques (with different sizes), therefore are indicated by single lines on the figure, but with different thickness, according to their size;

T_{Σ} is the largest torque, in absolute value equal to the sum of other two torques T_{Dmin} and T_{Dmax} , and therefore is marked with a double line.

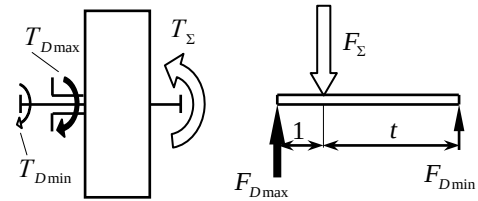


Fig. 1 Planetary gear train with three external shafts, their torques and the lever analogy

b.) Equilibrium of the real (considering the losses) external torques

$$\sum T'_i = T'_{Dmin} + T'_{Dmax} + T'_{\Sigma} = 0 \quad (2)$$

where

T'_{Dmin} , T'_{Dmax} and T'_{Σ} are the same external torques as above, but real now considering the losses in the gear train.

c) Sum of ideal (not considering the losses) powers

For the simpler case, when the gear train is with one fixed shaft, i.e. working with $F = 1$ degree of freedom, the condition is

$$\sum P_i = P_A + P_B = T_A \cdot \omega_A + T_B \cdot \omega_B = 0 \quad (3)$$

where

P_A , T_A and ω_A are the input power, torque and angular velocity;

P_B , T_B and ω_B - the output power, torque and angular velocity;

The above condition is used to determine the speed ratio

$$i = \frac{\omega_A}{\omega_B} = -\frac{T_B}{T_A} \quad (4)$$

d) Sum of real (considering the losses) powers

$$\sum P'_i = \eta \cdot P'_A + P'_B = \eta \cdot T'_A \cdot \omega_A + T'_B \cdot \omega_B = 0 \quad (5)$$

where

P'_A , T'_A and ω_A are the input power, torque and angular velocity;

P'_B , T'_B and ω_B - the output power, torque and angular velocity;

From this follows the formula for the efficiency

$$\eta = -\frac{T'_B/T'_A}{\omega_A/\omega_B} = -\frac{i_T}{i_k} \quad (6)$$

In this formula i_T means the ratio of the real external torques T'_B and T'_A at the input A and output B of gear train, as signified more as dynamic [11], as a power ratio or torque transformation [14, 18]. The other ratio i_k is the usual speed ratio and unlike the above, if necessary, the index k - from the "kinematic" can be used.

To determine the real external torques T'_i it is necessary that the directions of relative (rolling) powers $P_{rel i}$ are identified in each gear train according to the respective carrier, and each gear train has its own internal efficiency [11, 14, 18].

In most cases the direction of relative (rolling) power P_{rel} in one planetary gear train (from the sun gear 1 to the ring gear 3 and vice versa) can be determined, proceeding from the direction of the torque on the sun gear and its relative angular velocity toward the carrier $\omega_{1rel} = \omega_1 - \omega_H$, by the following simple criteria:

- when the directions of the torque T_1 and the relative angular velocity ω_{1rel} coincide i.e. $\omega_{1rel} \cdot T_1 > 0$ - the relative power is transmitted from the sun gear 1 through the planets 2 to the ring gear 3, or in other words, the sun gear appears to be the driving one in the relative motion;
- when $\omega_{1rel} \cdot T_1 < 0$ - the relative power is passed from the ring gear 3 to the sun gear 1;

In relatively rare cases this situation is not that clear. Then it is appropriate for determining the direction of the relative power to use the method of the samples [17].

Along with the foregoing known principles of mechanics, the following two small but very useful innovations are made:

e) For the greatest possible illustration of the method the known symbol of the Wolf [20] (Fig. 2) is used, but modified [1, 3, 4, 5, 6, 7, 8, 9, 10]. The each elementary (single-carrier) gear train, which has three external shafts is depicted with a circle, from which the three shafts are coming out, marked differently from the original - i.e. not with numbers, letters or inscriptions, but by the thickness of the lines corresponding to the size of the external torque, as already mentioned above. This little innovation concerning the manner of marking the shafts makes the method very clear and useful.

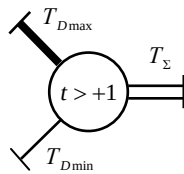


Fig. 2 Modified symbol of Wolf with three external shafts and their torques

f) Besides using the modified symbol of Wolf, where appropriate another innovation is made. A new torque ratio is defined - the one of the unidirectional external torques [1, 3, 8]

$$t = \frac{T_{Dmax}}{T_{Dmin}} > +1 \quad (7)$$

because $T_{Dmax} > T_{Dmin}$ (fig. 1).

This innovation is especially important. It is connected to the lever analogy.

g) Ideal external torques are always in a certain ratio, expressed with the torque ratio t

$$T_{Dmin} : T_{Dmax} : T_{\Sigma} = T_1 : +t \cdot T_1 : -(1+t)T_1 = 1 : +t : -(1+t) \quad (8)$$

in which always

$$T_{Dmin} < T_{Dmax} < |T_{\Sigma}| \quad (9)$$

however:

- How many degrees of freedom F (F = 1 or F = 2) the gear train is running with;
- Which shaft is fixed at F = 1 degree of freedom;

- What is the direction of power flow, respectively does the gear train works as a reducer or a multiplier at F = 1 degree of freedom, respectively such as a collecting or as a separating gear at F = 2 degrees of freedom, i.e. as a differential;
- Does the gear works as a single or as a component train along with others in a compound planetary gear train.

3. Application of the Torque Method

The application of the torque method is best illustrated in [6, 7]. Main points as determination of relative power direction in component planetary gear trains, circulation or division of power, etc. are presented and explained.

Coefficient of efficiency of the PGTs is in direct proportion of the coefficient of internal losses ψ_0 and the basic (internal) coefficient of efficiency η_0 . This is the coefficient of efficiency of the PGT at immovable carrier H ($\omega_H = 0$), i.e. gear as normal, nonplanetary. When losses in the meshing prevail, the basic coefficient of efficiency η_0 is calculated starting from the coefficients of overlapping ε_a of the two meshings - external and internal, and the coefficient of friction μ_z of the meshing [30, 34, 35, 36 and 37]. There is also a simplified formula for determining the basic (internal) coefficient of efficiency [14 and 32]

$$\eta_0 = 1 - \psi_0 \approx 1 - 0,15 \left(\frac{1}{z_1} + \frac{1}{z_3} \right) + 0,2 \left(\frac{1}{z_2} - \frac{1}{z_3} \right). \quad (10)$$

For the coefficient of efficiency determination of the PGT according to the torque method the real external torques (considering losses) must be determined, for which you need to know the direction of power transmission with respect to the carrier H, i. e. the relative power P_{rel} . There are two options - it is transmitted from the sun gear 1 through the planets 2 of the ring gear 3 or vice versa. Using basic (internal) coefficient of efficiency η_0 for these two cases, the following relations are obtained for the real external torques

$T'_3 = \eta_0 \cdot t \cdot T'_1$ - when the relative power is transmitted from 1 to 3;

$T'_1 = \eta_0 \frac{T'_3}{t}$ - when the relative power is transmitted from 3 to 1.

The very direction of the relative power P_{rel} transmission is defined by the following criteria - a match or mismatch of the direction of the torque T_1 of the sun gear 1 with the direction of the relative angular velocity $\omega_{1rel} = \omega_1 - \omega_H$ with respect to the carrier H.

Problems of the power circulation are explained in [2].

4. Analysis of the Four Stage Planetary Change-Gear Train through the Torque Method

Figure 3 presents a four-carrier planetary change-gear train (kinematic scheme).

Ideal torques, real torques, check their values by formulae (3) and (5), speed and torque ratios and efficiency for all ways of operating are determined (Figs. 4, 5, 6 and 7). The basic efficiency of all stages are chosen equal each other $\eta_{0I} = \eta_{0II} = \eta_{0III} = \eta_{0IV} = 0,97$.

Figure 8 shows how to determine the load spectrum of an element of the change-gear while working with different gear-ratio steps (speeds).

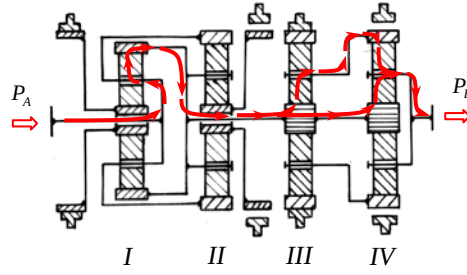


Fig. 3. A four-carrier planetary change-gear with four gear-ratio steps (speeds)

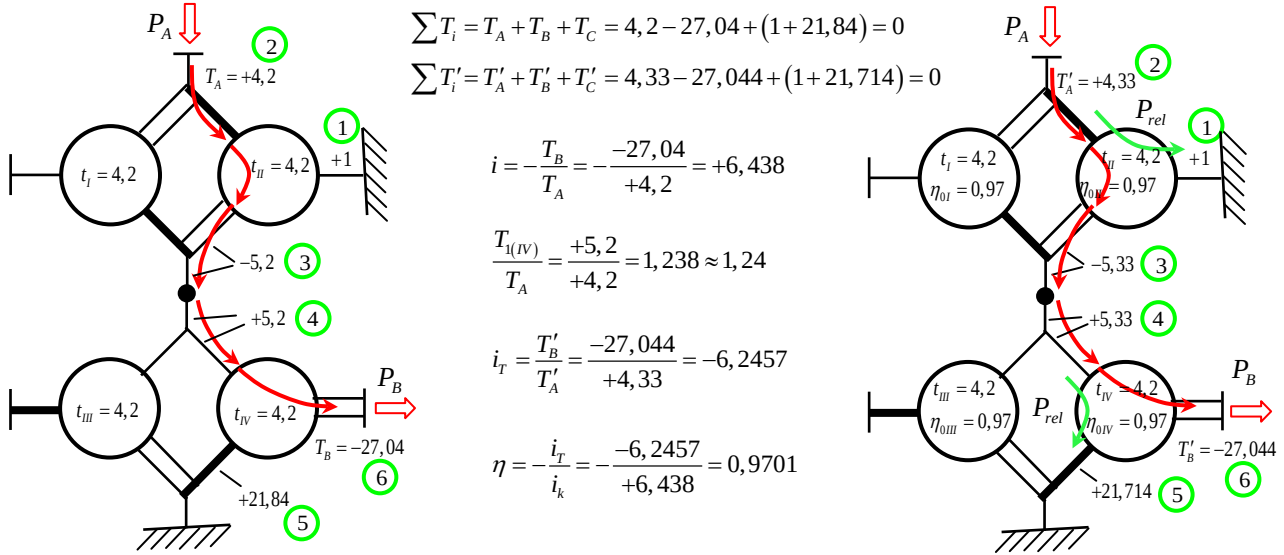


Fig. 4. Ideal and real torques, speed and torque ratios and efficiency of "first speed" of the planetary change-gear from Fig.3

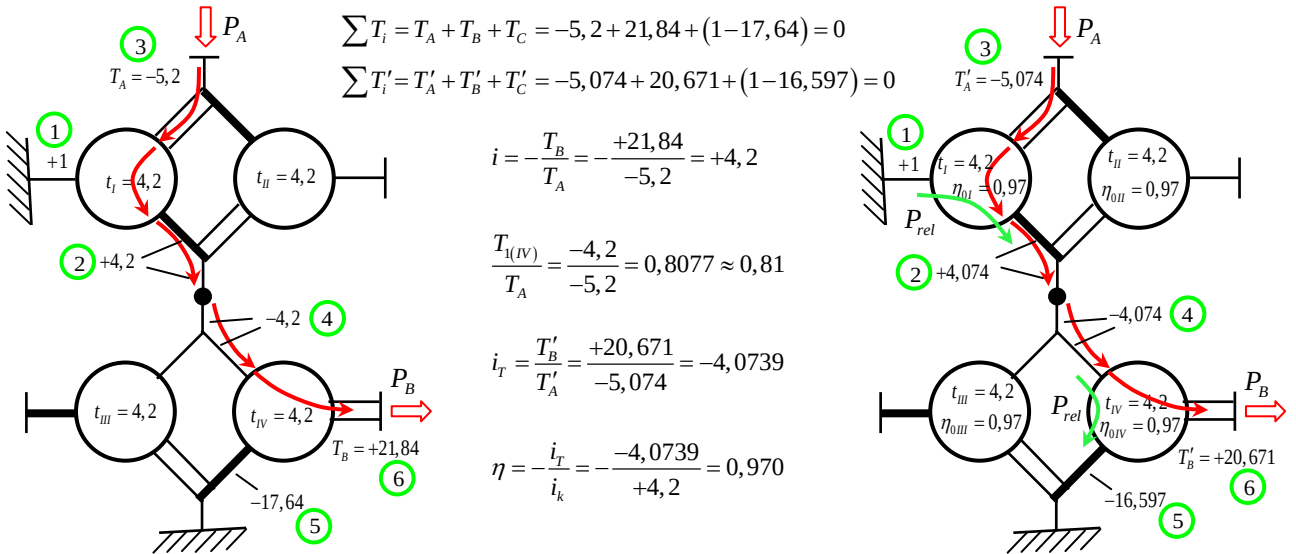


Fig. 5. Ideal and real torques, speed and torque ratios and efficiency of "second speed" of the planetary change-gear from Fig.3

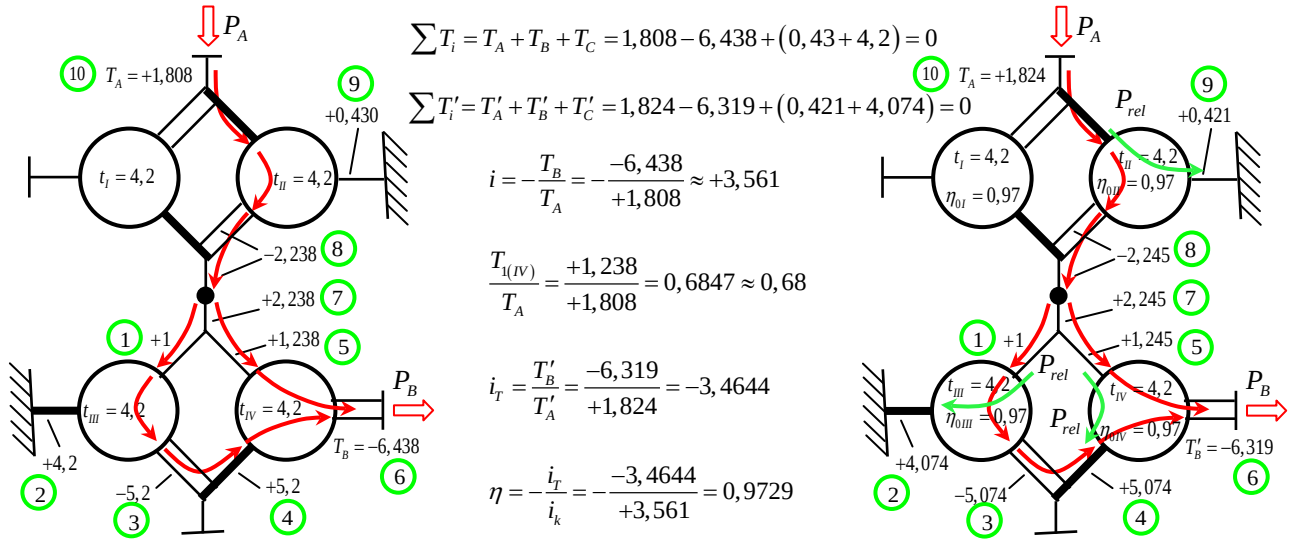


Fig. 6. Ideal and real torques, speed and torque ratios and efficiency of “third speed” of the planetary change-gear from Fig.3

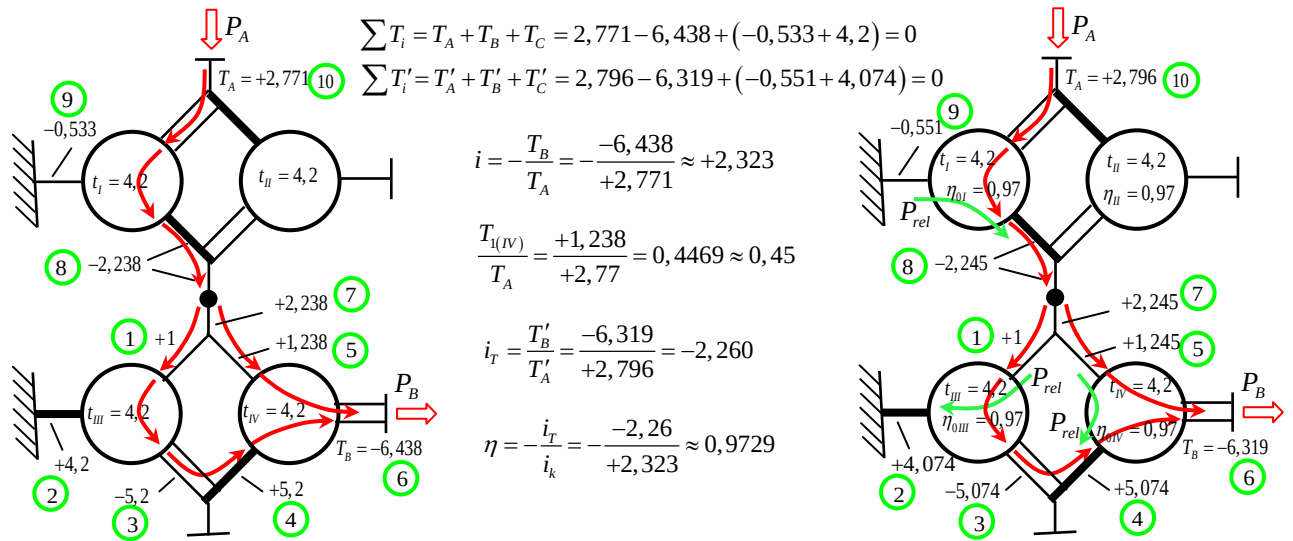


Fig. 7. Ideal and real torques, speed and torque ratios and efficiency of “fourth speed” of the planetary change-gear from Fig.3

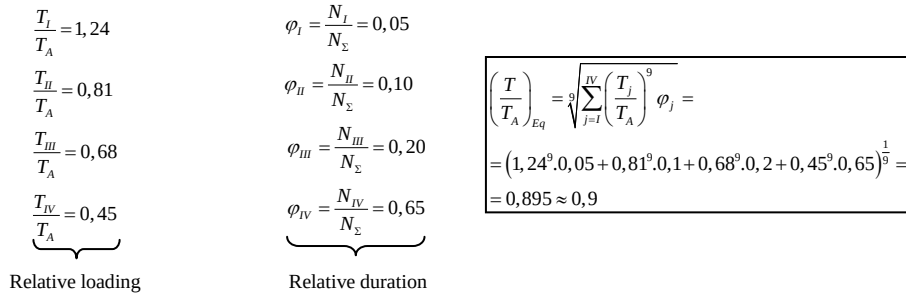


Fig. 8. Determination of load spectrum of an element (sun gear of the fourth stage) of four-carrier change-gear while working with different gear-ratio steps (speeds)

When the change-gear from Fig. 3 works at “first speed” (Fig. 4) power pass through II and IV stage which operated with $F = 1$ degrees of freedom as in series connected planetary gear train. At “second speed” (Fig. 5) power pass through I and IV stage which operated with $F = 1$ degrees of freedom as in series connected planetary gear train too. In the other two cases (Figs. 6 and 7) the IV stage works with $F = 2$ degrees of freedom and power pass through the loop (III and IV stage) with division.

All four simple planetary gear trains operate with movable carrier and their relative powers are less than relevant absolute powers. Because this the efficiency of change-gear η is practically equal (a little bit bigger) to basic efficiency η_0 of the connected simple planetary gear trains.

5. Conclusion

Unlike the most commonly used methods of Willis and Kutzbach-Smirnov that use the angular and peripheral velocities, at the presented torque method here another parameter of mechanics is used – the torque. This alternative method is characterized with the following:

1. The method is characterized by simplicity, maximum clarity and ease of usability (relevance), combining in itself, accuracy and clarity, existing separately in the Willis and Kutzbach-Smirnov's methods.
2. The method allows achieving more goals than is possible with the methods of Willis and Kutzbach-Smirnov - determining not only the speed ratio, but also the internal power flows by size and direction, as a prerequisite for the determination of the efficiency. Also the determining of the load spectra of elements of the compound change-gears – gear-wheels, shafts and bearings, while working with different gear-ratio steps (speeds) as a prerequisite for their reliable load capacity calculation.
3. The dependence of the designer on a particular literary source is avoided, so he may act independently.
4. The method allows easy verification of calculations by the conditions of equilibrium of the ideal and real external torques.
5. Because of the clarity and ease applicability, the method is suitable either for industry - for engineers, or for learning process - for students.

Considering all these possibilities and the current acceptance of the torque method in different countries (Giger 2007, Müller 1998, Troha 2011), there is reason to believe that the torque method can successfully compete with those of Willis and Kutzbach-Smirnov, especially in the analysis of complex compound planetary gear trains.

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COMBUSTION SYNTHESIS AS A FAST ROUTE TO PRODUCE NOVEL NANOMATERIALS

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Abstract: Combustion synthesis was applied as a novel approach to produce carbon-related nanostructures. Redox reactions in the systems Mg/Si/GO/SiF_x yielded interesting products like silicon carbide nanowires (SiCNWs) and graphene-related nanostructures.

Keywords: COMBUSTION SYNTHESIS, SILICON CARBIDE NANOWIRES, GRAPHENE-RELATED NANOSTRUCTURES

1. Introduction

There are two basic approaches to synthesize nanomaterials, characterized by novel and specific properties: top-down and bottom-up. In the latter one (following the Feynman's idea¹) molecules, atoms and ions combine together forming larger structures, specifically called nanomaterials if their size is smaller than 100 nm in one direction. There are many ways to atomize the matter but usually they involve high-energy activation. We propose here a Combustion Synthesis CS (also called Self-Propagating High-Temperature Synthesis, SHS) which is a relative simple (but still not widely explored) technique to produce novel nanomaterials on a bottom-up platform, this due to high temperatures and high pressure gradients resulting in quench conditions far from thermodynamic equilibrium²⁻⁴. As an example, we showed elsewhere⁵⁻⁸ that SiCNWs can be efficiently produced from the mixture of simple reactants Si/Teflon®. Here we aim at the formation of novel nanocarbons like graphene⁹⁻¹¹ and graphene/SiCNWs composites which due to low dimensionality have a unique variety of properties, which make them promising candidates for various applications.

2. Experimental

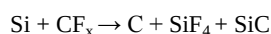
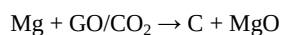
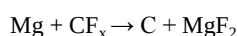
The experimental set-up and approach in CS is simple: the solid-phase reaction between a strong reducer and a strong oxidant results in a very short exothermic process leading to the formation of novel exotic compounds (via reactants intermediate atomization) this happens due to high temperature and pressure gradients, and fast quench. This usually very fast process (within seconds) is carried out in a high-pressure stainless-steel chambers (Fig. 1).



Fig. 1 Experimental set-up for combustion synthesis (stainless-steel reactors

of a volume 340 cm³, 550 cm³ and 2700 cm³).

Magnesium and silicon elemental were used as reducers while graphene/graphite oxide (GO) and fluorinated graphite (CF_x) were the oxidants. The following equations describe the chemical transformations in the systems under investigation



Before the combustion the reactants were loaded into the quartz crucible and placed in the reactor, which was then filled with the combustion gas (Ar, CO, CO₂...) and the combustion pressure was adjusted as pre-planned (between 1 and 50 atm). The reaction was started by resistive heating of the crucible content with the igniter (carbon, kanthal or tungsten tape). The combustion was usually terminated within a fraction of second. The solid products were collected to evaluate the progress of the combustion, the conversion degree and the composition/morphology using different techniques. Those include: XRD, SEM, TEM, EDX, Raman spectroscopy, elemental analyzes, and others.

3. Results and Discussion.

We present here the preliminary results of combustions regarding the following solid-phase reaction systems and starting reactants mixtures:

-Mg/CF_x

-Mg/GO

-Mg/CO₂

-Si/CF_x

-Si/GO

For such systems the following operational parameters were tested:

- different molar ratio of reactants
- different morphology of starting reactants
- different combustion atmospheres
- different starting pressures
- different mass of reactants

The highly exothermic reduction of carbon-bearing reactants with magnesium or silicon firstly results in atomization of all reactants. This is followed, on the quench stage, by the formation of solid magnesium oxide and/or SiCNWs while the remaining carbon vapors form also solid carbon. Surprisingly, this condensation leads towards the formation of graphite-like carbon. More interestingly, novel graphene- and carbon-related

nanostructures are also formed this happens due to fast condensation under thermal conditions close to graphitization. Such interesting preliminary results definitely call for more-in-depth research since graphene is currently considered as a wonder material of XXI century and new, efficient ways of its production are still extensively sought. To isolate the carbon phase, the raw products were leached with 3M HCl (removal of MgO and unreacted Mg) or with 30% KOH (removal of Si and SiO₂).

We present below XRD measurements (phase composition of products) of selected reactants and the results of SEM observations (morphology of products).

4.1. System Mg/CFx

Fig. 2 shows the results of XRD analysis of products from Mg/CFx combustion in Ar (5 atm), for raw and purified material.

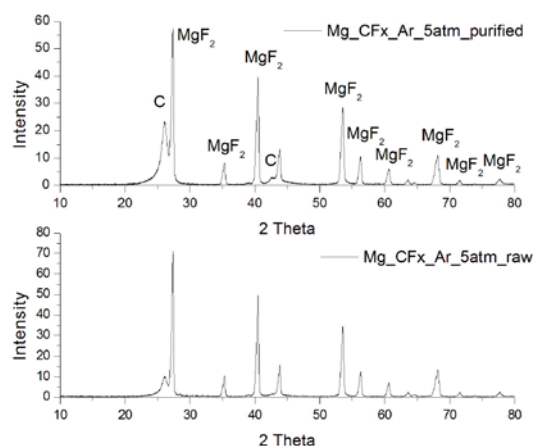


Fig. 2. XRD analysis of raw and purified product from Mg/CFx combustion

The phase composition shows that MgF₂ and carbon are the main components of products thus confirming the expected combustion. After the purification, the carbon peak is much more pronounced. Surprisingly, there is still some MgF₂ in final product thus pointing to its partial carbon encapsulation.

Fig. 3 presents the SEM image of the purified product. A petal-like layered microstructure of carbon resulting from de-fluorination and partial exfoliation of fluorinated graphite is evident.

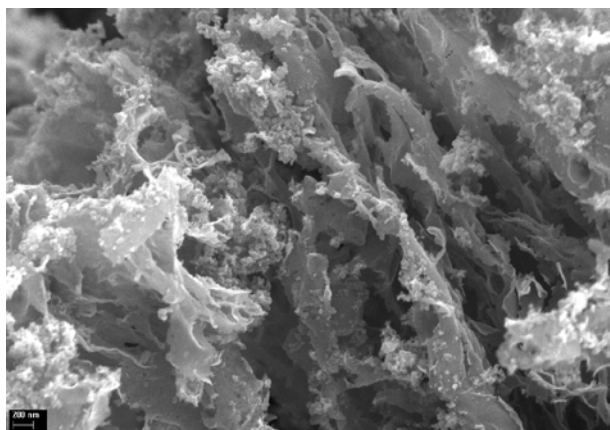


Fig. 3. SEM spectrum of purified product (Mg/CFx combustion in Ar, 5 atm)

3.2. System Mg/GO

Fig. 4 presents the XRD spectra of products from Mg/GO combustion in Ar (5 atm), for raw and purified material (graphene oxide GO of Chinese origin).

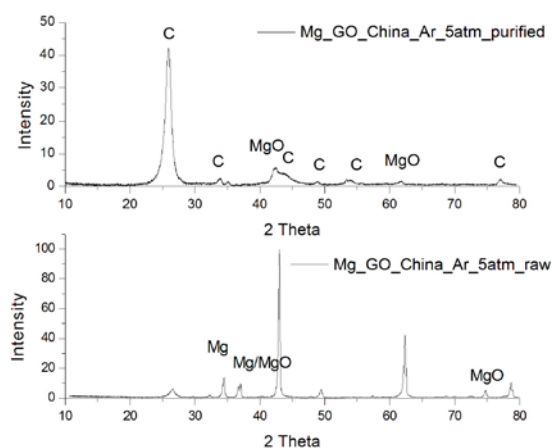


Fig. 4. XRD analysis of raw and purified product from Mg/GO combustion (GO of Chinese origin)

As before, those results confirm the combustion with MgO formed as the product of Mg oxidation and free carbon. The purification stage enriches the final product in carbon but there still exists some MgO, probably carbon-encapsulated. Much the same results were obtained in case of graphene oxide of Polish origin (Fig. 5)

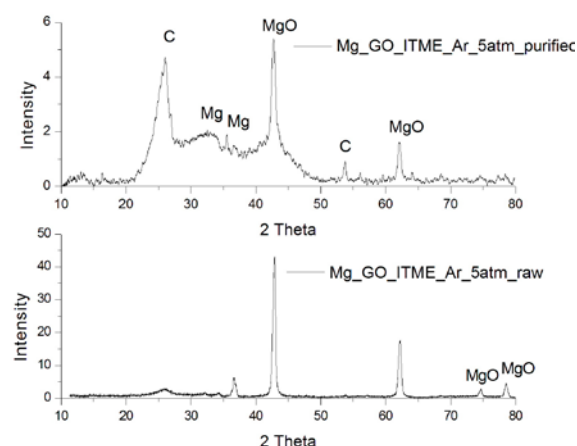


Fig. 5. XRD analysis of raw and purified product from Mg/GO combustion (GO of Polish origin)

Fig. 6 shows the morphology of purified product from Mg/GO (of Chinese origin) combustion.

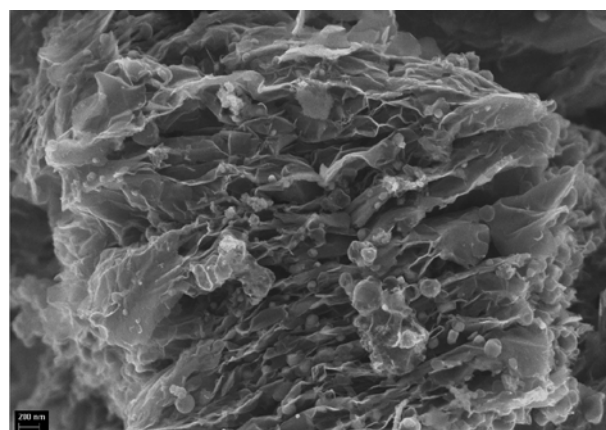


Fig. 6. SEM spectrum of purified product (Mg/GO combustion in Ar, 5 atm, GO of Chinese origin)

Again, the product has a layered microstructure. Some un-leached (this is probably due to carbon encapsulation) nanocrystallites of Mg or MgO can be also spotted in the image.

3.3. System Mg/CO₂

Fig. 7 shows the results of XRD analysis of products from Mg combustion in gaseous CO₂ (20 atm), for raw and purified material.

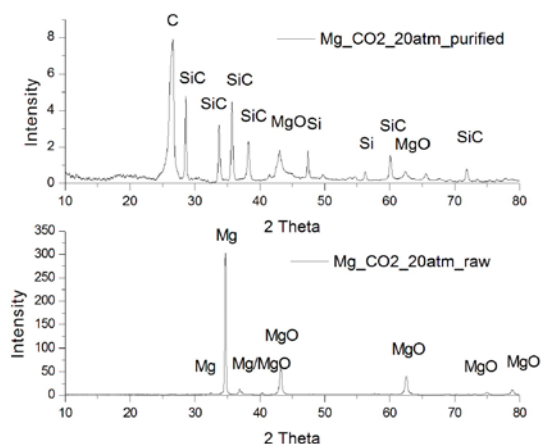


Fig. 7. XRD analysis of raw and purified product from Mg combustion in CO₂

Carbon oxide is efficiently reduced with magnesium. The purified product is almost pure, well graphitized carbon.

Fig. 8 shows the SEM images of purified combustion product (starting pressure of CO₂ 20 atm).

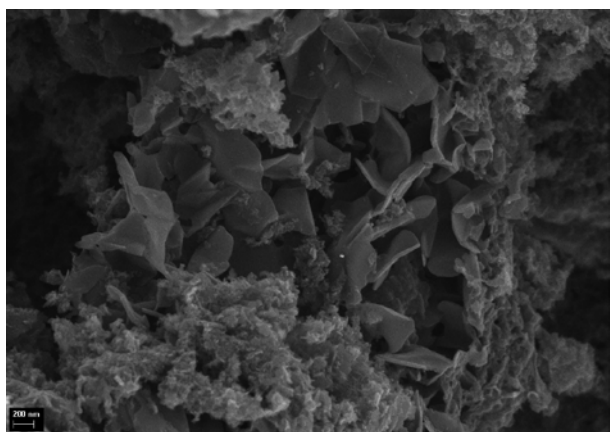


Fig. 8. SEM spectrum of purified product (Mg combustion in CO₂, 20 atm)

The product is composed of both nanocarbon (soot?) and well-crystallized layered microstructures. EDX measurements are under way to qualitatively identify those interesting components.

3.4. System Si/CFx

Fig. 9 presents the XRD spectra of products from Si/CFx combustion in Ar (5 atm), for raw and purified material.

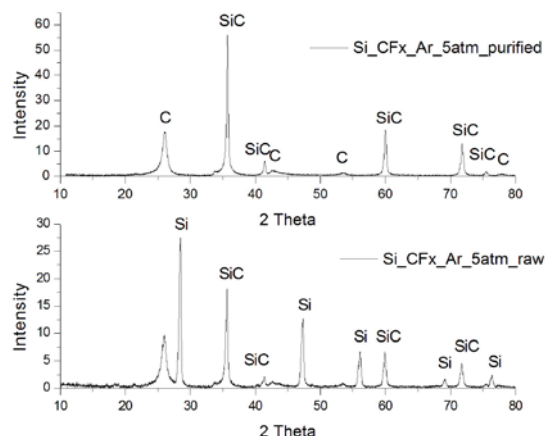


Fig. 9. XRD analysis of raw and purified product from Si/CFx combustion

Raw product contains carbon, unreacted Si and SiC while the purified product is highly enriched in carbon phase.

The morphology of the purified product is shown in Fig. 10.

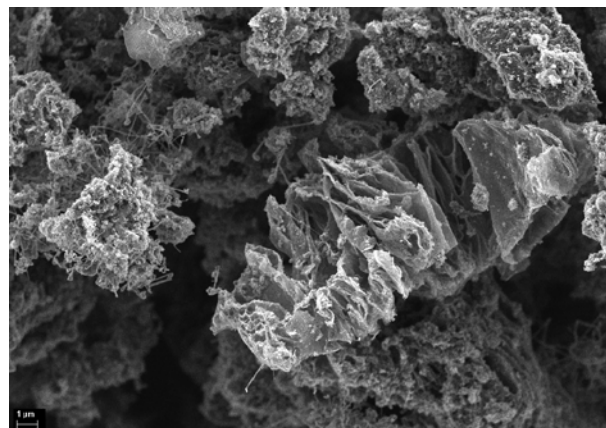


Fig. 10. SEM spectrum of purified product (Si/CFx combustion in Ar, 5 atm)

Both nanowires of SiC and exfoliated de-fluorinated starting oxidant (layered morphology) can be seen in the image. Si elemental evidently extracts fluorine and the exothermic effect of this reaction not only initiates exfoliation but also probably generates some free carbon which reacts with Si forming SiCNWs.

3.5. System Si/GO

Fig. 11 presents the XRD spectra of products from Si/GO combustion in Ar (5 atm), for raw and purified material (graphene oxide GO of Polish origin).

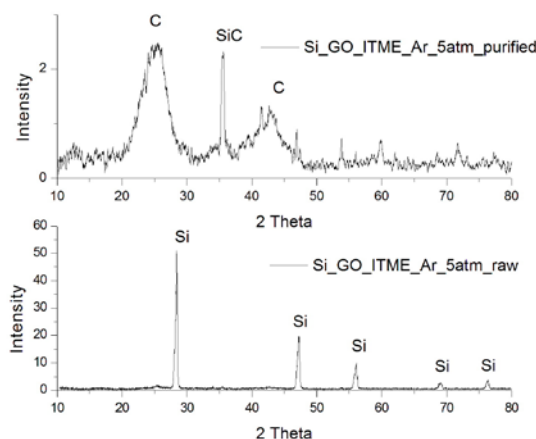


Fig. 11. XRD analysis of raw and purified product from Si/GO combustion (GO of Polish origin)

Si is much weaker reducer comparing to Mg but still can reduce graphene oxide. Surprisingly, not silica but SiC is a reduction product thus confirming such combustion is governed by kinetics (not by the thermodynamics).

The SEM image of the product is presented in Fig. 12.

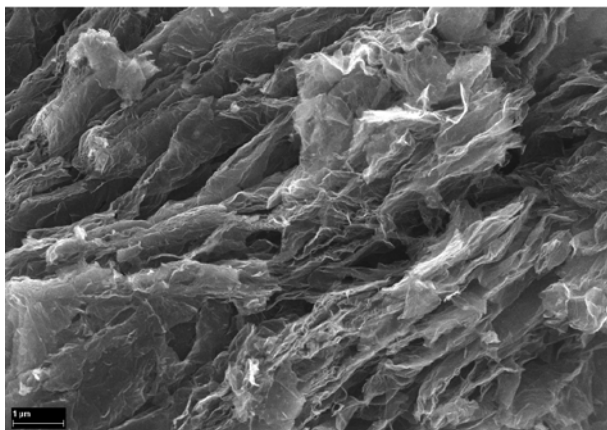


Fig. 12. SEM spectrum of purified product (Si/GO combustion in Ar, 5 atm)

Fine and layered microstructure of the product is clearly demonstrated confirming very efficient de-oxygenation/exfoliation of the starting graphene oxide. TEM observations (under way) should provide the more-in-depth profiles of the carbon of which the thickness of sheets is of crucial importance.

4. Summary

We show here that the combustion synthesis is a novel and fast route to efficiently produce interesting nanomaterials like silicon carbide nanowires and layered nanocarbons. Those preliminary results of research call, however, for a more-in-depth optimization of sought processes.

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IMPROVEMENT OF TECHNICAL AND OPERATIONAL CHARACTERISTICS OF DEVICES WITH OPTICAL ELEMENTS BY PRELIMINARY ELECTRON BEAM TREATMENT OF THEIR SURFACE

УЛУЧШЕНИЕ ТЕХНИКО-ЭКСПЛУАТАЦИОННЫХ ХАРАКТЕРИСТИК ПРИБОРОВ С ОПТИЧЕСКИМИ ЭЛЕМЕНТАМИ ПУТЕМ ПРЕДВАРИТЕЛЬНОЙ ЭЛЕКТРОННО-ЛУЧЕВОЙ ОБРАБОТКИ ИХ ПОВЕРХНОСТЕЙ

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Abstract: The results of experimental studies of the influence of electron beam parameters (density of heat action, the speed of movement) on the properties of the surface layers of the elements of optical ceramics (changes in the structure of the material through the thickness of the element, the amount of surface microhardness, values of residual thermal stresses in the layers, the thickness of the hardened layers, their stability to external thermal and mechanical stresses) are. The optimum range of parameters of the beam, within which there is improvement in the properties of the surface layers of the optical elements, which leads to the increase of the basic technical-operational characteristics of devices based on (reliability, lifetime) in the conditions of use of devices with the influence of external-heat are established.

KEY WORDS: optical ceramics, electron beam, elements of precision instruments

1. Introduction

Modern devices with optical elements for measurement and thermal control of different physical nature objects (flat plates and cylindrical disks as substrates of IR instruments filters, the input protective windows in sight for observation in the visible and infrared regions of the spectrum and so on) in the conditions of their use are exposed to intense external-heat (higher heating temperature and external pressure, the shock-heat in a shot and the flight and so on. d.) [1 - 3]. Under these conditions, there is a substantial change in the properties of the surface layers of the optical elements up to their destruction (cracking, chipping and other defects), which leads to significant deterioration of the technical-operational characteristics of devices and their failure.

So actual is the prevention of these adverse events at the stage of design and manufacture of devices considered to optical elements. In many studies carried out by different authors in the direction [2 - 7], it was shown that one of the most promising directions in removing undesirable changes in the properties of the surface layers of the optical elements is their finishing movable electron beam. In particular, it shows the possibility of the electron beam method in the formation of surface layers of optical ceramics with changed physico-chemical properties [2, 4, 5, 7]. However, systematic studies of the effects of the electron beam on the surface layers of the elements is currently very limited.

Therefore, this paper presents the results of studies to determine the optimum range of parameters of the electron beam (of the heat exposure, the speed of movement), leading to the most significant improvement of the properties of the surface layers of the elements of optical ceramics (KO1, KO2, KO3, KO5, KO12) and the main technical -operational characteristics of devices based on them (reliability, durability) in terms of their application taking into account the impact of external-heat.

2. Results and discussion

The above electron-microscopic analysis of images of the surface and transverse sections of the elements of the optical ceramics showed that there is a marked change in the structure of their depth (up to 200 ... 250 microns), which depends significantly on the electron beam parameters (density of thermal exposure F_n and speed of movement V). It is noticed a rough terrain (of strain origin) with elements of "viscous" destruction, which indicates the ability of the optical material to create resistance to fracture at a load.

The optimal range of parameters of the electron beam ($F_n = 5 \cdot 10^6 \dots 3 \cdot 10^7$ W/m², $V = 5 \cdot 10^{-3} \dots 1,5 \cdot 10^{-2}$ m/s), within which there is the most significant (more than several times) improving the basic properties of the surface layers of the element: increasing surface microhardness (H_v , MPa); the emergence of them compressive stress ($|\sigma_c|$, MPa), leading to the emergence of hardened layers thickness Δ (microns) is established. Thus, an increase F_n to $3 \cdot 10^7$ Wt/m² leads to an increase in the microhardness of the elements surface treated by an electron beam 1,8 ... 6,3 times compared with the untreated elements; wherein a reduction moving speed of the beam from $V = 1,5 \cdot 10^{-2}$ m/s to $V = 5 \cdot 10^{-3}$ m/s also conducts to increase of the elements microhardness 1,3 ... 1,5 times (Fig. 1,2).

Results of research of the microhardness measurement on depth of the optical ceramics elements treated by an electron beam, indicate that the microhardness of the material of all types of ceramics considered sufficiently rapidly decreases, tending to its value for the untreated material. The thickness of the hardened layer, where there are major structural changes and it increases the microhardness of the treated material for the parameter of the electron beam, changes in the range of 50...130 microns to 100...250 microns with thicknesses of workpieces $4 \dots 6 \cdot 10^{-3}$ m. The value Δ depends strongly on the nature of the ceramic, and the parameters of the electron beam (Fig. 3): an increase F_n from $5 \cdot 10^6$ W/m² to $3 \cdot 10^7$ W/m² leads to an increase in the thickness of the hardened layer 1,6...3,1 times and increasing the moving speed the beam from $5 \cdot 10^{-3}$ m/s to $1,5 \cdot 10^{-2}$ m/s leads to a reduction in the thickness of the hardened layer 1,3...1,4 times.

As a result conducted X-ray studies have shown that regardless of the nature of ceramics (KO1, KO2, KO3, KO12, KO5) in the surface layers of the elements treated by an electron beam to considered range changes density of a thermal exposure and the moving speed of notable phase changes were not observed, but there is an increase in the size of the crystal grains of the material. In respect to the extension lines of the X-ray it is revealed that almost irrespective of the crystallographic directions in the crystal lattices of ceramics after electronic processing occurs a marked change microdistortions and size of the mosaic blocks: the value of the original mosaic blocks to processed by an electron beam optical element is increased in 3,9 times for the elements of the KO1, in 5,5 times for the elements of KO2, in 3,3 times for the elements of KO12, in 4,7 times for the elements of the KO3 and in 7,7 times for elements of KO5 and microstrain value decreases in 3,7 times for elements of KO1, in 5,4 times for the elements of KO2, in 4,2 times

for the elements of KO12, in 5,5 times for the elements of KO3 and in 5,9 times for the elements of KO5.

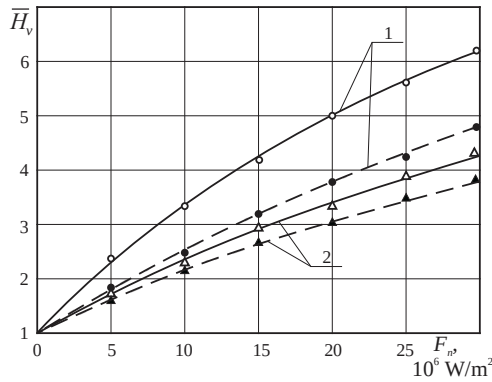


Fig. 1. Dependence of the relative microhardness $\bar{H}_v$ ($\bar{H}_v = \frac{H_v}{H_{v0}}$),

где H_v , H_{v0} – microhardness of the treated and untreated element, respectively) of the surface of the elements of the optical ceramics KO12 (1) and KO5 (2) from the density of the thermal exposure of the electron beam ($H_{v0} = 1,18 \cdot 10^3$ MPa (KO12); $1,21 \cdot 10^3$ MPa (KO5)): — — $V = 5 \cdot 10^{-3}$ m/s; - - - $V = 1,5 \cdot 10^{-2}$ m/s; Δ , $\circ$, $\blacktriangle$, $\bullet$ - experimental data.

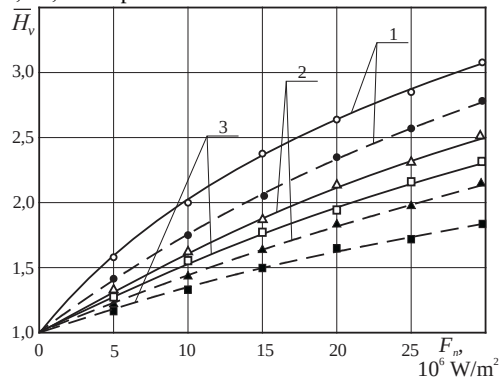


Fig. 2. Dependence of the relative microhardness $\bar{H}_v$ of the surface of the optical ceramics elements KO3 (1), KO2 (2) and KO1 (3) from the density of the thermal exposure of the electron beam ($H_{v0} = 1,85 \cdot 10^3$ MPa (KO3); $2,17 \cdot 10^3$ MPa (KO2); $2,86 \cdot 10^3$ MPa (KO1)): — — $V = 5 \cdot 10^{-3}$ m/s; - - - $V = 1,5 \cdot 10^{-2}$ m/s; Δ , $\circ$, $\square$, $\blacktriangle$, $\blacksquare$, $\bullet$ - experimental data.

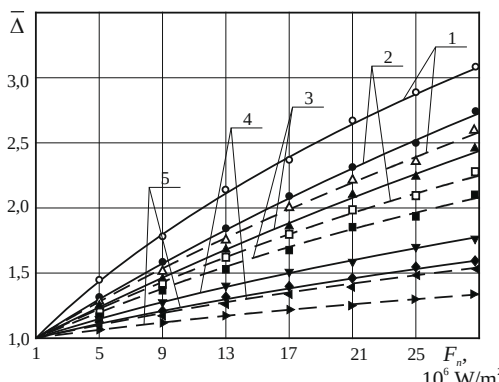


Fig. 3. Dependence of the relative thickness of hardened layers by electron beam $\bar{\Delta}$ ($\bar{\Delta} = \frac{\Delta}{\Delta_0}$, where Δ , Δ_0 - the thickness of

hardened layers, respectively at the current value F_n and at $F_n = 10^6$ W/m²) of optical ceramics elements KO5 (1) KO3 (2) KO1 (3), KO2 (4) and KO12 (5) on the values of its thermal effects density ($\Delta_0 = 80$ microns (KO1), 121 microns (KO2), 67 microns (KO3), 49 microns (KO5), 129 microns (KO12)): — — $V = 5 \cdot 10^{-3}$ m/s; - - - $V = 1,5 \cdot 10^{-2}$ m/s; Δ , $\circ$, $\square$, $\blacktriangle$, $\blacksquare$, $\blacklozenge$, $\blacktriangledown$, $\bullet$, $\blacktriangleright$, $\blacktriangleleft$ - experimental data.

The analysis of received changes of the crystal lattice parameters of elements after the electronic treatment in accordance with known methods for calculating these radiographs [2], which are based on the direct analytical dependence between the residual stresses in the surface of the element and change of the period of the main components crystal lattice of the considered ceramics, showed the presence of compressive stresses in thin surface layers of the elements of the depth of 40 ... 60 microns to the center of the treated areas (portions size $4 \cdot 10^{-2} \dots 5 \cdot 10^{-2}$ m) in the considered range of parameters changes of the electron beam (Fig. 4). It is determined that the increase F_n from $5 \cdot 10^6$ W/m² to $2,7 \cdot 10^7$ W/m² leads to the increase of compressive stress in the surface layers of the elements in 2...6 times; thus the increase moving speed electron beam from $5 \cdot 10^{-3}$ m/s to $1,5 \cdot 10^{-2}$ m/s leads to the reduction of compressive stresses in 1,6...2,3 times.

In addition, the change for the selected ranges $F_n = 5 \cdot 10^6 \dots 2,7 \cdot 10^7$ W/m² and $V = 5 \cdot 10^{-3} \dots 1,5 \cdot 10^{-2}$ m/s the following condition is performed

$$|\sigma_c| < \sigma^*, \quad (1)$$

where σ^* – the maximum permissible thermoelastic stresses in the surface layers of the considered elements, the excess of which leads to their destruction (cracks, chips and other defects). For example, under normal conditions ($T_0 = 300$ K, $P = 10^5$ Pa) for the considered ceramics $\sigma^* = 8 \cdot 10^7$ N/m² (KO1), $7,5 \cdot 10^7$ N/m² (KO2), $5,7 \cdot 10^7$ N/m² (KO3), $1,4 \cdot 10^8$ N/m² (KO5), $1,18 \cdot 10^8$ N/m² (KO12) [2], that is, in accordance with Fig. 4, fully the condition is satisfied (1).

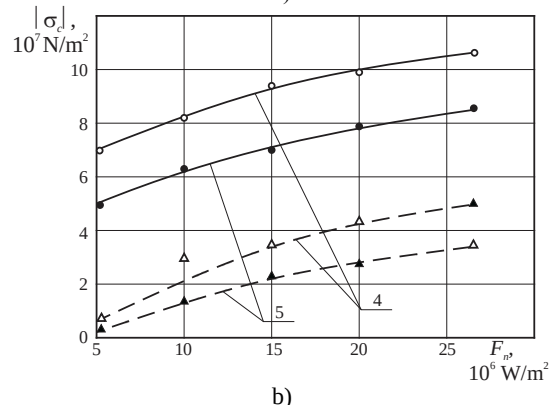
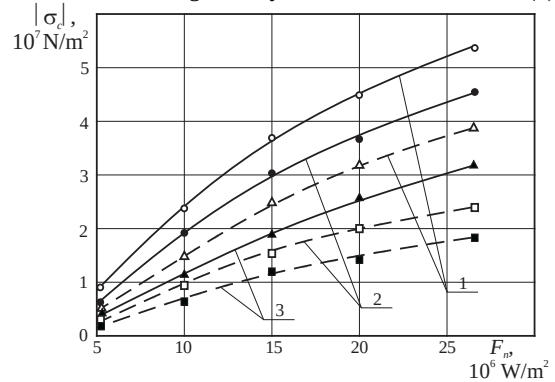


Fig. 4. Dependence of module of the compressive thermoelastic stresses $|\sigma_c|$ in the surface layers of the elements from optical ceramics KO1, KO2, KO3, KO5 KO12 from the density of the thermal exposure of the electron beam: — — $V = 5 \cdot 10^{-3}$ m/s; - - - $V = 1,5 \cdot 10^{-2}$ m/s; a) - the elements of the optical ceramics KO5 (1), KO1 (2) and KO3 (3); b) - elements of optical ceramics KO12 (4) and KO5 (5); Δ , $\circ$, $\square$, $\blacktriangle$, $\blacksquare$, $\bullet$ - experimental data.

The tests for resistance to external thermal influences untreated and treated by an electron beam optical elements are conducted on the equipment that protected by patents of Ukraine [1, 2], simulating the effect of external heat fluxes and high pressure on their working surfaces. It is established (Fig. 5) that for the

elements treated by an electron beam, the critical values of external thermal flows q_n^* (the time of their impacts t^*) for the studied range of parameters change of the beam are increased in 1,5 ... 1,7 times; thus the increase of the external pressure from 10^5 Pa to 10^7 Pa leads also to the decrease of the value q_n^* in 1,3 ... 1,5 times.

That is, after the electron beam treatment of the working surfaces of the optical ceramics elements (KO1, KO2, KO3, KO5, KO12) their resistance to external thermal effects on 30 ... 70% for the whole range of variation of external pressure $P = 10^5 \dots 10^7$ Pa is increased.

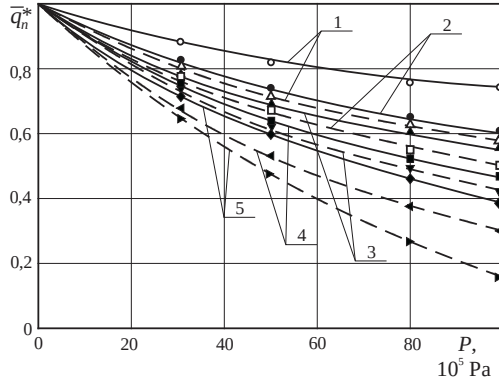


Fig. 5. Dependence of relative critical values of the external thermal

flow q_n^* ($q_n^* = \frac{q_n^*}{q_{n0}^*}$, where q_n^* and q_{n0}^* - the current value q_n^* and its value at $P = 10^5$ Pa, respectively) from pressure for different

times of its exposure to the optical ceramics elements KO5 (1) KO1 (2), KO12 (3) KO3 (4) and KO2 (5): — — $t = 20$ s; - - - $t = 10$ s; Δ , $\circ$, $\square$, $\blacktriangle$, $\blacksquare$, $\blacklozenge$, $\blacktriangledown$, $\bullet$, $\blacktriangleright$, $\blacktriangleleft$ - the experimental data.

The tests for resistance to external mechanical influences of optical elements untreated and treated by an electron beam were carried out in a known method "Autoglass" [2] it was found the critical values of the height H_{kp} from what the steel ball of diameter $d = 4 \cdot 10^{-3} \dots 5 \cdot 10^{-3}$ m, free falling on the element surface destroys it (the appearance of cracks, chips and other defects).

Table 1

The influence of the electron beam processing of working surfaces of optical cylindrical disks on the dependence of the relative amount of their damages (k) from the heating rate q_n^* (discs from the optical ceramics KO2 of diameter $3 \cdot 10^{-2} \dots 5 \cdot 10^{-2}$ m and thickness $4 \cdot 10^{-3} \dots 6 \cdot 10^{-3}$ m, $T_0 = 300$ K, $P = 10^5$ Pa)

Disc Speed of heating disc K/s	k, %	
	Untreated by electron beam	Treated by electron beam
200...250	30...40	10...20
250...300	40...50	20...30
300...400	50...60	30...40

^{*)} Note. $k = k_p / k_0$, where k_0 , k_p - the total number of the tested plates and the number of plates that were destroyed, respectively.

It is established (Fig. 6), that the elements treated by an electron beam, the values of $\bar{H}_{cr}$ 1,4...3 times higher than the values for untreated elements.

Thus, their resistance increases to the external mechanical stresses after the electron beam treatment of working surfaces of optical ceramics elements (KO1, KO2, KO3, KO5, KO12) in some times. It was shown that pre- electron beam treatment of the working surfaces of cylindrical optical discs used, for example, as substrates of diffusing screens, input protection windows, sighting systems for observation in IR spectrum, and so on and under conditions of variable external heating, which simulates their actual operating conditions, taking into account the effect of external thermal influences, heat, leads to reducing the amount of damage of

the plates in 2,5...3 times (Table 1) and increases the service life in 2...2.5 times.

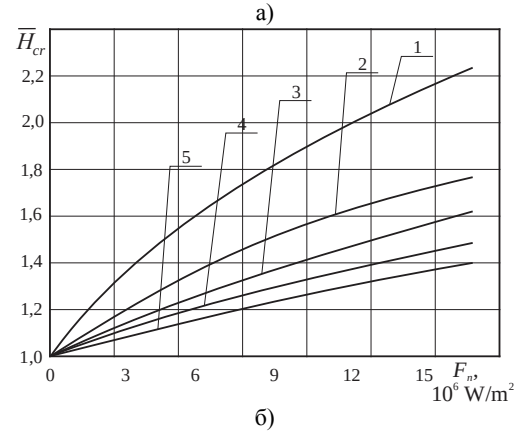
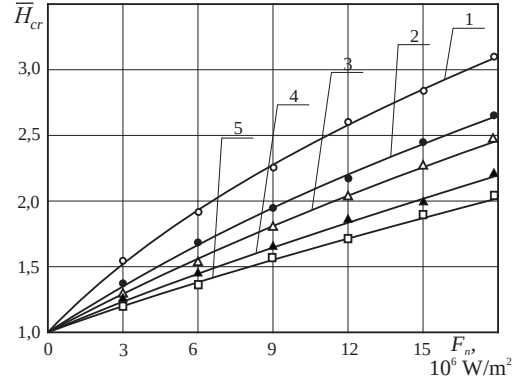


Fig. 6. Dependence of the relative values of the critical height of fall

of a steel ball $\bar{H}_{cr}$ ($\bar{H}_{cr} = \frac{H_{cr}}{H_{cr0}}$, where H_{cr} , H_{cr0} - the

elevation of the height of the elements, treated and untreated by an electron beam, respectively (0,42 m (KO1), 0,33 m (KO2), 0,25 m (KO3), 0,51 m (KO5), 0,48 m (KO12) [2])) on the surface of the optical ceramics elements KO3 (1), KO2 (2) KO5 (3), KO12 (4) and KO1 (5) from the density of the thermal exposure of the electron beam for different speeds of its movement ($T_0 = 300$ K, the thickness of the element $4 \dots 6 \cdot 10^{-3}$ m): a) - $V = 5 \cdot 10^{-3}$ m/s; b) - $V = 1,5 \cdot 10^{-2}$ m/s; Δ , $\circ$, $\blacktriangle$, $\bullet$, $\square$ - experimental data.

3. Conclusions

1. It is found that by pretreating the working surfaces of the optical ceramics elements (KO1, KO2, KO3, KO5, KO12) by movable belt electron beam by adjusting its parameters in the optimal range of variation (density of thermal exposure ($F_n = 5 \cdot 10^6 \dots 3 \cdot 10^7$ W/m² and beam movement speed $V = 5 \cdot 10^{-3} \dots 1,5 \cdot 10^{-2}$ m/s), it is possible to improve the basic properties of the surface layers of the elements:

- increasing F_n to $3 \cdot 10^7$ W/m² and decreasing V from $1,5 \cdot 10^{-2}$ m/s to $5 \cdot 10^{-3}$ m/s leads to the increase of the microhardness of the surface elements that are processed by an electron beam 1,5...6,3 times compared with untreated elements;
- increasing F_n from $5 \cdot 10^6$ W/m² to $3 \cdot 10^7$ W/m² leads to the increase of the thickness of the hardened layer in 1,6...3,1 times; thus increasing the moving speed of the beam from $5 \cdot 10^{-3}$ m/s to $1,5 \cdot 10^{-2}$ m/s already leads to decreasing value Δ in 1,3... 1,4 times;
- compressive stresses in thin surface layers of elements of depth of 40...60 microns with increasing F_n from $5 \cdot 10^6$ W/m² to $2,7 \cdot 10^7$ W/m² increase in 2...6 times, and the increase V from $5 \cdot 10^{-3}$ m/s to $1,5 \cdot 10^{-2}$ m/s leads to their reducing in 1,6...2,3 times.

2. The tests of optical elements in their resistance to external thermal and mechanical stress are shown:

- the elements treated by an electron beam are subjected to fracture at the critical values of the external thermal flows q_n^*

(since their impact t^*), which are 1,5... 1,7 times greater than in the case of untreated elements; thus, increasing the external pressure from 10^5 Pa to 10^7 Pa in both cases leads to decreasing q_n^* (or t^*) in 1,3...1,5 times;

– for elements untreated by an electron beam, the critical height drop of the steel ball on their surface, leading to the destruction of the elements 1,4 ... 3 times lower than for treated elements.

3. It was found that pre- electron beam treatment of cylindrical disks of optical ceramics used as working parts of instruments for measurement and thermal control of different physical nature objects, leads to reducing the amount of destructions in 2,5 ... 3 times under conditions of variable external heating and also increases their resistance to external mechanical stress (more than some times), thereby increasing the service life of the instrument in 2...2,5 times.

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TIME-HARMONIC PROBLEMS FOR CRACKED FUNCTIONALLY GRADED MAGNETO-ELECTRO-ELASTIC COMPOSITES

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Abstract. In this study we consider functionally graded magneto-electro-elastic materials (MEEM) subjected to anti-plane time-harmonic load. The purpose is to evaluate the dependence of the stress concentration near the crack tips on the frequency of the applied external load. The mathematical model is described by a boundary value problem for a system of partial differential equations. Due to the existence of fundamental solutions the boundary value problem is reduced to a system of integro-differential equations along the crack. The fundamental solutions are derived in a closed form by the Radon transform. For the numerical solution software code in FORTRAN 77 is created and validated. Simulations show the dependence of the stress intensity factors (SIF) on frequency of the incident wave for different types of load, configurations of cracks and different parameters of inhomogeneity.

KEYWORDS: MEEM, ANTI-PLANE INCIDENT WAVE, RADON TRANSFORM, SIF

1. Introduction

Piezoelectric/ piezomagnetic composites are new smart materials having wide application in modern engineering structures. They possess magneto-electric effect that doesn't exist in piezoelectric or piezomagnetic phase. This new effect was reported for the first time by VanSuchtelen [1] in 1972. Due to different physical and chemical properties of the constituents in the composite a process called delamination may occur. To avoid the abrupt change of the material properties functionally graded materials (FGM) have been created. First practical application of FGM was in Japan, 1984, during the project SPACEPLANE. Researchers required a material that can created 1000 degrees temperature difference in 10mm thickness. Confronted with this challenge they come up with the novel idea of functionally grading [2], [3]. The composition of the FGM varies continuously with dimension and thus eliminates the sharp difference of the material properties of the phases in the composites.

Cracks inevitably exist in magneto-electro-elastic materials. Subjected to external load these cracks may extend and cause mechanical failures. Therefore crack analysis plays an important role in construction of smart structures.

In this study we consider FGMEEM with one or two cracks subjected to time-harmonic incident wave and evaluate the dependence of the stress concentration near the crack tips on the incident wave. The mathematical model is described by a boundary value problem for a system of partial differential equations. The boundary value problem is reduced to a non-hypersingular traction boundary integral equation along the crack. This is possible because of the existence of the fundamental solution, which is derived in a closed form by the Radon transform. After discretization of the cracks the resulting algebraic system is solved numerically. The software code in FORTRAN 77 is validated using available examples in literature.

2. Statement of the problem

The MEEM that we study are transversely isotropic. Therefore we consider a rectangular coordinate system $Ox_1x_2x_3$ and assume Ox_3 is the axis of symmetry and polling direction and Ox_1x_2 is the isotropic plane. The solid is subjected to an external anti-plane mechanical, and in-plane electrical and magnetic time-harmonic load with respect to the isotropic plane. We consider mechanical waves with low frequency and assume that electric and magnetic fields are potential. We also assume that the problem is two dimensional i. e. the material properties are the same in all planes parallel to the isotropic plane. In compact notation the constitutive equations can be written in the following way Sladek et al. [4], Soh and Liu [5]:

$$\sigma_{ij} = C_{ijkl} u_{k,l} \quad (1)$$

where C_{ijkl} is the generalized elasticity tensor defined as follows:

$$C_{i33l} = \begin{cases} c_{44}, i=l \\ 0, i \neq l \end{cases}, C_{i34l} = C_{i43l} = \begin{cases} e_{15}, i=l \\ 0, i \neq l \end{cases},$$

$$C_{i35l} = C_{i53l} = \begin{cases} q_{15}, i=l \\ 0, i \neq l \end{cases}$$

$$C_{i44l} = \begin{cases} -\varepsilon_{11}, i=l \\ 0, i \neq l \end{cases}, C_{i45l} = C_{i54l} = \begin{cases} -d_{11}, i=l \\ 0, i \neq l \end{cases}$$

$$C_{i55l} = \begin{cases} -\mu_{11}, i=l \\ 0, i \neq l \end{cases}.$$

σ_{ij} is the generalized stress, $\sigma_{ij} = (\sigma_{i3}, D_i, B_i)$ $i=1,2$, $J=3,4,5$ and u_j is the generalized displacement, $u_j = (u_3, \varphi, \psi)$. In this notation c_{44} is the elastic module, e_{15} is the piezoelectric coefficient, q_{15} is the piezomagnetic coefficient, ε_{11} is the dielectric permittivity, μ_{11} is the magnetic permeability, d_{11} is the magnetoelectric coefficient, u_3 is the coordinate of the displacement vector along Ox_3 , φ and ψ are electric and magnetic potential respectively, σ_{i3} is the mechanical stress, D_i and B_i are the components of the electric displacement and magnetic induction respectively. Here comma means differentiation and we assume summation under repeated indexes. We use quasi-static approximation of Maxwell equation, because the frequency of the incident wave is low compared with frequency of the electromagnetic wave. The electric current density of free currents $J_f = 0$. We obtain (see Sladek et al [4]):

$$\nabla \times E = 0, \quad \nabla \times H = 0 \quad (2)$$

From (2) we conclude that $E = -\text{grad}\varphi$ and $H = -\text{grad}\psi$. Using equation of motion, and also $\text{div} D = 0$ when there is no free charges and $\text{div} B = 0$ we obtain the governing equations for time harmonic load:

$$\sigma_{ij,i} + \rho_{JK} \omega^2 u_K = 0 \quad (3)$$

In (3) ω is the frequency of the applied time-harmonic load and

$$\rho_{JK} = \begin{cases} \rho, J=K=3 \\ 0, J, K=4 \text{ or } 5 \end{cases}, \text{ where } \rho \text{ is the density.}$$

We suppose that the material properties vary in the following way:

$$e_{15}(x) = h(x)e_{15}, c_{44}(x) = h(x)c_{44}, q_{15}(x) = h(x)q_{15},$$

$$\varepsilon_{11}(x) = h(x)\varepsilon_{11}, d_{11}(x) = h(x)d_{11}, \mu_{11}(x) = h(x)\mu_{11},$$

$$\rho(x) = h(x)\rho, \text{ where the inhomogeneity function has the}$$

$$\text{following form: } h(x) = e^{2(k_1 x_1 + k_2 x_2)} = e^{2\langle k, x \rangle}.$$

The material is subjected to an incident, anti-plane, time-harmonic wave. When it interacts with the crack a scattered wave is produced. The total displacement and traction in any point of the plane can be found using the superposition principle:

$$u_j = u_j^{\text{in}} + u_j^{\text{sc}}$$

and

$$t_j = t_j^{\text{in}} + t_j^{\text{sc}}.$$

Here u_j^{in} and t_j^{in} are the displacement and traction of the incident wave field and u_j^{sc} and t_j^{sc} are the displacement and traction of the scattered by the crack wave field. The boundary conditions are:

$$t_j^{\text{in}} + t_j^{\text{sc}} \Big|_{\Gamma} = 0, \quad (4)$$

Here Γ is the crack, t_j is the total generalized traction defined as $t_j = \sigma_{ij} n_i$, $n = (n_1, n_2)$ is the normal vector to the crack. This means that the crack is impermeable, i. e. free of mechanical traction, electric charges and currents. We also assume that:

$$u_j(x_1, x_2) = 0 \quad (5)$$

when $(x_1^2 + x_2^2)^{1/2} \rightarrow \infty$.

We will solve the boundary value problem (3),(4),(5) transforming it into an equivalent integro – differential system of equations on the crack and then solve this system numerically.

The fundamental solution of the system of partial differential equations (3) is the solution of:

$$\sigma_{iJK,i}^* + \rho_{JK} \omega^2 u_{KM}^* = -\delta_{JM} \delta(x - \xi), \quad (6)$$

where $\sigma_{iJK}^* = C_{iJKl} u_{KM,l}^*$, $\delta(x - \xi)$ is the Dirac's delta function and δ_{JM} is the Kronecker's symbol. Following Rangelov et al. [6] and Manolis and Shaw [7] we make the transformation $u_{KM}^* = h^{-1/2} U_{KM}^*$ in (6) and obtain:

$$C_{iJKl} U_{KM,ii}^* + [\rho_{JK} \omega^2 - C_{iJKl} h^{-1/2} (h^{1/2})_{,ii}] U_{KM}^* = -h^{-1/2} \delta_{JM} \delta(x, \xi). \quad (7)$$

The solution of (7) is found in a closed form by direct and inverse Radon transform and generalized function calculations. Once fundamental solution is derived, following Wang and Zhang [8], Gross et al [9] for piezoelectric case we obtain the following traction boundary integral equation:

$$t_j^{\text{in}}(x) = -C_{iJKl} n_i(x) \int_{\Gamma} [(\sigma_{\eta JK}^*(x, y, \omega) \Delta u_{J,\eta}(y, \omega) - \rho_{QJ} \omega^2 u_{QK}^*(x, y, \omega) \Delta u_J(y, \omega)) \delta_{\lambda l} - \sigma_{\lambda JK}^*(x, y, \omega) \Delta u_{J,l}(y, \omega)] n_{\lambda}(y) d\Gamma(y)$$

where $\Delta u_J = u_J \Big|_{\Gamma^+} - u_J \Big|_{\Gamma^-}$ -the jump of the displacement along

the crack or crack opening displacements (COD). The incident wave t_j^{in} is known. The unknown COD are found numerically after crack discretization. If we know COD we can find the scattered field at any point in the solid.

The stress, electric field and magnetic field concentration near crack tips are computed using the expressions:

$$K_{III} = \lim_{x_1 \rightarrow \pm c} t_3 \sqrt{2\pi(x_1 \mp c)},$$

$$K_E = \lim_{x_1 \rightarrow \pm c} E_2 \sqrt{2\pi(x_1 \mp c)},$$

$$K_H = \lim_{x_1 \rightarrow \pm c} H_2 \sqrt{2\pi(x_1 \mp c)},$$

where c is the half-length of the crack.

3. Numerical realization

The crack is divided into 7 boundary elements. The unknown COD are approximated using parabolic shape functions. The material constants for the piezoelectric/piezomagnetic composite $BaTiO_3 / CoFe_2O_4$, that is used in this study can be found in Soh and Liu [5], Li [10]. We compare our results with the results of Zhou and Wang [11] who used dual integral equation method to investigate the dynamic behavior of two parallel equal cracks (see fig. 1). The distance h between the cracks is increasing: $h = 0.2c, \dots, 6.5c$, where $c = 5\text{mm}$ is the half length of the crack. The normalized frequency of the incident wave is fixed

$$\Omega = c \sqrt{\rho c_{44}^{-1}} \omega = 0.4 \text{ and the normalized SIF is } K_{III}^* = \frac{K_{III}}{t_3^{\text{in}} \sqrt{\pi c}}.$$

The comparison is given in fig.3, where the normalized SIF versus the ratio $\frac{h}{c}$ is presented.

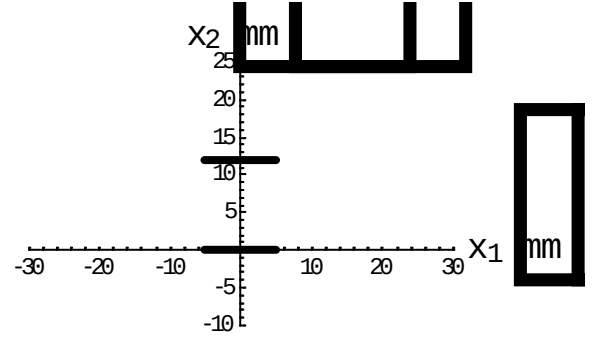


Fig. 1 Two equal parallel cracks in MEEM.

We see very good coincidence of the results with difference no more than 2%.

As another example we compare the results for one crack with the results for two collinear equal cracks when the distance between them is large so that the crack interaction is minimal (see fig. 3). The results are obtained by the BIEM. The comparison is given in fig. 4. We see very close results as is to be expected. The maximal difference no more than 3%.

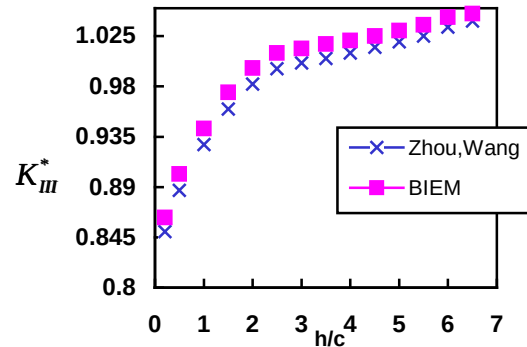


Fig. 2 Comparison between the results of Zhou and Wang and BIEM for two parallel cracks in MEEM.

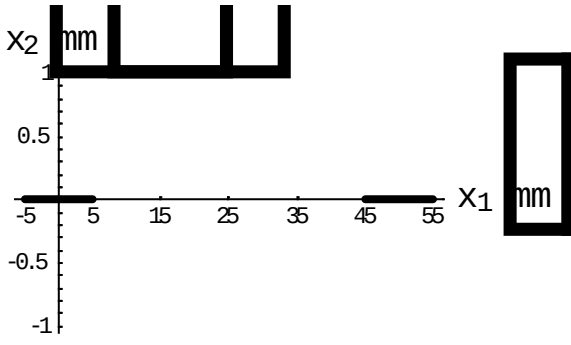


Fig. 3 Two distant collinear cracks in MEEM.

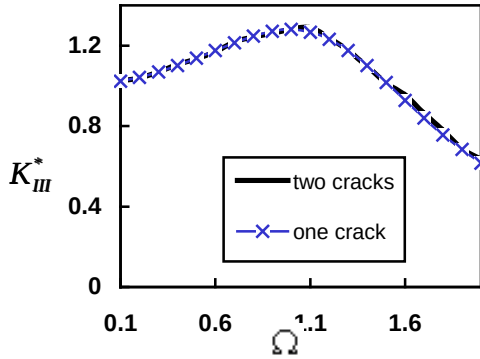


Fig. 4 Comparison between the results of two distant collinear cracks with results for one crack in MEEM.

As another validation example we can consider two parallel equal cracks when the distance between them is large. Similar to collinear cracks we expect the crack interaction to be minimal. The results for the normalized SIF with respect to the normalized frequency obtained by the BIEM are given in fig. 5. The comparison shows good coincidence, which is to be expected. The difference is no more than 4%.

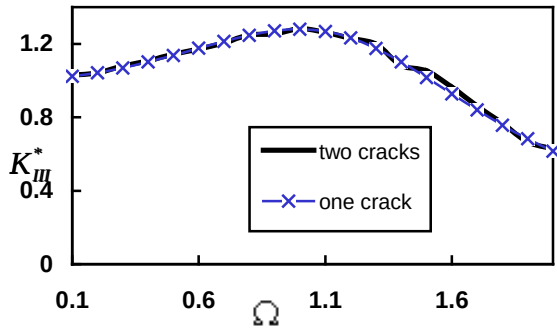


Fig. 5 Comparison between the results of two distant parallel cracks with results for one crack in MEEM.

Simulation studies show the dependence of the stress intensity factor, electric field intensity factor (EFIF) and magnetic field intensity factor (MFIF) on the normalized frequency for different parameters of the inhomogeneity function. These parameters are presented in the following way: $(k_1, k_2) = \frac{\beta}{2c} (\sin \alpha, \cos \alpha)$. The normalized EFIF and MFIF are computed as follows:

$$K_E^* = 10 \frac{K_E}{t_3^{in} \sqrt{\pi c}} \text{ and } K_H^* = 10^4 \frac{K_H}{t_3^{in} \sqrt{\pi c}}.$$

In fig. 6 a), b), c) we present the normalized SIF, EFIF and MFIF versus the normalized frequency for normal incident wave. The

cracks are equal and collinear and the distance between them is $h = 0.5c$. The inhomogeneity angle is fixed: $\alpha = 0.0$, while the inhomogeneity magnitude β is increasing: $\beta = 0.0, 0.2, 0.4, 0.6$. The case $\beta = 0$ corresponds to homogeneous material. SIF, EFIF and MFIF are computed at the right crack tip of the left crack. The results show decreasing of the generalized SIF with increasing of the inhomogeneity magnitude β . We also see that this effect is frequency dependent. The conclusion is that the concept of the FGM to reduce stress concentration and improve the strength of the materials works.

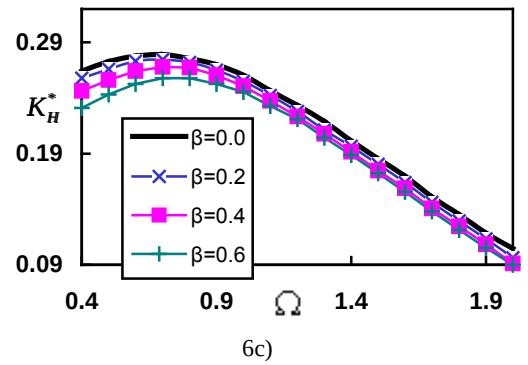
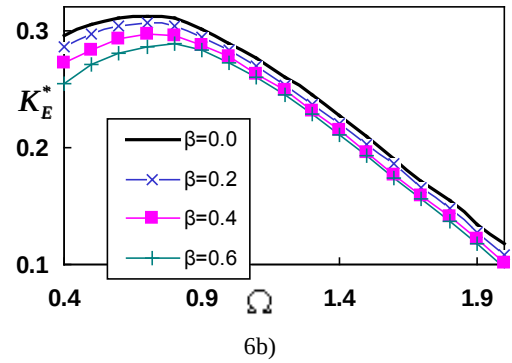
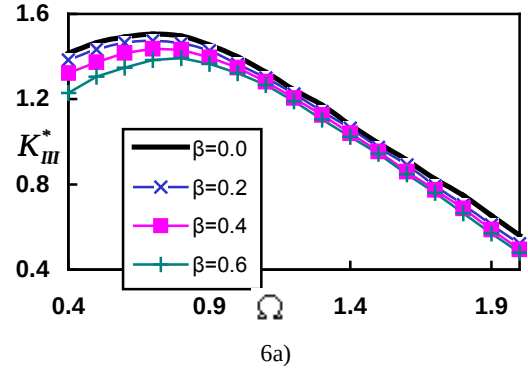


Fig. 6 a),b),c) SIF, EFIF and MFIF with respect to the normalized frequency for normal incident wave.

4. Conclusion

In this study we presented numerical solution of a system of integro-differential equations for FGMEEM with one or two cracks, subjected to an incident SH wave. FORTRAN 77 code, based on the BIEM is developed, validated and used in simulations studies. The numerical results show the sensitivity of SIF, EFIF and MFIF to distance between the cracks and parameters of the inhomogeneity function. I also shows that FGM can be used to enhance the strength of the multifunctional materials. This software can be further developed to solve problems in FGMEEM with more complex crack

configurations, materials with nanoheterogeneities, heterogeneous structures, thermo-elastic problems, MEEM under in-plane waves, problems in finite domains, inverse problems. It also has applications in non-destructive material testing.

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METALLOGRAPHIC INVESTIGATION OF STAINLESS STEEL TUBES FOR SOLAR COLLECTORS

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Abstract: This investigation was performed on the request of the Company for production of the solar systems collectors. Subject of the investigation is the segment of the solar stainless steel collector for the heating water in the swimming pool. The system was installed in the private property and was in use until August 2015 (about one month after installation) when it was disconnected for a period of about one month. After that system was restarted again and it was noticed that many cracks appeared in vertical tubes $\phi 8$ mm of collector manufactured of S304 stainless steel. In the horizontal pipes made of S316 steel cracks were not detected. This investigation should give the answer what is the reason for appearing of cracks in stainless steel pipes for pretty short period of exploitation.

Keywords: SOLAR COLECTORS, STAINLESS STEEL, STRESS CORROSION CRASCKS, TIG WELDING

1. Introduction

For production of solar collectors generally were used copper tubes but in the current time tubes produced from austenitic stainless steels are in use nowadays. Besides good physical properties these steel possess excellent corrosion properties. But presence of chlorine in water can cause serious problem during exploitation conditions of these tubes. Such problems appear during exploitation in this case too. It means that many cracks appear in the embedded solar pipes. Performed metallographic investigations had to show what is the reason or reasons for cracks appearing.

2. Material and investigation

Solar thermal collectors consist of stainless steel tubes. Vertical tubes are with diameter of $\phi 8$ mm and thickness of 0.4 mm, and were produced from AISI 304 austenitic steel. Horizontal tubes are produced from AISI 316 austenitic steel with diameter of $\phi 18$ mm and thickness 1 mm. Chemical composition of tubes is given in table 1.

Fillet welds (branch) of tubes was performed. Welding of pipes was done by TIG welding process. As filler material was used welding wire from AISI 316 steel (diameter of 1 mm), Argon was used as a protective gas (10 l/min). Welding current is 50 -60 A.

Table 1 Chemical composition of investigated stainless steel tubes

Chem. comp, %	AISI 316	AISI 304
C	0.0184	0.0364
Cr	17.74	18.42
Si	0.387	0.386
Ni	9.5	7.70
Mo	2.08	0.216
Mn	1.89	1.31
P	0.035	0.043
S	0.05	0.05
W	0.066	0.023

Damaged welded segment consisting of horizontal and vertical pieces (tubes) was given for investigation. The segment was cut in order to obtain two equal parts. One of them is shown in figure 1. This segment was prepared for metallographic investigation. Standard metallographic preparation of specimen was performed. After grinding at different abrasive papers, polishing with

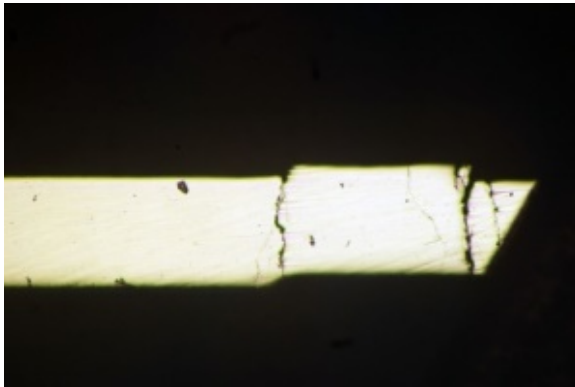
suspension of Al_2O_3 was done. Finally chemical etching with V2A etchant was made. Macro photo of investigated segment is given in Figure 1. After polishing specimen was analyzed under optical microscopy (OM) using different magnifications. Figures 2 (a and b) presents micro photos taken from the polished specimen, and concern to the vertical (inclined) tube. As can be seen from the micro photos besides the biggest crack which can be seen with naked eye, many thinner cracks were detected. They are located beneath and above the biggest crack.



Figure 1 Macro photo of welded segment (branch weld) cut for metallographic preparation



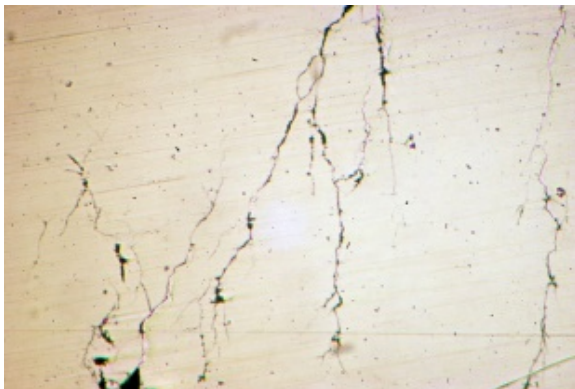
a



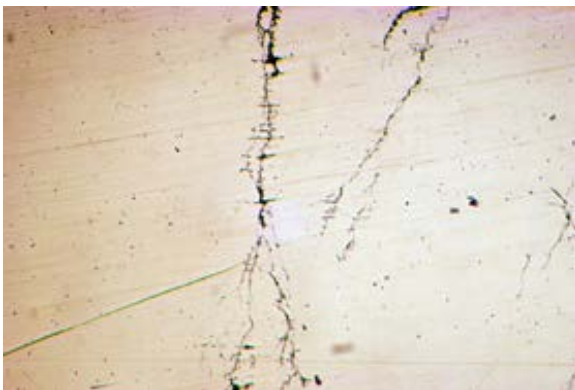
b

Figure 2 Micro photo of polished specimen (vertical tube), with the main crack x50

Figures 3 concern to the same tube (vertical) and it can be seen that these cracks are pretty thin and have characteristic branch form. It has to be said that that these crack propagate trough entire thickness of the tube wall.



a



b

Figure 3 Micro photo of polished specimen (vertical tube), x200

In some cases as first appear pitting corrosion and after that stress corrosion cracks appear, figure 4

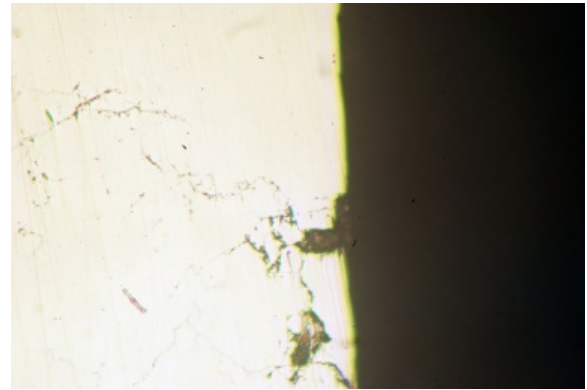
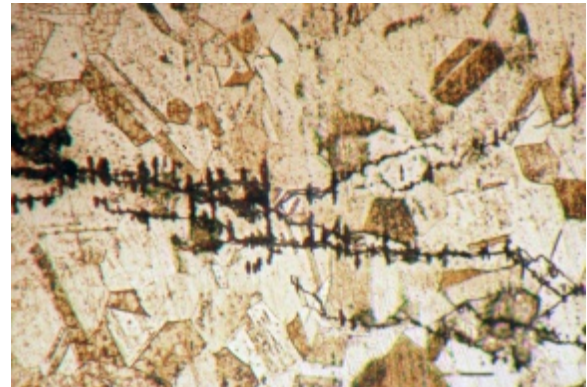
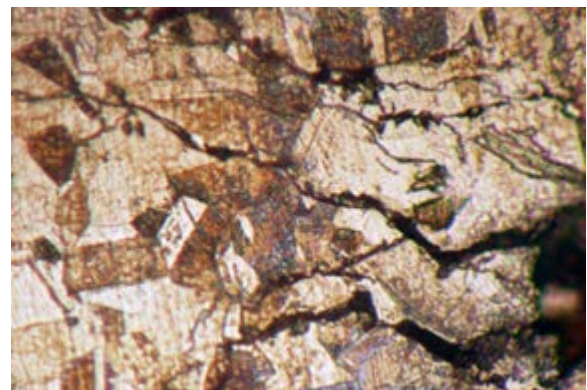


Figure 4 Micro photo of polished specimen (vertical tube), x200

Figures 5 concerns to the etched microstructures of inclined tube. Austenitic grains are clearly seen and in all case stress corrosion cracks (SCC) are present. Cracks propagate mainly transgranularly but in some case intergranular propagation can be seen.



a



b

Figure 5 Micro photo of etched specimen (vertical tube), x200

3. Discussion

As can be seen from macro photo (Figure 1) the biggest crack is clearly seen and includes almost one half of the tube vertical segment. It can be seen too that this cracks is located on the corroded surface of the inclined tube. It can be seen from the figure 1 that there is neither corrosion products nor cracks in the horizontal tube S316. Weld metal can be clearly seen too. It is obvious that weld size is too big for this thickness of pipes. It means that too much heat is input which contributes for residual stress in the welded joint.

Another thing that some characteristic defects in the weld area can't be seen.

As can be noticed from micro photos many cracks are present at different position in the specimen (vertical tube). They are located beneath and above the main crack. But all of them are located in the corroded area. It is noticeable that these cracks have form of branches and almost all of them propagate through entire thickness of the wall. Propagation of cracks is mainly trans granular (through the austenite grains), but in some cases intergranular crack propagation can be seen (across the grain boundaries).

It can be said the vertical (inclined) tube is extremely corroded. These cracks detected in the vertical tubes are typical examples of stress corrosion cracks (SCC). The main reason for their appearing is interacting of the work of collector system. In that period, chlorine water in the didn't circulate through the tubes. The remaining water in the tubes evaporates and concentration of chlorine in the inner surfaces of the tubes drastically increased. Much higher than usual concentration in the water during the normal work of the collectors. Temperature of tubes according obtained information was over than 200 °C.

According obtained information, almost all cracks at vertical tubes are located at the same position (in the lower part of tubes) like on the investigated specimen. It is well known from appropriate technical literature that SCC appears in the sea water and in medium with increased concentration of chlorine. It is known too that SCC appears at temperature over 60 °C [1]. And very significant factor is presence of longitudinal tensile strength in material. It could be residual stresses, from welding for example. As can be seen from the macro photo weld thickness is much higher than the pipe thickness. In this case there is welding heat input in these thin pipes. When collector system was restarted, cold water pass through the tubes heated at temperature of about 200 °C which caused thermal shock in the tubes. In this case all main factors for SCC appearing were fulfilled – high chlorine concentration, temperature over 60 °C and tensile strength. It has to be point out that if the collectors worked continuously appearing of stress corrosion cracks should be avoid

Three main factors dealing at the same time are the most influencing factors which cause stress corrosion cracks appearing i.e. increased temperature residual stress and presence of chlorine,

4. Conclusion

It is obvious that stress corrosion cracks in the smaller, vertical pipes appear as result of three main factors which act in the same time – increased chlorine concentration, increased temperature and tensile strength. It is a period when the collector was not in function (for the period of about one month). In that period, because of high temperature of tube (over 200 °C) water in the tubes evaporate and the concentration of chlorine on the tube walls increase many times compared with concentration of chlorine in the water. During restart of the system very fast cooling of the tubes (200 °C) with water at ambient temperature are the reason for appearing of cracks in the pipes and damaging of collector system.

In our opinion if the collector system was working permanently appearing of SCC cracks should be avoid. According obtained information, collectors were working about one month before to be interrupted. During this period of permanent work of collectors cracks didn't appear. They appeared immediately after restart of the collector system.

Molybdenum increase corrosion properties of austenitic steels too

5. Literature

<http://www.npl.co.uk/upload/pdf/stress.pdf>

http://www.npl.co.uk/upload/pdf/stress_corrosion_cracking_basics.pdf

<http://www.asminternational.org/documents/10192/1849770/06355>

[G_Sample.pdf/daf91547-a566-4f77-83a0-1fca83b87157](http://www.asminternational.org/documents/10192/1849770/06355_G_Sample.pdf/daf91547-a566-4f77-83a0-1fca83b87157)

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