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Dual-flow dissymmetrical low pressure steam turbine energy analysis – comparison of both turbine cylinders

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Abstract: In this paper is performed energy analysis of the dual-flow dissymmetrical low pressure steam turbine, which operates in a coal-fired power plant. Based on the measured operating parameters during exploitation it is calculated and presented an ideal and real power, energy losses and energy efficiencies of a whole turbine and both of its cylinders. Right cylinder of the analyzed turbine develops higher real (polytropic) and ideal (isentropic) power in comparison to left turbine cylinder. The first steam extraction of each cylinder dictates cylinder power (both ideal and real). Right cylinder has a higher energy loss and energy efficiency in comparison to left cylinder - the difference in energy loss is notable (5735.74 kW in comparison to 5447.23 kW), while the difference in energy efficiency is low, almost negligible (92.371% in comparison to 92.357%). Percentage differences between observed turbine cylinders show that left cylinder has approximately 5% lower real (polytropic) as well as ideal (isentropic) power and simultaneously approximately 5% lower energy loss.

KEYWORDS: DUAL-FLOW DISSYMMETRICAL STEAM TURBINE, LOW PRESSURE, TURBINE CYLINDERS PERFORMANCE COMPARISON, ENERGY ANALYSIS

1. Introduction

Steam power plants and systems are the dominant electrical power producers worldwide [1, 2]. Along with its dominant function, steam power plants and systems can be used for various other purposes, for example as marine propulsion plants [3, 4], for simultaneous production of electrical power and heat [5], as a part of complex combined plants [6, 7], as a part of complex industry or marine plants [8-11], etc.

In the majority of steam power plants and systems, main steam turbines are composed of several cylinders, usually mounted on the same shaft [12]. Therefore, the main steam turbines are usually complex ones, while steam turbines with only one cylinder are in the most of the cases used as an auxiliary turbines [13, 14]. Steam produced in steam generators (or nuclear reactors in nuclear power plants) is in the most of the cases delivered directly to all turbines which exist in the plant [15].

Steam turbine cylinders can be single-flow or dual-flow cylinders. In dual-flow steam turbine cylinder, steam enters into the cylinder in its center and expand simultaneously through its left and right side [16]. Such dual-flow cylinders are beneficial from the viewpoint of steam axial force self-balancing. Also, such cylinders are nowadays dominantly used in nuclear power plants due to high steam mass flow rate produced in nuclear reactors [17]. Conventional steam power plants in the most of the cases use dual-flow cylinders as a low pressure cylinders (before main steam condensers).

In this paper is performed energy analysis of the dual-flow dissymmetrical low pressure steam turbine from a coal-fired power plant. Due to unequal extractions from left and right cylinder of the observed steam turbine, it was interesting to compare real and ideal power, energy efficiencies and losses of both cylinders. It is observed that, for the analyzed turbine, first steam extractions from each cylinder dictates all the obtained differences.

2. Description and characteristics of the dual-flow dissymmetrical low pressure steam turbine

The whole analyzed LPT (Low Pressure Turbine) is presented in Fig. 1. LPT is a dual-flow steam turbine, composed of two cylinders: LPC-L (Low Pressure Cylinder-Left) and LPC-R (Low Pressure Cylinder-Right). In Fig. 1 are also presented operating points required for the energy analysis. A steam mass flow rate which enters into LPT (operating point 1) is equally divided, so one its half expand through LPC-L and second half expand through LPC-R. Analyzed LPT is dissymmetrical turbine because of its extractions – in operating points 2 and 3 from the turbine cylinders are extracted different mass flow rates at different pressures.

All LPT extractions lead steam to low pressure condensate heating system [18], Fig. 1, while remaining steam mass flow rate after expansion in both cylinders (operating point 6) is delivered to steam condenser [19].

It should be highlighted that cumulative steam mass flow rate in operating points 4 and 5 is composed of two mass flow rates

extracted from LPC-L and LPC-R at the same pressures for each operating point, Fig. 1. It is assumed that cumulative steam mass flow rate in operating point 4 is equally divided on the extraction from LPC-L and LPC-R. In a same manner is assumed that cumulative steam mass flow rate in operating point 5 is equally divided on the extraction from LPC-L and LPC-R.

At each cylinder outlet will be determined steam mass flow rate balances, because cumulative steam mass flow rate measured in operating point 6 is not equally divided on both LPT cylinders.

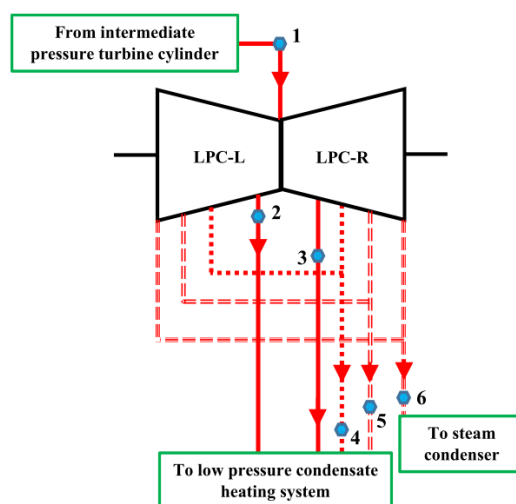


Fig. 1. Scheme of the analyzed dual-flow dissymmetrical low pressure steam turbine along with required operating points

Steam expansion processes (real and ideal) for both LPT cylinders are presented in h-s diagram, Fig. 2. In Fig. 2 can clearly be seen the difference between LPC-L and LPC-R real (polytropic) processes in the superheated steam area. For the LPC-L should be noted that the first extraction (operating point 2) occurs much earlier (at higher steam specific enthalpy) than the first extraction in LPC-R (operating point 3). At each extraction cylinders losses a part of the steam mass flow rate, therefore, LPC-L will earlier lose a certain amount of steam mass flow rate in comparison to LPC-R. Real (polytropic) steam expansion process of LPC-L is marked with operating points 1-2-4-5-6, while real (polytropic) LPC-R expansion process is marked with operating points 1-3-4-5-6, Fig. 2. Operating points for the real (polytropic) steam expansion processes in Fig. 2 are in accordance with operating points from Fig. 1.

Both LPT cylinders have the same ideal (isentropic) steam expansion process marked with operating point's 1-2is-3is-4is-5is-6is, Fig. 2. Ideal (isentropic) steam expansion process assume always the same steam specific entropy as at the LPT (or any cylinder) inlet, while the pressures remain the same as in the real process.

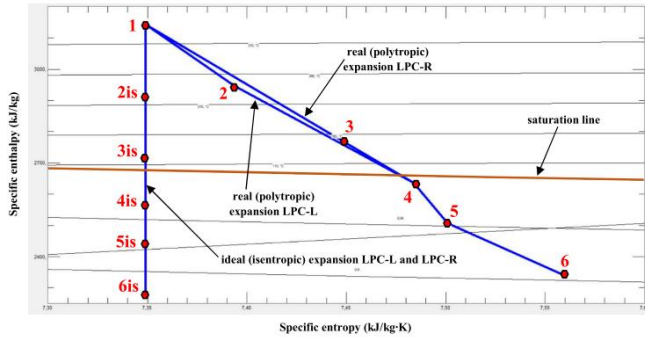


Fig. 2. Real (polytropic) and ideal (isentropic) steam expansion processes of the LPC-L and LPC-R in h-s diagram

3. Equations for the energy analysis

3.1. General equations and principles

In comparison to exergy analysis, which takes into consideration parameters of the ambient inside which component or system operates [20, 21], energy analysis did not take into consideration any parameter of the ambient [22, 23]. General energy balance equation, valid for any system or component, can be written as [24, 25]:

$$\dot{Q}_{inlet} + P_{inlet} + \sum \dot{E}n_{inlet} = \dot{Q}_{outlet} + P_{outlet} + \sum \dot{E}n_{outlet} \quad (1)$$

It should be highlighted that in the general energy balance equation, Eq. 1, potential and kinetic energies are disregarded [26].

In a standard operation of any system or a component, mass flow rate leakage did not occur, so mass flow rate balance is:

$$\sum \dot{m}_{inlet} = \sum \dot{m}_{outlet} \quad (2)$$

Total energy power of any fluid stream in Eq. 1, is defined according to [27] as:

$$\dot{E}n = \dot{m} \cdot h \quad (3)$$

Overall definition of any system or a component energy efficiency can be written as:

$$\eta_{en} = \frac{\text{cumulative energy outlet}}{\text{cumulative energy inlet}} \quad (4)$$

In the equations above and throughout the paper text, P is used or produced power in (kW), $\dot{Q}$ is heat transfer in (kW), $\dot{E}n$ is the total energy power of any fluid stream in (kW), $\dot{m}$ is the fluid mass flow rate in (kg/s), h is fluid specific enthalpy in (kJ/kg) and η is efficiency.

3.2. Equations for the energy analysis of low pressure steam turbine and both of its cylinders

Equations for the energy analysis of the whole LPT and both of its cylinders (LPC-L and LPC-R) are based on the operating points presented in Fig. 1 and Fig. 2.

LPT left cylinder (LPC-L)

- Mass flow rate balance:

$$\dot{m}_{6,Left} = \frac{\dot{m}_1}{2} - \dot{m}_2 - \frac{\dot{m}_4}{2} - \frac{\dot{m}_5}{2} \quad (5)$$

- Real (polytropic) power:

$$P_{re,LPC-L} = \frac{\dot{m}_1}{2} \cdot (h_1 - h_2) + \left(\frac{\dot{m}_1}{2} - \dot{m}_2 \right) \cdot (h_2 - h_4) + \frac{\dot{m}_1}{2} - \dot{m}_2 - \frac{\dot{m}_4}{2} \cdot (h_4 - h_5) + \left(\frac{\dot{m}_1}{2} - \dot{m}_2 - \frac{\dot{m}_4}{2} \right) \cdot (h_5 - h_6) \quad (6)$$

- Ideal (isentropic) power:

$$P_{id,LPC-L} = \frac{\dot{m}_1}{2} \cdot (h_1 - h_{2is}) + \left(\frac{\dot{m}_1}{2} - \dot{m}_2 \right) \cdot (h_{2is} - h_{4is}) + \left(\frac{\dot{m}_1}{2} - \dot{m}_2 - \frac{\dot{m}_4}{2} \right) \cdot (h_{4is} - h_{5is}) + \left(\frac{\dot{m}_1}{2} - \dot{m}_2 - \frac{\dot{m}_4}{2} - \frac{\dot{m}_5}{2} \right) \cdot (h_{5is} - h_{6is}) \quad (7)$$

- Energy power loss:

$$\dot{E}n_{Loss,LPC-L} = P_{id,LPC-L} - P_{re,LPC-L} \quad (8)$$

- Energy efficiency:

$$\eta_{en,LPC-L} = \frac{P_{re,LPC-L}}{P_{id,LPC-L}} \quad (9)$$

LPT right cylinder (LPC-R)

- Mass flow rate balance:

$$\dot{m}_{6,Right} = \frac{\dot{m}_1}{2} - \dot{m}_3 - \frac{\dot{m}_4}{2} - \frac{\dot{m}_5}{2} \quad (10)$$

Energy analysis of LPC-R is performed with a same equations as for LPC-L (from Eq. 6 to Eq. 9), by using this modifications:

- In all the equations from Eq. 6 to Eq. 9, index LPC-L should be changed with LPC-R,

- In Eq. 6, $\dot{m}_2$ should be replaced with $\dot{m}_3$ and h_2 should be replaced with h_3 ,

- In Eq. 7, $\dot{m}_2$ should be replaced with $\dot{m}_3$ and h_{2is} should be replaced with h_{3is} .

Whole LPT (WLPT)

- Mass flow rate balance:

$$\dot{m}_6 = \dot{m}_{6,Left} + \dot{m}_{6,Right} \quad (11)$$

- Real (polytropic) power:

$$P_{re,WLPT} = P_{re,LPC-L} + P_{re,LPC-R} \quad (12)$$

- Ideal (isentropic) power:

$$P_{id,WLPT} = P_{id,LPC-L} + P_{id,LPC-R} \quad (13)$$

- Energy power loss:

$$\dot{E}n_{Loss,WLPT} = P_{id,WLPT} - P_{re,WLPT} \quad (14)$$

- Energy efficiency:

$$\eta_{en,WLPT} = \frac{P_{re,WLPT}}{P_{id,WLPT}} \quad (15)$$

Comparison of LPC-L and LPC-R

Comparison of both LPT cylinders is performed as a percentage difference of calculated values:

$$\text{Difference (\%)} = 100 - \frac{\text{calculated value for LPC-L}}{\text{calculated value for LPC-R}} \cdot 100 \quad (16)$$

4. Steam operating parameters

For the analyzed LPT, steam operating parameters in each operating point of Fig. 1 were found in [28] and presented in Table 1. According to the steam operating parameters from Table 1 are calculated all the other operating parameters in each operating point of Fig. 1 required for the analysis.

Table 1. Steam parameters in each operating point of Fig. 1 [28]

O.P.*	Mass flow rate (kg/s)	Pressure (bar)	Specific enthalpy (kJ/kg)
1	183.38	8.600	3144.39
2	10.39	3.600	2946.62
3	6.43	1.300	2758.30
4	6.96	0.600	2635.89
5	8.06	0.250	2506.11
6	151.56	0.065	2339.02

* O.P. = Operating Point (according to Fig. 1)

From known steam pressure and specific enthalpy in each operating point of Fig. 1 (Table 1) are calculated steam temperature, steam specific entropy and steam quality by using NIST-REFPROP 9.0 software [29] and presented in Table 2.

Table 2. Calculated steam operating parameters in each operating point of Fig. 1

O.P.*	Temperature (°C)	Specific entropy (kJ/kg/K)	Steam quality
1	342.14	7.3490	Superheated
2	240.61	7.3939	Superheated
3	142.00	7.4512	Superheated
4	85.93	7.4839	0.993
5	64.96	7.5009	0.953
6	37.63	7.5598	0.905

* O.P. = Operating Point (according to Fig. 1)

Ideal (isentropic) steam expansion process assumes always the same steam specific entropy as at the LPT inlet (pressures during such expansion remains the same as in the real expansion process). For LPC-L and LPC-R ideal expansion process is the same, Figure 2. Isentropic specific enthalpies, required for the calculation of ideal (isentropic) power of the LPT and both of its cylinders, are also calculated by using NIST-REFPROP 9.0 software [29] (according to Fig. 2) and presented in Table 3.

Table 3. Calculated steam operating parameters for the ideal (isentropic) expansion

O.P.*	Pressure (bar)	Specific entropy (kJ/kg/K)	Isentropic specific enthalpy (kJ/kg)
1	8.600	7.3490	3144.39
2is	3.600	7.3490	2923.80
3is	1.300	7.3490	2716.90
4is	0.600	7.3490	2587.50
5is	0.250	7.3490	2454.80
6is	0.065	7.3490	2273.50

* O.P. = Operating Point (according to Fig. 2)

5. Results and discussion

As noted in the description of Fig. 2 and in Table 1, LPC-L has first extraction in operating point 2 at the higher pressure in comparison to first extraction from LPC-R (operating point 3), Fig. 1. This element results with a fact that the LPC-L will earlier lose a certain amount of steam mass flow rate and after the first extraction throughout LPC-L will expand lower steam mass flow rate in comparison to LPC-R. The result of such extractions in both of the cylinders is that the LPC-R develop higher real (polytropic) and ideal (isentropic) power in comparison to LPC-L. Real and ideal LPC-L power are equal to 65828.14 kW and 71275.36 kW, respectively, while the real and ideal LPC-R power are equal to 69444.86 kW and 75180.61 kW, respectively, Fig. 3.

The whole LPT develops real (polytropic) power equal to 135273 kW, while ideal (isentropic) power of the whole LPT is equal to 146455.97 kW, Fig. 3.

From the considerations above can be concluded that the first steam extraction of each LPT cylinder dictates cylinder power (both ideal and real). The lower pressure and lower quantity of extracted steam mass flow rate in the first extraction of any cylinder will lead to higher power.

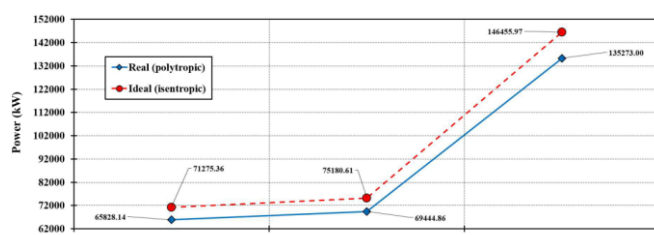


Fig. 3. Real (polytropic) and ideal (isentropic) power of LPC-L and LPC-R as well as of the whole observed LPT

A comparison of both observed cylinders shows that the LPC-R has higher energy loss and higher energy efficiency. The difference in energy loss between LPC-L and LPC-R is notable (5447.23 kW in comparison to 5735.74 kW), while the difference in energy efficiency between two observed cylinders is low, almost negligible (92.357% in comparison to 92.371%), Fig. 4.

Energy loss of the whole observed LPT is equal to 11182.97 kW and its energy efficiency equals 92.364%, Fig. 4. The final comparison in observed operating parameters between LPC-L and LPC-R will be presented in Fig. 5.

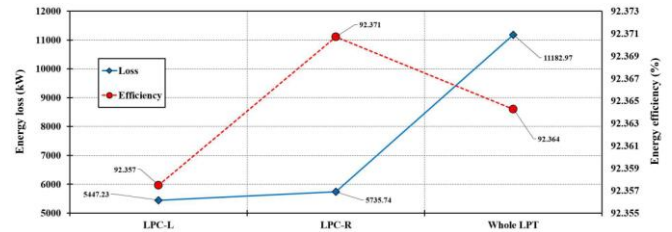


Fig. 4. Energy loss and energy efficiency of LPC-L and LPC-R as well as of the whole LPT

As can be seen from Fig. 5, comparison of differences between LPC-L and LPC-R shows that the LPC-L has approximately 5% lower real (polytropic) and ideal (isentropic) power as well as approximately 5% lower energy loss in comparison to LPC-R. The percentage difference in energy efficiency between two observed cylinders is almost negligible.

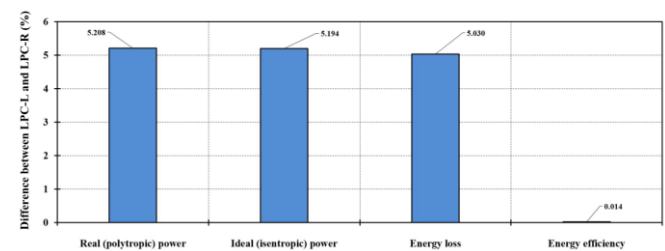


Fig. 5. Percentage difference in calculated power, energy loss and energy efficiency between LPC-L and LPC-R

Further research of the analyzed dual-flow dissymmetrical steam turbine and comparison of the obtained results with other dual-flow dissymmetrical steam turbines will be based on the results of energy and exergy analyses (turbine and both cylinders power, efficiencies and losses). The intention will be to create a sufficient dataset on which will be applied artificial intelligence techniques and methods already developed by our research team [30-35]. As a final result, the goal will be to obtain accurate and precise algorithm for a fast prediction of differences between cylinders in any dual-flow dissymmetrical steam turbine.

6. Conclusions

This paper presents an energy analysis of the dual-flow dissymmetrical low pressure steam turbine. Unequal extractions from left and right cylinder of the observed steam turbine makes various differences between observed cylinders. Based on the measured operating parameters from exploitation it is calculated ideal and real power, energy efficiency and energy loss for both cylinders and a whole turbine. The main conclusions obtained in this analysis are:

- The first steam extraction of each LPT cylinder dictates cylinder power (both ideal and real). The lower pressure and lower quantity of extracted steam mass flow rate in the first extraction of any cylinder will lead to higher power.
- LPC-R develops higher real (polytropic) and ideal (isentropic) power in comparison to LPC-L. The real and ideal power of LPC-L are equal to 65828.14 kW and 71275.36 kW, while the real and ideal power of LPC-R are equal to 69444.86 kW and 75180.61 kW, respectively.

- LPC-R has a higher energy loss and higher energy efficiency in comparison to LPC-L. The difference in energy loss is notable (5735.74 kW in comparison to 5447.23 kW), while the difference in energy efficiency is low, almost negligible (92.371% in comparison to 92.357%).

- Comparison of differences between LPC-L and LPC-R shows that the LPC-L has approximately 5% lower real (polytropic) and ideal (isentropic) power as well as approximately 5% lower energy loss. The percentage difference in energy efficiency between two observed cylinders is almost negligible.

7. Acknowledgment

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Contribution to the implementation of software control for seeding plates

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Summary: Seed plates of all seeding machines for widerow plants are powered by wheel of seeding machine and mechanical transmission. That has impact to volume and possibiltiz of steering. This paper show possibilities of using electromotor for power of seed plates as well as analysis possibylities acting steering by electro system. In this paper are research measurement system and create steering by programabil logic controller and shown idea for implementation steering of speed rotating of seed plates. That has aim to go about nominal seed space in row.

KEY WORDS: SEED MACHINES, SEED PLATE, PROGAMABIL LOGIC CONTROLER, ALGORITHM.

1. Introduction

The key agronomic factors that affect the nominal germination of seeds and consequently the adequate development of plants are the correct choice of culture in relation to the climate and type of soil on which seeding is performed, the method of soil preparation before seeding, the correct selection of seeds in terms of its type and geometric shape and selection of seeding dates and conditions [1,2].

The operation of one drill, and consequently the corresponding parts of the drill, can be divided into five phases:

1. shrinkage / leveling of surfaces,
2. surface consolidation by pre-compaction,
3. pulling the furrow and lowering the seeds,
4. pressing the seeds into the furrow and closing it,
5. compacting the soil around the seeds.

It should be noted that in most seed drill solutions, the individual phases partially overlap or occur simultaneously. Among all the mechanical assemblies of the seeder that ensure the execution of a certain phase of seeding, the highest degree of dynamism is possessed by the seeding machine by means of which the seed is lowered into the ground. As this is the most responsible machine assembly of the drill, there are a large number of solutions and designs that, in combination with the air flow, ensure the fulfillment of the role of the seeding machine [3].

The three key requirements for a seeding machine in the seeding process are:

- as much force as possible for pressing the seeds into the soil,
- the most precise distance and distribution of seeds per plot,
- no seed damage [4].

The germination rate depends on the manner and intensity of seed-soil contact, which later affects the resistance and development of the plant. Well-pressed seeds into the soil easier get moisture and nutrients, germinates faster and develops a root apparatus that affects the later stability, resistance and development of the plant. Therefore, it is necessary to achieve close contact between seeds and soil by pressing the seeds with as much force as possible. Depth of seeding for corn is 6-8cm, and for hemp and sunflower 4-7cm [5].

The even distribution of plants on the plot enables the plants to have equal access to resources, which entails even development and yield over the entire surface of the plot. A key prerequisite for achieving this goal is to invest the seeds in the soil at an equal, prescribed, distance between the seeds and later the plants within the row, since the distance between the rows is easy to adjust and maintain. Also, a very difficult requirement is placed in front of the seeding machine if "zigzag" seeding is needed, because then the work of the seeding machines on the seeder needs to be coordinated independently from section to section [6].

Damage to the seed is possible in several places during the journey that the seed crosses from the tank on the seeder to the furrow. Although not common, seed damage is still possible, mainly due to crushing and impact.

Each seeding machine takes the seed from the tank and lays / inserts it into the furrow formed in the soil. According to the stated requirements and functions that must be fulfilled by the seeding machine, it consists of three functional assemblies (Figure 1), closely connected and intertwined: seed plate which is the seed carrier from the moment of taking it from the tank to its ejection into the ground, scraper, excess seed from the seed plate which removes the seeds if the seed plate has taken several grains from the tank into one of its openings so that only one grain remains in the opening, and a seed ejector which is in charge of correctly and precisely laying the seeds in the soil. Air current of vacuum or compressor type is necessary in fulfilling the roles of the seeding machine, and in some types of pneumatic seeders it independently performs the roles of the above-mentioned assemblies [7,8].

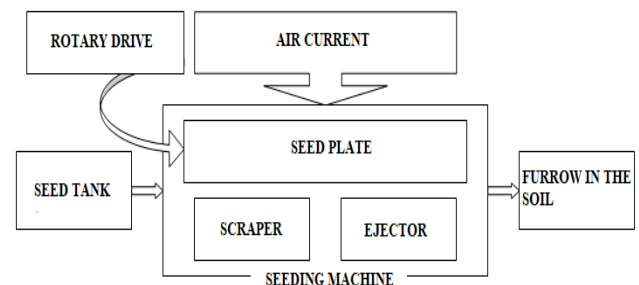


Figure 1. Structural diagram of seeding machine

2. Material and Method

In order to control the speed of the seed plows, it is first necessary to measure the speed of the tractor or the connected tillage machine. In this context, the speed of the tractor and the machine is transmission speed, and the speed of the seed plate is relative and depends on the transmission. It follows that it is necessary to measure the transmission speed, and introduce this signal as an input to the control body (programmable logic controller) which generates an output signal to control the speed of rotation of the working bodies through the executive control organ [9].

The measuring points for measuring of the transmission speed can be different depending on the type of machine and the type of sensor used. For mounted machines, the speed must be measured on the tractor as a driving machine. For towed and semi-mounted machines, which are most often used in practice, it is most convenient to measure the speed at the wheel of machine. In this case, it is possible to use an incremental encoder or inductive proximity sensor.

With the help of an incremental encoder, it is possible to measure the speed and angle of rotation of the seed plates with a resolution of up to 1/1500 per turn. However, the application of the

incremental encoder on tillage machines has so far been mostly only theoretical, as these machines are exposed to high vibrations that adversely affect the accuracy of the encoders themselves. In addition, the working conditions on the fields imply the exposure of the sensor to dust and precipitation, so this also calls into question the reliability of the encoder in the role of a speedometer for the tractor or seeder in the work on the plot.

Inductive encoders are by nature sensors of much more robust construction, and as such much more adaptable to the agricultural complex, ie the needs and conditions that prevail in tillage. These sensors work on the principle of inducing metal objects, so it is necessary to additionally equip the machine itself. The best way is to place the screws on the rim of the wheel of the machine at the same radius from the shaft. The number of screws also dictates the measurement resolution.

However, as it is practically impossible to achieve the resolution as when using the encoder, it is enough to place one screw on the rim of the wheel, and fasten the sensor axially in relation to it so that one pulse is induced when the screw passes the sensor. In this case, each pulse corresponds to one turn, and the resolution is corrected by software. The response of the system in terms of control is always better when there are several benchmarks around the perimeter and when each turn is manifested with more impulses. However, since the speed when seeding is of the order of 5-8 km/h, then a completely satisfactory quality of control is achieved with only one benchmark on the rim.

The first module is a power supply unit used to convert the mains voltage to DC stabilized voltage, which is necessary for the safe operation of the PLC, and an external voltage, which is used to power other consumers. The module itself is realized as a switching power supply with galvanic isolation. On the front of the module there are LED diodes as an indication of the correctness of the input voltages, a connector for connection to the mains voltage and a connector for external voltage. At the back of the module there is an EBUS connector through which the other modules are supplied with a DC stabilized voltage of 8-24V DC. This power supply module also features short-circuit protection, current protection, temperature protection and soft start. The CPU executes the driver, manages the IO modules and communicates with the superior system. On the front of the module there is a connector for serial communication with a random station or other CPU module, a circular switch for determining the PLC address in the network as well as LED indications of correct operation of the module and a connector for connecting external power. A PC is used as a programming and testing workstation and programming is done in LD language in accordance with IEC 1131-3.

The digital input / output module has 8 digital 24VDC inputs with a common end and 8 transistor outputs. The first two digital inputs can be used as counters. The last module was added to power the previous one.

3. Research Results And Discussion

In order to control the speed of the seeder, it is first necessary to measure the speed of the tractor with the seeder. This speed is transmission and the speed of the seed plate is relative and depends on the transmission speed. Therefore, it is necessary to know the transmission speed, and to introduce this signal as an input speed in the control body (programmable logic controller) which generates an output signal for speed control of working bodies through the executive control body [10].

For seeders, the speed is best measured at the wheel of the seeder. In this case, it is possible to use an incremental encoder or an inductive proximity switch.

With the help of an incremental encoder, it is possible to measure the speed and angle of rotation of the seed plates with a resolution of up to 1/1500 per turn. However, the application of the incremental encoder on seeders has so far been mostly only theoretical, while for a wider practical application it would be necessary to perform such an assembly that would protect the encoder from vibrations that adversely affect the measurement accuracy. Also, in order to be more precise, protection from dust and dirt should be performed [11].

Inductive sensors are by nature sensors of much more robust construction, and as such are much more adaptable to the needs and conditions that prevail when working in contact with the ground. These sensors work on the principle of inducing metal objects and it is necessary to additionally equip the seeders itself in the form of protrusions that are placed on the wheel. One way is to place the screws around the perimeter of the seeders wheel at the same radius from the shaft. The number of benchmarks also dictates the measurement resolution. The higher the number of benchmarks, the higher the resolution. However, as it is practically impossible to achieve the resolution as when using the encoder, it is enough to place one benchmark on the rim of the wheel, and the sensor itself is fixed axially relative to it so that one pulse is induced when the benchmark passes the sensor. In that case, each pulse corresponds to one revolution, and the lack of resolution is compensated by software. The response of the system in terms of management is always better when there are several benchmarks around the perimeter and when each turn is manifested with more time intervals. However, since the seeding speed is in the interval 5-8km / h, then a completely satisfactory quality of control is achieved by using only one benchmark per rim. The time that elapses between two benchmarks, ie between successive passes of the benchmark against the inductive sensor, determines the time interval, ie the measurement period on the basis of which the average speed of the seeder in that time interval is determined. The mean velocity for that time interval is calculated as the quotient of the circumference of the circle of that radius which corresponds to the distance of the measuring benchmark from the wheel axis and the measured time interval that characterizes that measuring period [12,13]. The seeders speed thus obtained is used to calculate the required seed plate rotation speed, provided that new information on the average seeders speed is obtained at the end of each time interval. It is used during the next time period to control the rotation speed of the seed plate, ie to determine the time after which the disc should be rotated to achieve seed equidistance in the furrow and at variable seeders speed. The stated logic of speed control of the seed plate is manifested in the generation of the time after which it is necessary to rotate the seed plate, shown in the algorithm in Figure 2.

Control in such a system is realized by means of programmable logic controllers, so it is impossible to measure time continuously, but only discretely. That is why it is necessary to ensure that the controller has the best possible characteristics in the sense that the duration of equidistant pulses generated by the programmer's clock is as close as possible to zero. The number of these pulses n that pass between two passes of the benchmark against the sensor multiplied by the duration of one pulse t_i determines the time interval t used to calculate the average speed at that interval (if only one screw is placed on the rim of the wheel then it is also the time of one turn):

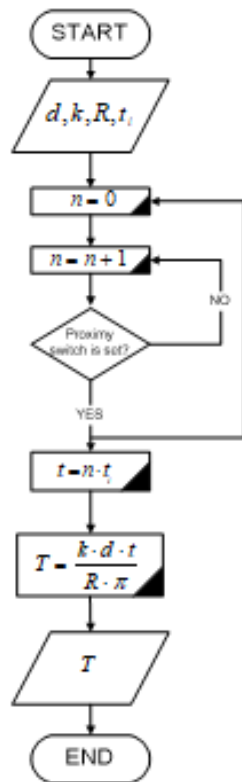


Figure 2. Block diagram of algorithm for speed rotation adjustment of seed plates

$$t = n \cdot t_i$$

where is:

T_i - the time after which the electric motor rotates the plate for a given angle,

k – number of benchmarks,

d - inter-seed distance,

t_{1-1} – time interval between two benchmarks in the previous countdown,

R - the diameter of the circle describing the center of the screw around the wheel axle.

The time after which the electric motor rotates the plate is subject to change and is always re-established at the end of each time interval required for the passage of the benchmark against the sensor which can remain unchanged if the controller stated that during the new and old measurement period, the same number of pulses was counted between the moments when the screws passed the sensor.

The benchmark itself has a certain dimension, so the sensor registers it along the entire length of that diameter when the screw passes against the sensor. Therefore, it is necessary to define that the controller measures the time intervals between the ascending or between the descending edges of the pulses that determine the activation / deactivation of the sensor, depending on whether the proximity sensor is set as normally open or normally closes the switch. In Figure 3, a variant of time measurement between the ascending edges of the pulse is selected.

In this way, the speed of rotation of the machine wheels, ie the machine itself, was measured, which is represented by the number of pulses between two adjacent passes of the benchmark next to the sensor (in the case of only one benchmark) that is, the number of pulses between the passage of two screw benchmarks near the sensor (in the case of two or more benchmarks). The number of pulses is inversely proportional to the number of benchmarks. The pulse diagram for the switches and parameters used is shown in Figure 3. Imp 10ms are programmer clock pulses of 10 milliseconds each, the switch is set when the sensor is against the screw, TrVrem is the number of counted pulses between the ascending edges of the pulse switch, PrVrem is the number of pulses in the previous countdown cycle.

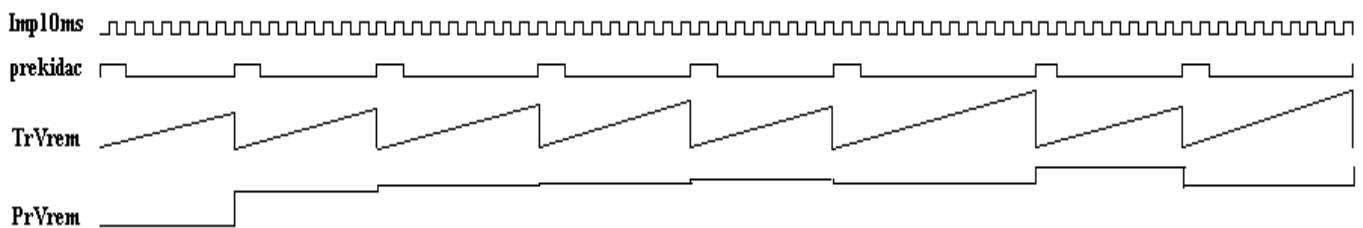


Figure 3. Impuls diagram; during the testing of the software in the monitoring mode, a logical change of parameters was noticed, which indicates the proper functioning of the control body.

4. Conclusion

One of the possible directions of development of pneumatic seeders could be automation of seed plate rotation, especially with vacuum seeders, which would simplify the construction of the seeders, reduce their robustness, and enable electronic control and monitoring of seeding. According to this possible solution, the seed plates would not achieve their rotational movement by means of bulky and complicated mechanical transmissions, but simply by means of electric motors or hydraulic motors. The speed of the seeder would be measured by means of an inductive proximity sensor placed on the wheel of seeder based on whose signal, and the appropriate algorithm and the desired seeding distance, the programmable logic controller (PLC) would control the engine speed and consequently the seed plate itself. The problem in the

realization of this idea from the aspect of using electric motors could be the power of the motor to overcome the resistance, ie the realization of the desired torque. A hydraulic motor would not have a problem of this kind, but from its point of view, the problem could be a long response time, and an expensive and robust hydraulic installation. Further research should be directed towards testing the torques of seed plates in order to enable full automation of their work [14].

Further development of the entire control system should be done in the direction of connecting with adequate executive bodies that can respond to the control signal and at the same time physically achieve the same control. It is also possible to connect the control console to the display on the PLC or to connect the system to the tractor control system via the CANbus system. The software designed in this way supports the delay management system, whereby this delay is constant during the management

process so that it does not affect its quality, because the time intervals in which the movement of the seed plate is initiated are equidistant.

5. Acknowledgments

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Comparative Analysis of Geometrical Characteristics of a Test Specimen for Testing the Tensile Strength Before and After Punch Sharpening

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Abstract: In the present article, a comparative analysis of the widths and thicknesses of a test specimen prepared by punching a hydraulic press before and after sharpening the guillotine blades is made. The types of characteristics of the punch are considered. The comparative analysis was performed by a non-destructive method using a 3D computed tomography.

Keywords: WIDTH, THICKNESS, TEST SPECIMEN, PUNCH, 3D TOMOGRAPHY

1. Introduction

During the tensile test, test specimens are tested, the shape of which must ensure a homogeneous uniaxial tensile condition of tension in its working part during the test.

The design of the technology for cutting a metal test specimen necessary for the tensile strength test provides for determining the shape and dimensions of the test specimen, determining the number, type, and sequence of intermediate operations (if any) and determining the required force for the implementation of technological operations. The standard by which the test specimen is prepared is BDS EN ISO 6892-1 [1].

The present work aims to make a comparative analysis of a test specimen for tensile strength testing. The specimen was prepared on a hydraulic press and the specimen was taken before and after sharpening the guillotine blades. The analysis was performed by using a 3D industrial computed tomography.

2. Experimental Setting

2.1. Specimen for research

Normally, the tested metal tensile strength specimens shall have widenings at both ends of the parallel length, which engage the jaws of the test machine. The other reason for these widenings is to avoid the rupture of the test specimen at the jaw grip of the test machine (Figure 1),

where:

a_0 - thickness of the test specimen, mm;

b_0 - width of the original thickness of a flat test specimen, mm;

S_0 - section of the test specimen, mm;

L_c - parallel length, mm;

L_0 - original overall length, mm;

L_t - total length of the test specimen, mm2.2. Basic equipment used

The dimensions of the test specimen are determined according to the standard BDS EN ISO 6892-1 with a width and tolerance of 20 ± 1 mm.

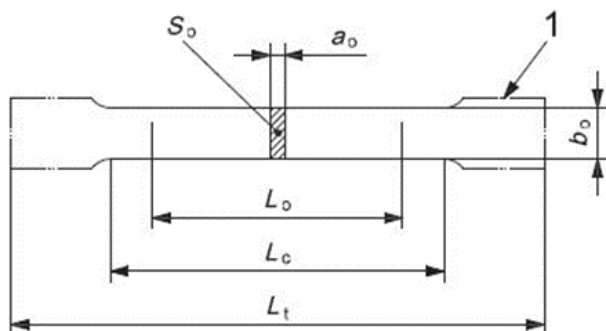


Fig. 1 Model of punched test specimen with a rectangular cross-section.

2.2. Technological preparation - punching

Punching makes it possible to quickly produce a product from the starting material with high precision and a perfect desired shape, which can immediately move on to the next stage of production or even be put into operation. During the punching process, the material does not lose its original properties such as strength and corrosion resistance.

The force of pressure, which is performed by mechanical or hydraulic punching presses, carries out the processing of sheet materials by plastic molding. The molding process begins with the creation of a specific matrix according to which the element will be made. After completing the die to be used in the manufacturing process, the sheet or strip is placed on the die, and pressure is applied to the metal by force. Thanks to the good interaction between the press and the die, the sheet material is formed into a final product without any defects and without the need for additional processing [2, 3].

Cutting is done with mechanical scissors with parallel or inclined blades or with disc scissors. In mechanical scissors with inclined blades, also called guillotines, the upper blade is inclined to the lower at a certain angle in the range $2-6^\circ$. Therefore, only a certain part of the cross-section of the sheet is cut with them at any one time, and therefore the cutting force is less. A disadvantage of guillotine shears is that the cut strip bends in the direction of movement of the upper blade and it has to be straightened. A pair of disc blades that rotate in opposite directions does cutting with disc scissors. Under the action of friction forces, the sheet material is entrained between the discs and is gradually cut similar to cutting with guillotine shears.

In the specific case, the press used is hydraulic with a single cutting punch with a simple action with a test specimen. The punch for the press is manufactured in the tool department of the company according to the requirements that must be met for the production of the desired sample for a test specimen. The hole of the punch for placing the test specimen has dimensions $H \times W - 300 \times 40$ mm.

Figure 2 shows a test specimen with the presence of edges in the cutting area before punch sharpening (marked with elliptical shapes in the figure). The detail was taken from the last batch before stopping the machine for sharpening the guillotine blades of the punch in the company's workshop.



Fig. 2 Test specimen with edges (before punch sharpening).

2.3. Used equipment

The Nikon XT H 225 3D industrial computed tomography was used for the analysis of the linear values of width and thickness (Fig. 3) [4, 5].

Computed tomography (CT) is a non-destructive method that provides high accuracy and can examine the internal and external dimensions of the provided test specimen. It also provides an additional view through the density of the material and its microstructure.



Fig. 3 3D industrial computed tomography Nikon XT H 225.

3. Experimental Results

The obtained data from the experimental results are presented in tabular form. Table 1 shows the values of a test specimen measured with a 3D computed tomography by using a non-destructive method before punch sharpening of the press, and Table 2 after punch sharpening the press. One specimen was analyzed before punch sharpening of the press, and measurements of the width were made at three points and three planes, shown in fig. 5, 6, and 7. After sharpening the blades, an analysis of 1 specimen was also performed at three points in one plane.

Table 1: Test specimen values measured with a 3D computed tomography before punch sharpening of the press.

Measurement	Number of measurement	Beginning	Middle	End
Width, mm	1	19,93	20,04	19,81
	2	19,95	20,04	19,69
	3	19,94	20,05	19,63
Thickness, mm	1	0,92	1,04	0,88

Table 2: Test specimen values measured with a 3D computed tomography after punch sharpening of the press.

Measurement	Number of measurement	Beginning	Middle	End
Width, mm	1	19,98	19,96	19,96
Thickness, mm	1	1,01	0,97	1,01

After the 3D computed analysis of the test specimen, prepared before sharpening the guillotine blades of the press, a defect on its surface is visualized. Due to the wear of the blades, the metal is

crushed and deformed. The size of the defect is 0.12 mm, as is shown in Fig. 4.

From the analysis of the two types of specimens, it is clear that in the examined specimen produced before sharpening the blades, the deformation is visible. The positions of the measurements are at three planes, presented in the beginning, middle, and end (Fig. 5).

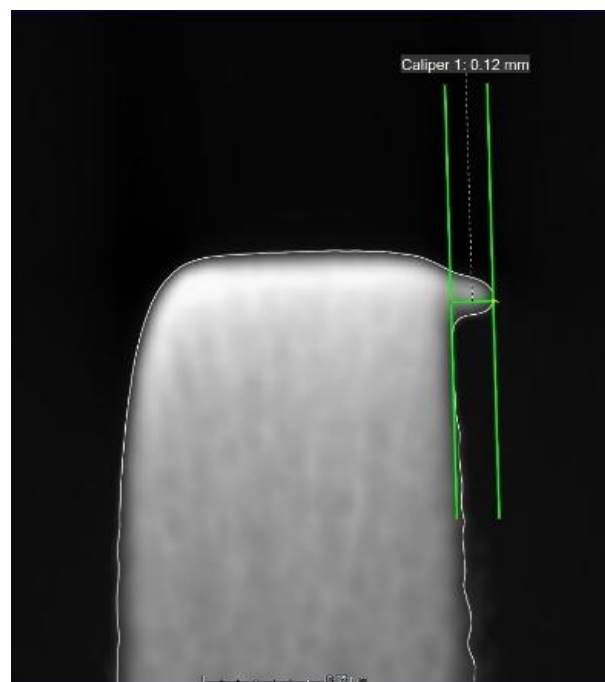


Fig. 4 Defect of the test specimen after punching.

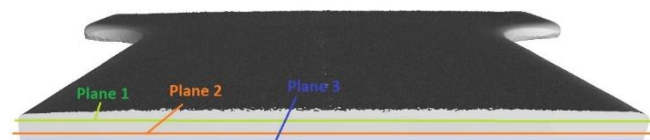


Fig. 5 Position of the plane.

In Fig. 6 in the first plane (the upper side from which the blade falls on the metal sheet) are taken 3 sizes of width – 19.81 mm; 19.69 mm; 19.63 mm. On this surface, the metal is crushed and there the width is the narrowest. In the next plane - the middle (Fig. 7) the width is the largest – 20.04 mm; 20.04 mm; 20.05 mm. In the third plane of Fig.8 (the lower point of the metal sheet) there is a deformation, displacement of the metal, the so-called edge with dimensions of width: 19.93 mm; 19.95 mm; 19.94 mm. The defect that occurs is seen in fig. 9 when measuring the thickness of the specimen. Significantly less thickness was measured at the edges of the specimen than the actual thickness in its middle - 0.92 mm; 1.04 mm; 0.88 mm.

From the analysis of the test specimen prepared after punch sharpening of the press, a uniform width (Fig. 10) and thickness (Fig. 11) is observed. The dimensions of the width are: 19.98 mm; 19.96 mm; 19.96 mm, and those of thickness is 1.01 mm; 1.03 mm, 1.01 mm.

The punch has guillotine blades and after long use, there is an edge on the surface of the test specimen, which must be cleaned or the knives of the die must be sharpened.

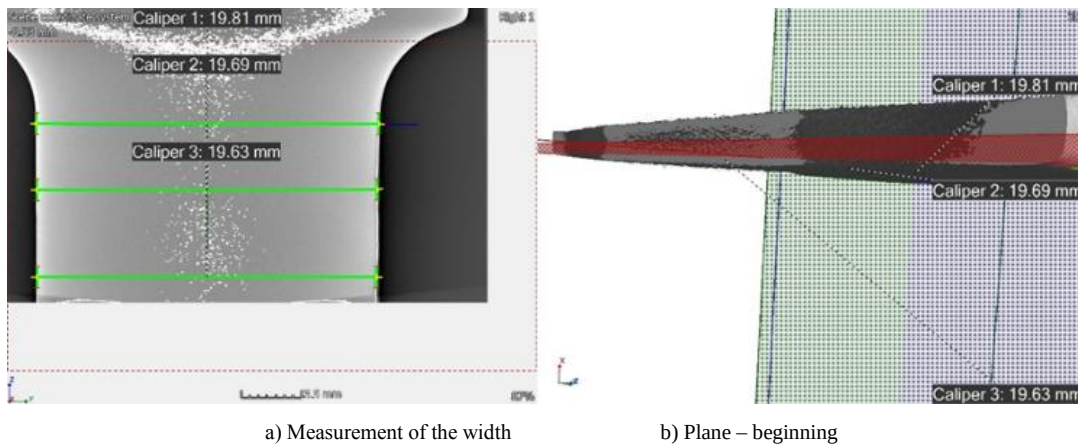


Fig. 6 Measurement of the width of a specimen in the plane – beginning.

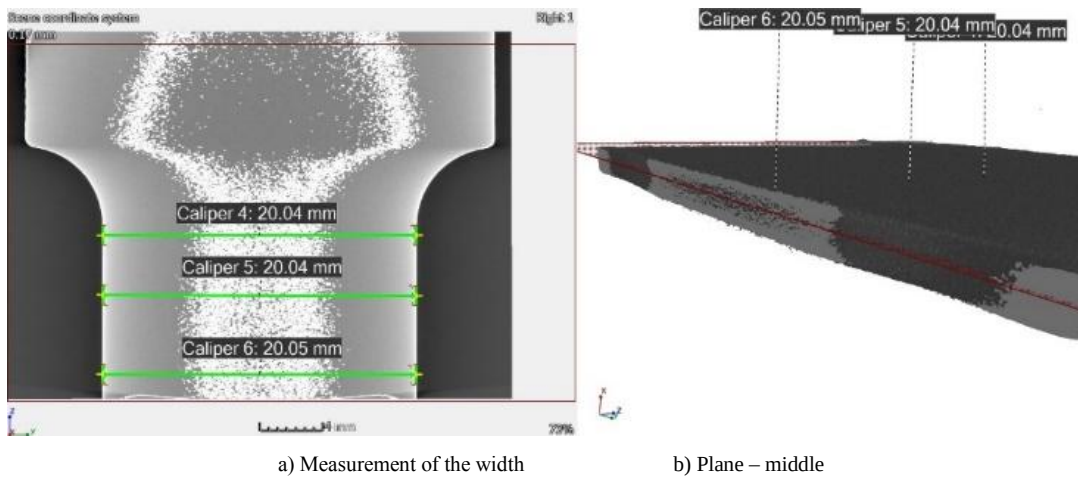


Fig. 7 Measurement of the width of a specimen in the plane – middle.

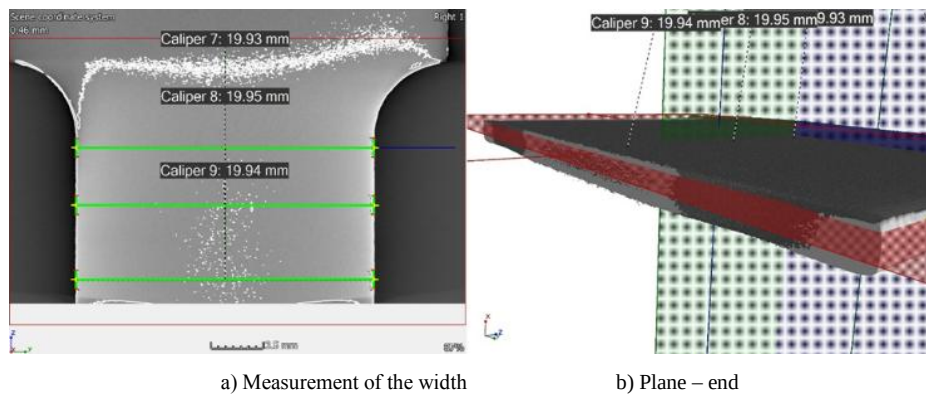


Fig. 8 Measurement of the width of a specimen in the plane – end.

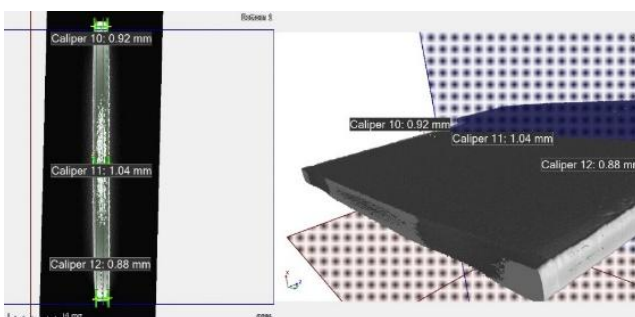


Fig. 9 Measurement of specimen thickness before sharpening.

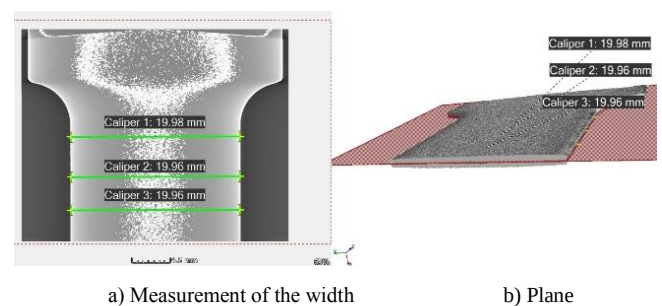


Fig. 10 Measurement of specimen thickness after sharpening.

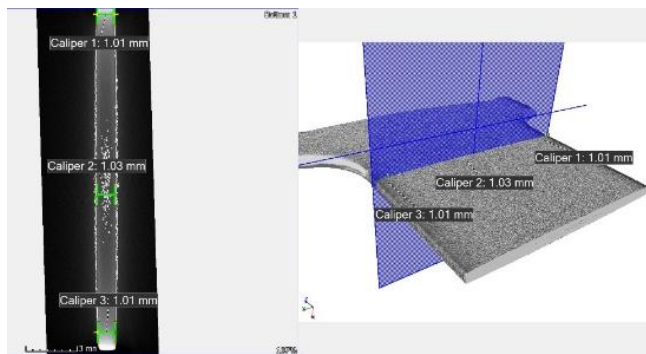


Fig. 11 Measurement of specimen thickness after sharpening.

4. Conclusion

From the comparative analysis of the geometrical characteristics of a metal test specimen for tensile strength testing, prepared before and after sharpening of the guillotine blades of the press, significant differences were found. From the measurements made on a 3D computed tomography it was found that when the blades are worn out, large defects occur on the surface of the specimen. During the detailed measurement of the width, there is a crushing of the metal on the upper side of the blade, uniformity in the middle, and a defect in the lower part of the specimen. And the thickness in the final widths is 0.12 mm less, in contrast to the test specimen prepared after sharpening, where the thickness and width are uniform.

Due to the variety in the hardness and thickness of the test specimen, it is difficult to say after what period of work the guillotine blades of the punch wear out. According to observations for the needs and workload of the current production, it is necessary to sharpen every 2 years on average. Timely sharpening of guillotine blades on the press can lead to a more accurate measurement of tensile strength.

An intermediate inspection of the test specimen for 6 months is recommended, depending on the press load.

Future analysis will be performed to the mechanical parameters when testing the tensile strength of the test specimen before and after sharpening the guillotine blades of the press.

Acknowledgment

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Mechanical finger prosthesis design and manufacturing by modern technologies

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Abstract: The article deals with the use of CAD software and additive technology to produce a simple, low-cost mechanical finger prosthesis. The goal was to use SOLIDWORKS and Cura software to design and manufacture an index finger prosthesis from PLA (polylactic acid) material, using an FFF (Fused Filament Fabrication) desktop 3D printer Bq WitBox. The mechanical finger prosthesis is used for flexion and extension performance of the missing joints to enable lost gripping function. The designed prosthetic finger has a simple construction consisting of components made on a 3D printer and its movement functions are initiated by specifically attached cable system. The practical part of the paper contains procedures for prototype and final version design, manufacturing and testing. The prototype was designed to imitate healthy finger digits movement initiated by the specific cable system. Final version of the finger prosthesis has been designed after the successful flexion/extension system testing. The design of the components was modified to resemble a healthy finger and a socket has been added to the prosthesis. Flexion and extension performance of the prosthesis was tested using cables of different diameters. After summarizing the results, it has been confirmed that the prosthesis can be easily applied to the arm and its dimensions, construction and movement correspond to an anatomically healthy finger and that 3D printing is a technology suitable for efficient and fast production of individual prosthesis components, which is an indisputable advantage compared to the traditional method of prosthesis production.

Keywords: FINGER PROSTHESIS, ADDITIVE MANUFACTURING, FUSED FILAMENT FABRICATION

1. Introduction

The human hand is one of the most important organs for man, since it distinguishes us from other animals. The reason for this uniqueness is that it can oppose the thumb, which allows it to manipulate objects and perform precise grips. Arms and grasps are very important for everyday activities such as eating, hygiene, dressing and the like. The powerful elements during the individual phases of gripping are the fingers and thumb. In case of their injury, illness or amputation, the performance of normal motor activities is considerably complicated or completely impossible. Prosthetic finger replacements made by additive manufacturing can solve these problems. The article describes the design and methodology of prosthetic finger production using modern technologies.

2. Methodology

The aim of the work was to create a functional mechanical finger prosthesis that will allow flexion and extension in the PIP (proximal interphalangeal) and DIP (distal interphalangeal) joint. The reason is the amputation in the proximal phalange and thus the absence of the possibility of performing grips. Before designing the prosthesis, itself, it is necessary to clarify what movement functions of the arm need to be replaced and in what most suitable way it can be realized.

One of the most important tasks is to ensure that the prosthesis matches in the size parameters of the finger joints, as well as in their movement paths [1].

Prosthesis design phases:

- Design, 3D modelling and printing of a prototype.
- Assembly and functional testing of a prototype.
- Design, 3D modelling and printing of the final version
- Folding, application of the final prosthesis and testing

3. Solution

3.1 Design, 3D modelling and printing of a prototype

The construction of the prosthetic finger movement chain model consists of four artificial phalanges connected by joints, which represent the individual phalanges and joints of the index finger, including the MCP (metacarpophalangeal) joint, which is the most proximal in this chain. The functionality of this model is ensured by the application of a cable system passing through the individual finger joints and phalanges and is anchored proximally to the MCP joint, which is the driving element bending the prosthesis components [2, 3].

Through a specially designed system of channels and holes in the prosthesis, the cables serve to initiate flexion and extension in the PIP and DIP joints (Fig. 1). Bending the MCP joint lengthens the distances A, B and shortens C, D, which causes flexion in the PIP and DIP joints [4, 5].

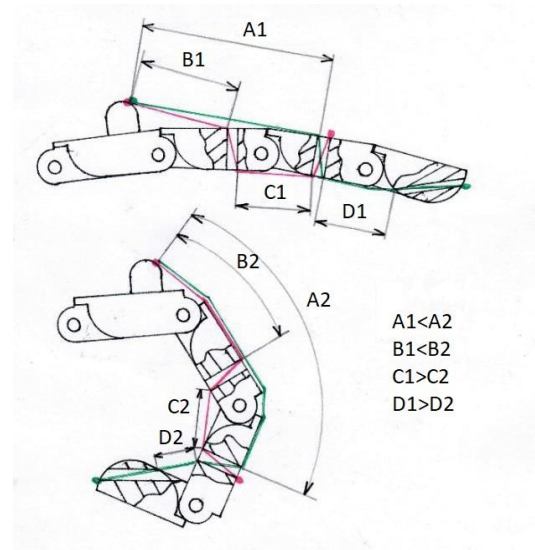


Fig. 1 Design of a prosthesis cable system.

All components have been designed in SOLIDWORKS (Dassault Systemes, Waltham, USA) software. Parts of the prototype were printed in a larger scale, for easier handling and the design is simplified.

The design of the prototype consists of eight components (Fig. 2), which are:

- 1x fingertip (distal joint),
- 3x phalange,
- 1x anchorage (for fixing the cable system),
- 3x peg (articulated connection)

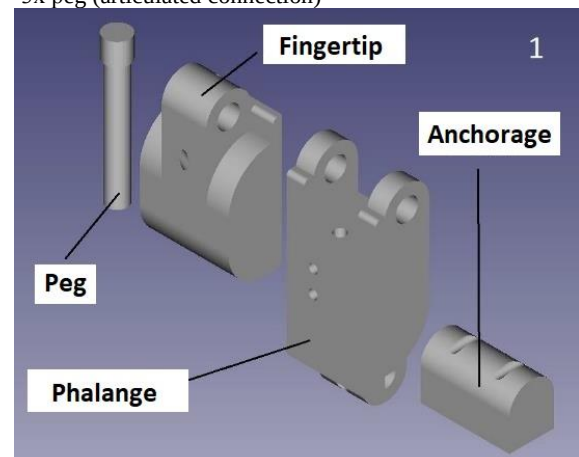


Fig. 2 Prosthesis prototype components.

The individual components of the prosthesis were manufactured on a Bq WitBox (bq Engineering, Madrid, Spain) 3D printer. This printer allows printing of large objects or multiple components at once. It is a fully enclosed printer with a front door locking system that prevents accidental access during printing. Its fully enclosed design helps minimize noise, while preventing heat leakage and maintaining a constant temperature inside the printer.

Bq Witbox is an FFF printing system, which means that a fibre of material leads through a Fibonacci guide tube into the nozzle. Due to this design, the feeder system remains inside the printer unit, thus reducing the amount of contact between the fibre and the tube.

The material used to make the prosthesis is PLA (polylactic acid) and the software used to set the printing parameters was the Cura (Cura Global GRC Solutions Pte Ltd., Singapore, Singapore) software.

Cura is a software that prepares and converts 3D computer-generated models into commands that follow the printer.

After positioning the model on the working platform, the software allows setting individual printing parameters, such as layer thickness, object fill density, print speed, nozzle temperature, support and thickness, or fibre flow (Fig. 3).

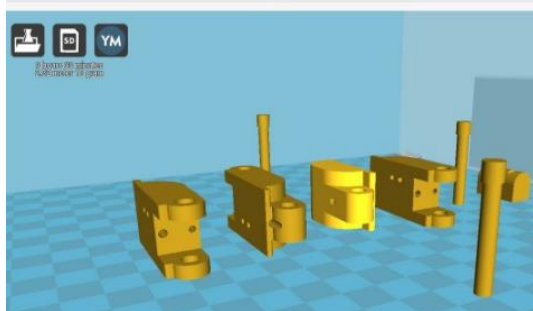


Fig. 3 Positioning models on a work platform.

Selected print parameters:

- Layer height = 0.1mm.
- Shell thickness = 1mm.
- Bottom / top wall thickness = 0.5mm
- Infill density = 10%.
- Print speed = 50mm / s.
- Without support.

After setting the individual parameters, the software automatically determined the length of the printing time (3h 38min.). The weight of the material used (18g) and the length of the fibre used (2.32m).

3.2 Assembly and Functional Testing of the Prototype

After 3D printing, the parts are carefully separated from the printer's work platform and are thoroughly cleaned. Another important step for the successful assembly of the prosthesis is postprocessing, i.e. grinding of all parts of the prosthesis, especially in places where the individual components meet residual support material. Thorough treatment of the components is followed by the assembly phase of the prototype prosthesis.

In the proposed model, the finger phalanges are connected by pegs in the DIP, PIP and MCP joints. The anchorage on which the rigid cables will be attached is attached to the proximal phalange, just behind the MCP joint (Fig. 4). In forming the extensor system, a knot is tied at one end of the elastic cord and the free end is threaded through an opening at the end of the distal member that extends through the entire component. In this way, it is passed through the individual links of the prototype and secured at the end of the proximal link. To create a flexor DIP joint system, it is necessary to knot one end of the rigid cable and pass the free end through the hole at the end of the distal phalange. The free end is removed from the hole on the palm side and then passed through the hole on the palm side on the next link, after which the end of the cable is attached to the anchorage. To form the flexor system of the PIP joint, one end of the rigid cable is knotted and passed through the dorsal opening of the cavity on a phalange proximal to the tip of the prosthetic finger. Subsequently, the cable is passed through the

palmar opening of the cavity on the more proximal phalange and the end is fixed to the anchorage [6].



Fig. 4 Finger prosthesis prototype.

With the applied cable systems, the prototype of the prosthesis is fully functional, i.e. flexion in the MCP joint induces flexion in both the PIP and the DIP joint (Fig. 5). After performing a functional test of the prototype, the production of the index finger prosthesis with a socket and an anatomically more accurate design continued.



Fig. 5 Functional testing of the prototype.

3.3 Design, 3D Modelling and Printing of The Final Version

In the final phase of the design of a prosthetic finger, it is also necessary to consider the aesthetic function. For this reason, it is necessary to emphasize the appearance, dimensions and shape of the socket. The prosthesis must resemble an anatomically correct index finger as much as possible, i.e. its dimensions and the location of the joints must correspond to the parameters of the original index finger. To obtain the most realistic finger, it is advisable to use the mirroring of the preserved healthy arm, as it is a paired organ.

The prosthesis socket is one of the most important parts of the prosthetic system and must not restrict or prevent the movements of the thumb and middle finger of a healthy arm. Its circumference must not differ significantly from the circumference of the stump in order to ensure its best possible attachment. Since the prosthesis will be hung on a wooden hand, a socket with the same inner circumference as the circumference of the artificial stump has been designed to make the suspension of the prosthesis as strong as possible. A sleeve has not been used.

The individual components of the prosthesis have a cylindrical shape, on the dorsal side they are equipped with stops that prevent the prosthesis from performing hyperextension, and a special system of cavities and ducts inside the prosthesis parts through which the cables will pass has been designed [7].

The construction of the final finger prosthesis (Fig. 6) consists of:

- 1x fingertip (distal link),
- 1x phalange (medial link),
- 1x phalange with socket (proximal link),
- 1x anchorage (for fixing the cable system),
- 2x peg (articulated connection)

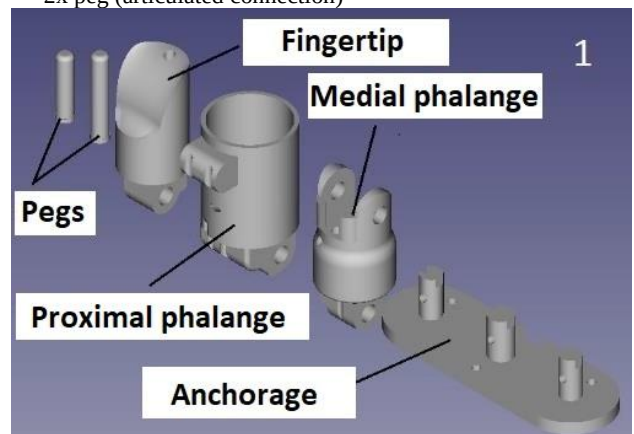


Fig. 6 Components of the final version of the finger prosthesis.

The material, production technology and process settings of the

final prosthetic finger are identical to the prototype (Fig. 7). Only the colour of the material has changed.

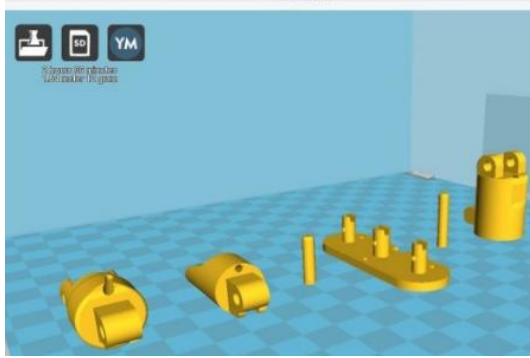


Fig. 7 Positioning models on a work platform.

Result of saving models in the Cura software:

- Print time length: 2h 36min.
- Weight of material used: 12g.
- Length of fibre used 1.54m.

3.4 Folding, Application of the Final Prosthesis and Testing

The procedure for assembling a prosthetic index finger is identical to the procedure for assembling a prototype prosthesis. It is important to thoroughly clean all components of unwanted residual material and, if necessary, to grind the areas where the individual components come into contact. Subsequently, the prosthesis can be built.

By connecting the distal and medial phalange with a shorter peg, a DIP joint is created. The same connection of the medial and proximal phalange with the longer peg creates a PIP joint. The constructed prosthesis is placed on the stump and the cable systems is inserted (Fig. 8).

While forming the extensor system, an elastic cable is used which has a knot at one end and the free end is threaded through an opening at the distal end of the socket. Next, the cable is guided through a cavity on the dorsal side of the medial phalange and subsequently through a cavity on the dorsal side of the distal phalange, at the end of which is the second knot.

Since the functionality of the double flexor system was confirmed during the prototype's testing and this system proved to be suitable, it is also applied in the final version of the prosthesis. To create a flexion in the DIP joint, a rigid cable is used, at the end of which there is a knot and the cable is guided through a distal opening on the distal phalange and subsequently the cable is threaded through it. The cable is further passed through the medial phalange through an opening in the distal part. A rigid cable was also used to form the flexor system of the PIP joint, at the end of which there is again a knot and the free end is guided through an opening on the dorsal side of the medial phalange. The cable emerges from the palmar opening and is threaded through the opening on the distal side of the socket, passing crosswise through the bottom and through the opening on the dorsal side.



Fig. 8 The final version of the finger prosthesis.

In places where the cables meet the edges, grooves have been

formed on the prosthesis' components to minimize friction and to prevent rigid cables from protruding from the prosthesis. This modification reduces the risk of damage to the cable systems and improves the contact of the prosthesis during the gripping of objects.

The cable system anchoring component is attached to the dorsal part of the palm of the wooden hand by means of two small cross screws proximal to the MCP joint to secure the cable systems as firmly as possible. When attaching rigid cables for anchoring, it is necessary to position the prosthesis in its end position, i.e. in the position in which the tip of the prosthetic finger touches the palm of the hand model. When the finger is in the given position, the cables are the most tensioned and are firmly knotted on the pins of the anchoring component. The cables are attached to two different pins (PIP joint bender on the left and DIP joint bender on the right), in order to make the tension adjustment as simple as possible and to prevent accidental tangling of the individual cables.

3.5 Finger Prosthesis Testing

After the assembly of the final prosthetic finger, the phase of its functional testing follows. To verify the effectiveness of the flexion of the finger prosthesis in order to design its modifications or correction, it is necessary to monitor the course of individual phases of this movement.

Prosthetic finger flexion phases (Fig. 9):

- Phase 1 (zero position / extension),
- Phase 2 (flexion of MCP, PIP and DIP joint),
- Phase 3 (flexion of MCP and PIP joint, DIP joint is in the maximum possible flexion),
- Phase 4 (final position - MCP, PIP and DIP joints are in the maximum possible flexion)

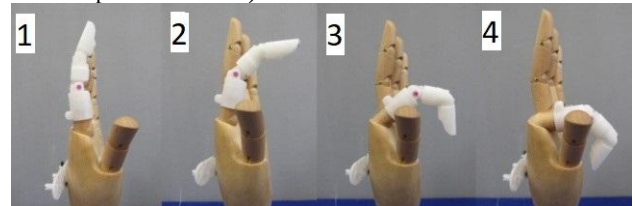


Fig. 9 Stages of finger prosthesis flexion.

4. Results and Discussion

Performing complete flexion in the MCP joint revealed, that during the transition from the 3rd to the 4th phase, the cable system of the DIP joint is deployed and the cable rubs against the lateral side of the MCP joint, and that the fingertip does not touch the palm of the hand model.

The first problem was eliminated by creating 2 cavities directly through the protrusion on the dorsal part of the socket, through which the rigid cables are passed, and the cable system of the DIP joint is attached to the more medial pin of the anchoring component. This removed the unwanted dislocation of the cable from its original bearing.

To solve the 2nd problem, different diameter of cables were applied (see Table 1) and the course of flexion in individual phases was documented.

Table 1. Cable types

Cable	Diameter (mm)	Load capacity (kg)
Cable 1	0,22	5
Cable 2	0,36	14
Cable 3	0,50	18

When using cable 1, there was no flexion in the PIP joint of the prosthesis and flexion in the DIP joint is incomplete. This diameter is not satisfactory. The application of cable 2 has improved the

flexion in both joints of the prosthesis, but the flexion in the PIP joint is incomplete and in phase 4 of the prosthesis flexion the fingertip does not touch the palm of the hand model. Using cable 3, the flexion in the joints of the prosthesis is complete and the fingertip touches the palm of the hand model (Fig. 10).

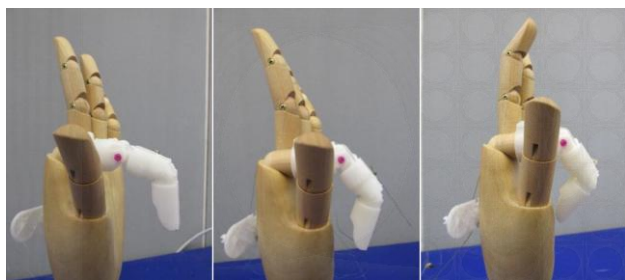


Fig. 10 Testing of the prosthesis cable system.

As shown on the procedure above, for selecting a suitable type of cable that the diameter of the cable has a significant effect on achieving the desired finger flexion. This is caused by different plastic deformations of different types of cables.

5. Conclusion

The aim of this article was to design, build and test a functional mechanical index finger prosthesis with components made by additive manufacturing. The design of the proposed prosthesis resembles an anatomical finger and its movement mechanism is simple and effective. The prosthesis can be easily applied to the arm and its dimensions and construction correspond to an anatomically healthy finger. 3D printing is a technology suitable for efficient and fast production of individual prosthesis components, which is an indisputable advantage compared to the traditional method of prosthesis production.

In the future, the application of sleeves is being considered, for which it is appropriate to upgrade the prosthetic finger. The reason is to improve the aesthetic function and obtain a more natural look, as well as to improve the functionality that can be achieved by applying anti-slip sleeves to increase the certainty of performing the grip. It is necessary to design a glove in which the cable systems of the prosthesis will be anchored, without limiting their functionality.

6. Acknowledgments

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Optimization of the electron beam welding of Steel 45 samples

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Abstract: An experimental study of the geometrical characteristics of the cross sections of the thermally affected areas obtained by electron beam welding of carbon steel 45 is made. The thermally affected zone and the molten area of the welds from non-stainless steels corresponds to a zone where the physical-mechanical properties and the microstructure of the processed material are changed after the processing. The process parameters that were changed during the experiments are: welding speeds were 0.5, 1.0 and 1.5 cm/sec, the beam current was changed in the range of 30 - 133 mA and the focus position was changed from 72 mm above the sample surface to 62 mm below the sample surface. The accelerating beam voltage was 50 kV. The geometry of the weld in the cases of a deep penetrating electron beam and narrow thermally affected zone is investigated. Electron beam welding process parameter optimization is performed, based on the estimation of regression models. In such way the electron beam optical systems can be tested and the specific quality requirements for the welds obtained by electron beam welding can be fulfilled.

Keywords: ELECTRON BEAM, WELD, HEAT-AFFECTED ZONE, REGRESSION ANALYSIS, OPTIMIZATIONS, STEEL 45

1. Introduction

Industrial use of carbon (0.45 wt.%) Steel 45 is connected with the production of gear shafts, crankshafts and camshafts, gears, spindles, cylinders, cams and other parts that are normalized, improved and subjected to surface heat treatment, and which require increased strength ($HB\ 10^{-1} = 170 \div 240\ MPa$). Steel 45 is difficult welding and special welding methods are applied, requiring heating and subsequent heat treatment. The chemical composition of Steel 45 in wt.% is: C is in the region $0.42 \div 0.5$; Si - $0.17 \div 0.37$; Mn $0.5 \div 0.8$; Ni - max. 0.25; S - max. 0.04; P max. 0.035; Cr - max. 0.25; Cu - max. 0.25; As - max. 0.08.

The accelerated introduction of new powerful heat sources - electron beams and lasers, compared to conventional fusion welding technologies is due to their advantages. Current research and development in the field of electron beam welding (EBW) is mainly related to process automation and quality improvement. This complex process produces welds long before the development of the scientific explanation for deep penetrating intense electron beams in metals [1 - 3]. The [4 - 6] physical and thermal models can serve only as a basis for forecasting of the geometric parameters of the obtained seams and are not suitable for use in the automation and control of EBW installations. Good alternative for the control of the process is the implementation of statistical approach to data processing and modeling of stainless steel [7 - 10].

In this work for the research of the EBW process Response Surface Methodology is implemented. An experimental study of the geometrical characteristics of the cross sections of the thermally affected areas obtained by electron beam welding of carbon steel 45 is made. The thermally affected zone and the molten area of the welds from non-stainless steels corresponds to a zone where the physical-mechanical properties and the microstructure of the processed material are changed after the processing (Fig. 1).

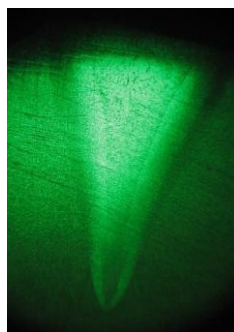


Fig. 1 Metallographic image of an experimental weld – the welded and the heat affected zones.

The process parameters that were changed during the experiments are: welding speeds were 0.5, 1.0 and 1.5 cm/sec, the beam current was changed in the range of 30 - 133 mA and the focus position was changed from 72 mm above the sample surface to 62 mm below the sample surface. The accelerating beam voltage was 50 kV. The geometry of the weld in the cases of a deep penetrating electron beam and narrow thermally affected zone is investigated. Electron beam welding process parameter optimization is performed, based on the estimation of regression models. In such way the electron beam optical systems can be tested and the specific quality requirements for the welds obtained by electron beam welding can be fulfilled.

2. Experimental conditions

Electron beam welding of carbon (0.45 wt.%) Steel 45 is performed [8, 10] and the experimental conditions that are shown in Fig. 2. The weld samples are placed at 30° towards the horizontal plane and moved by a manipulator. The sample movement results in different distances between the magnetic lens of the electron beam gun and the sample surface (z_s) and it is changed in the range between 228 mm to 362 mm. In same time the distance between the focus of the beam (marked as the distance "b" on Fig. 2) and the main surface of the magnetic lens of the electron gun is constant and it's 300 mm.

The influence of the variation of the process parameters: beam current (z_1), welding speeds (z_2) and the distances between the magnetic lens of the electron beam gun and the sample surface ($z_s - z_3$) on the geometrical characteristics of the Heat Affected Zones (HAZ) of the obtained welds is investigated.

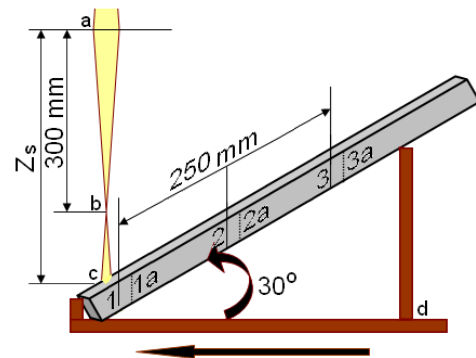


Fig. 2 Experimental conditions: a) main surface of the magnetic lens of the electron gun; b) beam focus (or beam waist); c) surface of the sample; d) manipulator in the EBW vacuum chamber.

The accelerating voltage is 50 kV; the beam current varies at four levels: 30, 66, 100 and 133 mA; and the welding speeds are 0.5, 1 and 1.5 cm/sec. The welded specimens are steel rods with rectangular sections (20 mm × 34 mm and 25 mm × 34 mm) and a length of 335 mm.

The geometrical characteristics of the thermally affected areas of the experimentally obtained welds were studied: transverse cross-section area S_{HAZ} , depth H_{HAZ} , surface width B_{THAZ} , average width B_{MHAZ} , as well as the ratio of depth to surface width of the heat affected area H_{HAZ}/B_{THAZ} . This ratio is important for setting the limit for the transition from the hemispherical toward deep and narrow welds (Fig. 3), which are typical for electron beam welding process. It can be accepted that for the heat affected zone this limit is $H_{HAZ}/B_{THAZ} = 1.2$, which will correspond to a ratio of 1.5 or more for the welded zone.

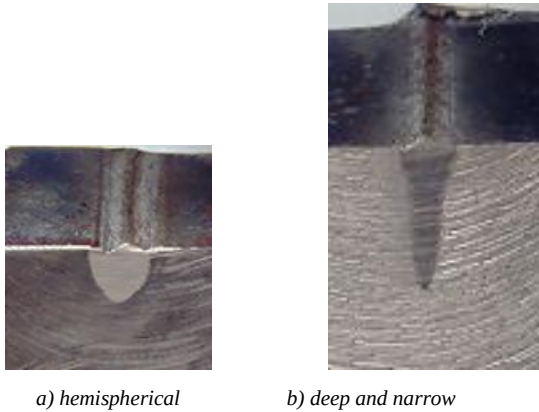


Fig. 3 Different shapes of the weld cross-sections.

The conducted experiment includes 58 process parameter sets and the corresponding geometry characteristics after EBW, measured after cutting the welded rods at an angle of 30°. Regression models were estimated for the geometrical characteristics of the thermally affected areas of the electron beam welds. The natural values of the factors (z_i) in the obtained regression models are coded in the region $[-1 \div 1]$ and the relation between the coded (x_i) and the natural values (z_i) is given by:

$$(1) \quad x_i = (2z_i - z_{i,max} - z_{i,min}) / (z_{i,max} - z_{i,min}),$$

where $z_{i,min}$ and $z_{i,max}$ are the corresponding values of the minimum and the maximum of the process parameters during the experiment.

3. Geometric characteristics of the thermally affected zones of the weld cross-sections

H_{HAZ}/B_{THAZ} is used to determine the limit value of the shape of the heat affected zone and can be used as a measure to roughly estimate the transition from a point to a linear heat source or from hemispherical toward deep and narrow welds (Fig. 3).

In order to apply the regression analysis a regression model for H_{HAZ}/B_{THAZ} ratio is estimated:

$$H_{HAZ}/B_{THAZ} = 2.2217645 + 0.71408576x_1 + 0.50453547x_2 - 1.0886828x_3^2 - 0.6469683x_2x_3^2$$

The value of the multiple correlation coefficient is $R = 0.8736$, and it is enough high and close to 1, so the estimated model for the H_{HAZ}/B_{THAZ} ratio can be considered as good enough for prediction and parameter optimization.

For the limit value of the ratio of depth to width of the surface of the thermally affected zone H_{HAZ}/B_{THAZ} the value 1.2 is accepted. The experimentally obtained results are divided into two, according to the limit value in order to increase the accuracy of the estimated models for the HAZ geometry.

For the range in which the $H_{HAZ}/B_{THAZ} > 1.2$, regression models for the geometric characteristics of the HAZ of the electron beam welds: S_{HAZ} - the cross-sectional area, H_{HAZ} - depth, B_{THAZ} - surface (top) width and B_{MHAZ} - mean width at the middle part of the weld are estimated and are presented in Table 1, together with the values of the corresponding multiple correlation coefficients R . All coefficients are tested for significance and their values are measures of the accuracy of the estimated models. The closer to 1 the value of R is, the better the model describes the variations of the geometric characteristics of the thermally affected areas as a function of the process parameters. All models have enough high and significant values of their multiple correlation coefficients and consequently they can be used for prediction and optimization of the considered HAZ geometric characteristics.

Table 1: Models for the geometric characteristics of the heat affected zones of the electron beam welds where $H_{HAZ}/B_{HAZ} > 1.2$.

	Regression models	R
S_{HAZ}	$35.103301 + 56.140867x_1 - 12.464795x_2 + 42.111488x_1^2 + 36.309514x_1x_2 - 39.204101x_1x_2^2$	0.8868
H_{HAZ}	$12.089812 + 11.083831x_1 - 2.267595x_2 + 5.7456571x_1^2 - 6.7284979x_1x_2^2 - 8.7193565x_1x_2^2 + 8.2757012x_1x_2$	0.8822
B_{THAZ}	$5.8525867 + 1.4094888x_1 - 0.82996409x_2 + 1.4303279x_1x_2 + 3.118566x_1x_2^2$	0.8062
B_{MHAZ}	$6.3864563 + 2.0095741x_1 + 1.8677278x_3 + 3.1053106x_1x_3^2 - 1.6123818x_2^2x_3$	0.7541

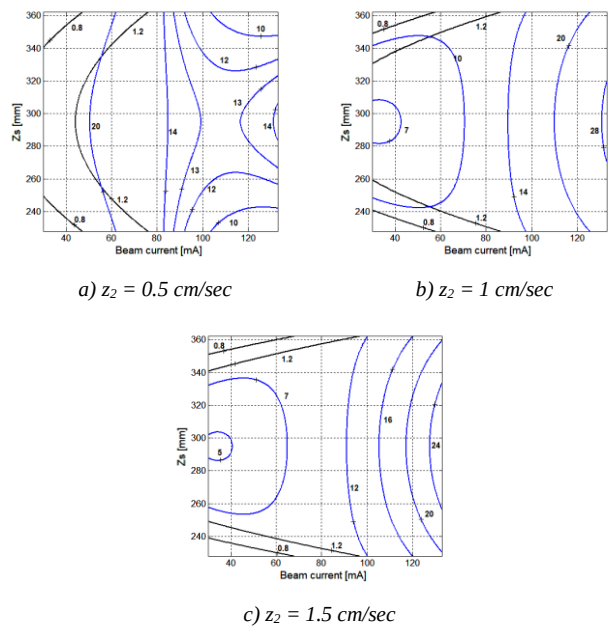


Fig. 4 Contour plots of the depth – H_{HAZ} with blue lines and H_{HAZ}/B_{THAZ} ratio – with black lines, depending on the variation of beam current (z_1) and the distances between the magnetic lens of the electron beam gun and the sample surface (z_3) for different values for the welding speeds – z_2 : a) welding speeds – $z_2 = 0.5$ cm/sec; b) welding speeds – $z_2 = 1$ cm/sec and c) welding speeds – $z_2 = 1.5$ cm/sec.

In Fig. 4 - 6 contour plots for the geometric characteristics of the thermally affected zones of the electron beam welds where $H_{HAZ}/B_{HAZ} > 1.2$, depending on the variation of the beam current (z_1) and the distances between the magnetic lens of the electron beam gun and the sample surface (z_3) for different values for the welding speeds – z_2 are presented.

From the contour plots in Fig. 4, the depth of the HAZ of the electron beam welds – H_{HAZ} is shown with blue lines. It can be seen that the maximum welding depth can be obtained when the beam current (z_1) is at its maximum, the distances between the magnetic lens of the electron beam gun and the sample surface (z_3) are

between 280 mm and 320 mm and the welding speed is $z_2 = 1$ cm/sec (Fig. 4b).

In Fig. 5 and Fig. 6 on the contour plots the top surface width of the HAZ of the electron beam welds – B_{THAZ} is marked with green lines and the mean width – B_{MHAZ} – with red lines.

In order to obtain welds with small depths the distances between the magnetic lens of the electron beam gun and the sample surface (z_3) should be between 280 mm and 320 mm, the beam current (z_1) has to be less than 60 mA for all considered cases.

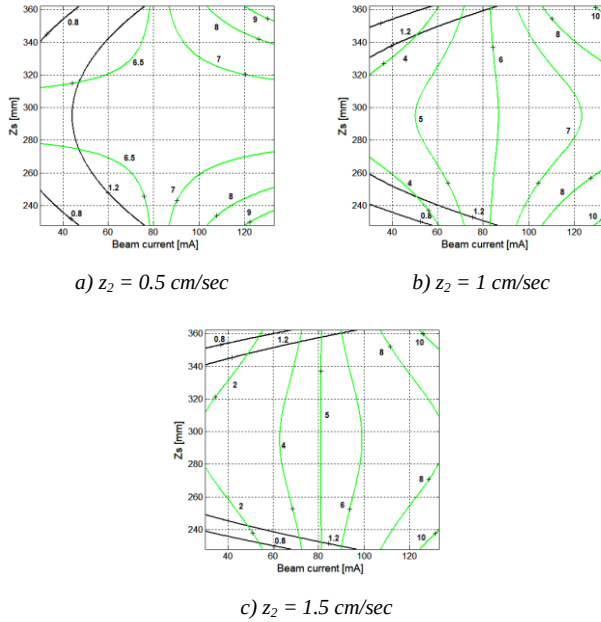


Fig. 5 Contour plots of the surface width of the thermally affected areas of the electron beam welds – B_{THAZ} with green lines and H_{HAZ}/B_{THAZ} ratio – with black lines, depending on the variation of beam current (z_1) and the distances between the magnetic lens of the electron beam gun and the sample surface (z_3) for different values for the welding speeds – z_2 : a) welding speeds – $z_2 = 0.5$ cm/sec; b) welding speeds – $z_2 = 1$ cm/sec and c) welding speeds – $z_2 = 1.5$ cm/sec.

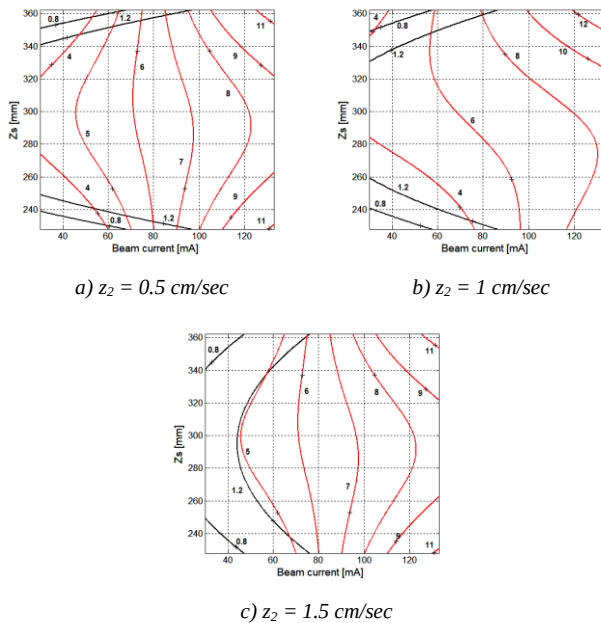


Fig. 6 Contour plots of the mean width – B_{MHAZ} in red line and H_{HAZ}/B_{THAZ} ratio – with black lines, depending on the variation of beam current (z_1) and the distances between the magnetic lens of the electron beam gun and the sample surface (z_3) for different values for the welding speeds – z_2 : a) welding speeds – $z_2 = 0.5$ cm/sec; b) welding speeds – $z_2 = 1$ cm/sec and c) welding speeds – $z_2 = 1.5$ cm/sec.

4. Optimization

Multi-criteria optimization unifying the requirements for obtaining narrow and deep welded joints is performed. Methods based on graphical optimization and on Pareto-optimization are implemented for solving this task.

Graphical optimization is a method for multi-criteria optimization, applicable in cases with formulated one- or two-sided constraints for the product quality characteristics. It is conducted in order to find the regions of the process parameters, working at which the requirements for the quality characteristics are fulfilled simultaneously.

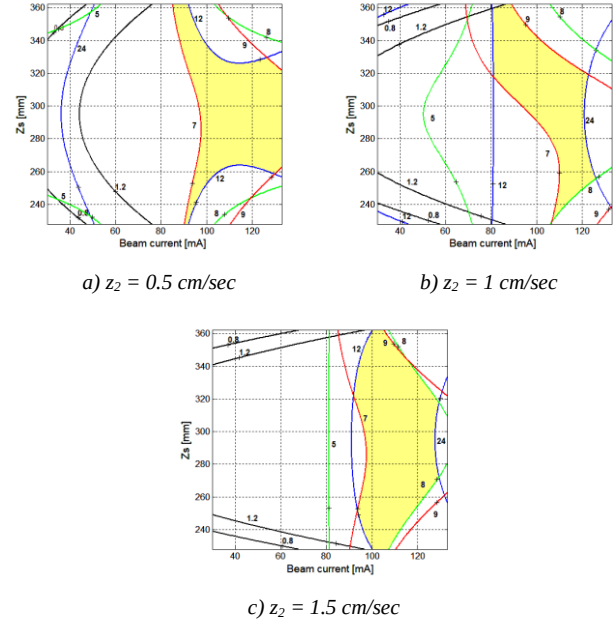


Fig. 7 Contour plots of the optimal regions of the process parameters: beam current (z_1) and the distances between the magnetic lens of the electron beam gun and the sample surface (z_3) for different welding speeds – z_2 : a) welding speeds – $z_2 = 0.5$ cm/sec; b) welding speeds – $z_2 = 1$ cm/sec and c) welding speeds – $z_2 = 1.5$ cm/sec, where the depth – H_{HAZ} is with blue color, the surface width – B_{THAZ} – green, the mean width – B_{MHAZ} – red and the H_{HAZ}/B_{THAZ} ratio – black.

The graphical multi-criteria optimization was used to find operating modes that meet the following technological requirements (constraints) for the HAZ of the welds:

- $12 \text{ mm} \leq H_{HAZ} \leq 24 \text{ mm}$;
- $5 \text{ mm} \leq B_{THAZ} \leq 8 \text{ mm}$;
- $5 \text{ mm} \leq B_{MHAZ} \leq 9 \text{ mm}$.

In Fig. 7 the optimal regions (yellow) of the process parameters values of the electron beam current (z_1) and the distances between the magnetic lens of the electron beam gun and the sample surface (z_3) for different welding speeds – z_2 are presented. From the figure it can be seen that the largest optimal region is obtained when the welding speed is at its largest value $z_2 = 1.5$ cm/sec (Fig. 7c).

Pareto-optimization is applied to find such compromise solutions that simultaneously meet the following requirements:

- $H_{HAZ} \rightarrow \text{maximum}$;
- $S_{HAZ} \rightarrow \text{minimum}$;
- $B_{THAZ} \rightarrow \text{minimum}$;
- $B_{MHAZ} \rightarrow \text{minimum}$.

Some of the estimated Pareto-optimal solutions are presented in Table 2. If these compromise solutions are compared two by two, one can note that some of the obtained optimal values are better but at least one value is worse than that in another compromise solution.

Table 2. Pareto-optimization – optimal process parameters and geometric characteristics of the thermally affected areas of the electron beam welds where $H_{HAZ}/B_{HAZ} > 1.2$.

№	z_1 mA	z_2 cm/sec	z_3 mm	S_{HAZ} mm ²	H_{HAZ} mm	B_{THAZ} mm	B_{MHAZ} mm
1	42.2467	1.3457	348.8814	3.3090	7.544 7	1.9131	4.2059
2	32.5647	1.04965	362	15.482 1	12.21 42	1.3327	3.3782
3	40.4442	0.5847	362	73.072 5	24.42 89	3.8794	3.0641
4	30	0.5873	228.0603	88.039 5	28.110 3	3.1958	0.5086
5	43.1222	1.33625	337.9805	3.2862	6.350 6	2.5710	4.6671
6	30.06695	0.77475	231.3165	50.941 8	19.33 63	2.6482	0.1129
7	36.8495	0.88905	228	29.506 7	15.09 97	2.3862	0.1637
8	40.3721	0.52695	230.2244	84.377 6	26.55 66	4.2649	2.0532
9	36.40145	0.6078	362	74.073 5	24.84 26	3.5211	2.7832
10	38.7241	0.7082	228	53.490 8	20.23 76	3.2695	0.8197

The choice between them is usually made by adding additional criteria or by an expert opinion, depending of the formulated technological requirements.

5. Conclusions

In this work the results from the investigation, modelling and multicriteria optimization of the geometry of the heat affected zone (HAZ) of the deep weld with depth to width ratio $H_{HAZ}/B_{THAZ} > 1.2$ is presented. Regression models for the dependence of geometrical

characteristics of the HAZ of the welds: S_{HAZ} - the cross-sectional area, H_{HAZ} - depth, B_{THAZ} - surface width and B_{MHAZ} - mean width on the EBW process parameters: beam current (z_1), welding speeds (z_2) and the distances between the magnetic lens of the electron beam gun and the sample surface (z_3) are estimated. Optimal results (regions and Pareto-optimal regimes) for the process parameters are obtained at setting specific requirements for the geometry of the welded samples.

Acknowledgements

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Survey of the geometric characteristics of a test specimen before punch sharpenings

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Abstract: This article analyses the widths and thicknesses of the test specimen after operating the punch before sharpening the guillotine blades. The principle of operation of a 3D computer tomograph with an accuracy of $3\mu\text{m}$ is considered. The analysis will be performed in two ways: by using a micrometer and a caliper and by using a 3D computed tomography for determining the width and thickness

Keywords: PUNCH, 3D TOMOGRAPHY, WIDTH, THICKNESS, TEST SPECIMEN

1. Introduction

Mechanical tests of materials in different structural states can be performed in the laboratory under strictly defined conditions to obtain specific characteristics of the mechanical properties. The force applied to the test piece causes it to deform, for example in tension. In the tensile test, the test specimens are tested, the shape of which must ensure a homogeneous uniaxial tensile state of tension in the working part during the test. When testing a steel sheet, the test body has a rectangular cross-section. For the preparation of the sample and the correct testing of the mechanical parameters, its linear dimensions (width and thickness) must meet a certain standard. The blades need to be observed often aiming not to wear. With worn blades, there is a loss of uniformity over the entire area. After the prolonged operation of the punch for cutting the test body, a notch is noticed on its edges and crushing on both sides of its working area. These defects are reflected in the further analysis of the tube - tensile strength testing.

Length is a physical quantity that characterizes the linear dimension of an object, usually in the directions of the largest size. The length of an object is the distance between its extreme points, in other words, the linear size along its length, measured from end to end. Width is a linear dimension, which is the distance between the two sides of an object, measured perpendicular to the length. In physics and engineering, length and width are denoted by l or L , and thickness by δ [1].

Length and width are one-dimensional measures, while the area is two-dimensional (product of length by width). The unit of measurement of length is in SI, meter-m, and thickness is mm.

The present work aims to compare the linear values of a test body for testing the tensile strength - width and thickness by measuring with a caliper and micrometer, as well as a 3D industrial computed tomography. The test body was prepared with a press and a punch, which was operated for a long time. The accuracy of the values of these quantities is of great importance, as they participate in the calculation of the tensile strength parameters. A more detailed analysis will be performed by scanning the sample using a 3D computed tomography, due to the greater accuracy of the device - visualization of the defects themselves from different angles, as well as taking precise and accurate data on width and thickness parameters.

2. Used Equipment

The traditional measuring instruments for measuring width and thickness are a micrometer (Figure 1) and a caliper (Figure 2).

The width and thickness of the test body (Fig. 3) were measured using an electronic caliper with a range: 0-150 mm / 0-6 " and an accuracy of 0.01 mm, and a mechanical micrometer with a range of 0-25 mm and an accuracy of 0.01 mm.



Fig. 1 Micrometer.



Fig. 2 Electronic caliper INSIZE [2]

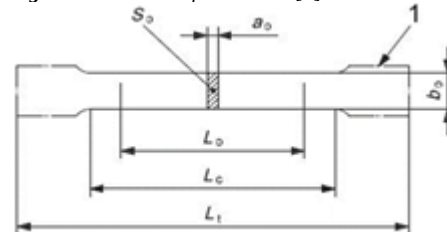


Fig. 3 Model of punched test body with a rectangular cross-section [3].

Where:

a_0 - thickness of the test body, mm;

b_0 - width of the original thickness of a flat test specimen, mm;

S_0 - section of the test specimen, mm;

L_c - parallel length, mm;

L_0 - original gauge length, mm;

L_t - total length of the test piece, mm.

The dimensions of the test piece are determined according to the standard BDS EN ISO 6892-1 [3] with a width and tolerance of 20 ± 1 mm.

Another method for measuring the linear characteristics is through 3D computed tomography, which allows for non-destructive testing with high accuracy in the study of the internal and external structure of objects. Computed tomography provides additional observations of the density of materials and their microstructure. The application of industrial 3D computed tomography proves to be effective in obtaining information about the internal characteristics of the examined object.

The test specimens must comply with the standard BDS EN ISO 6892-1 [3], for specimen preparation and BDS EN 10025 [4], BDS EN 10111: 2009 [5], BDS EN 10130: 2006 [6], BDS EN 10139: 1997 [7] for technical conditions of delivery of the material and tolerances for shape and dimensions according to standard BDS EN 10051: 2011 [8].

3. Principle of Operation of 3D Computed Tomography

Another The Nikon XT H 225 3D industrial computed tomography (Fig. 4) with an accuracy of $3\mu\text{m}$, was used for the analysis of the linear values of width and thickness [9, 10, 11].

Computed tomography (CT) is a non-destructive method that provides high accuracy and can examine the internal and external dimensions of the provided samples (samples, blanks). Besides, it provides an additional view of the internal structure of the microstructure of the object under study.

It works on the following principle: the sample is placed on a rotating table between the X-ray source and the detector; positioning the sample closer to the X-ray increases the accuracy of the data obtained; an X-ray is generated and transmitted through the sample; the digital detector captures an image that consists of multiple shades of gray based on a shadow caused by the absorption of X-rays as they pass through the scanned sample; thicker or denser materials, such as iron, copper, and lead, resulting in darker areas than thin or light materials such as plastics, paper, or air.

The CT is used as an X-ray source with microfocus, large inspection volume, high image resolution (maximum detector capacity is 1900x1500 with an active area of 467 cm²), fast 3D computer reconstruction, the cross-section of the X-Ray beam is below 3 µm, has five-axis positioning system. The maximum allowable weight that can be placed on the turntable is 15 kg, and the maximum dimensions of the object are 15x15x15 cm.

The obtained results are presented in the 3D volume, which consists of a series of consecutive 2D X-ray images, which are captured while the object is rotated 360° (Fig. 5). After scanning, the resulting images are reconstructed by the CT scanner software to generate a 3D image of the scanned object. Also, the reconstructed object contains all the information about the microstructure of the surfaces and the interior. Monitoring by computer tomography software on any surface is possible.



Fig. 4 3D industrial computed tomography Nikon XT H 225.

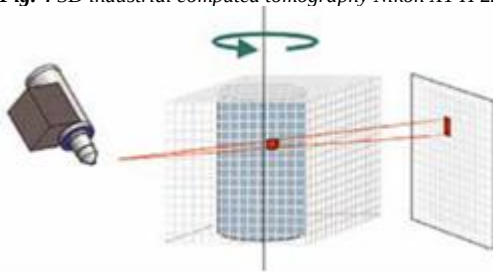


Fig. 5 Outline of X-ray technology [10]

4. Methodology for Scanning and Examination of Metal Samples

To perform a 3D CT scan of the provided metal samples, it is necessary to perform the following sequence of actions:

1. Introduction to the need for 3D CT scanning of metal samples.
2. Placing the metal sample in a base suitable for mounting in the computed tomography.
3. Determining the position of the metal sample relative to the X-Ray beam.
4. Set the required beam force.
5. Determining the required number of screenings (from 2000 to 8000)
6. Preparation and selection of necessary parameters for 3D reconstruction.
7. Analysis of the obtained images.
8. Determination of width and thickness.
9. Analysis of the obtained results.

The implementation and determination of the set tasks are personal for each metal sample. The above tasks are the key ones, which follow the expansion of some methods and the creation of new ones.

The metal sample was subjected to 3D X-ray scanning with an industrial computed tomography. The test specimen needs to be fixed. It is currently fixed in a porous material with a lower density. This avoids its occurrence during scanning. The porous material is attached to a specially designed stand for placement in the scanning area. It is envisaged to create a specialized method of fixing the samples to reduce the time for this operation. The objects are placed as close as possible to the X-ray beam to achieve a more detailed picture and increased accuracy. The required beam power and the number of projections are determined. The software of the manufacturer is used to read the values of thickness and width.

5. Experimental Results

An analysis of the linear dimensions of 10 pcs. test body with same parameters was made in two ways: by micrometer and caliper, as well as by 3D computed tomography as the test body was measured in 3 zones, each zone is measured in 3 points: top (at one site near the edges), middle (3 points are made successively from left to the right of the working area), and bottom (the opposite side of the test piece near the edges). The test piece must correspond to a thickness of $1,0 \pm 0,15$ mm and a width of $20,00 \pm 1$ mm. The experimental results of one of the specimens of the measurements are shown in Tables 1 and 2.

Table 1: Test specimen values measured with a micrometer and a caliper

Position of the sample measurement		Width, mm (b)	Thickness, mm (a)
Top	1	20,00	0,96
	2	20,01	0,96
	3	19,99	0,95
	Δ	20,00	0,96
Middle	1	20,01	0,97
	2	20,02	0,96
	3	20,02	0,96
	Δ	20,02	0,96
Bottom	1	20,01	0,95
	2	20,00	0,95
	3	20,00	0,96
	Δ	20,00	0,95

Table 2: Test specimen values measured with a 3D computed tomography.

Position of the sample measurement		Width, mm (δ)	Thickness, mm (t)
Top	1	20,06	1,02
	2	20,06	1,03
	3	20,03	1,02
	Δ	20,05	1,02
Middle	1	20,08	0,91
	2	20,09	1,03
	3	20,09	0,86
	Δ	20,09	0,93
Bottom	1	20,09	1,02
	2	20,09	1,01
	3	20,07	1,01
	Δ	20,08	1,01

When bringing the arithmetic mean of the measured widths and thicknesses of the test body, the following parameters will be obtained:

- Test specimen values measured with a micrometer and a caliper

$$a = 0.96 \text{ mm}; \quad b = 20.01 \text{ mm}$$

- Test specimen values measured with a 3D computed tomography

$$a = 0.99 \text{ mm}; \quad b = 20.07 \text{ mm}$$

If we do a simulation of tensile strength testing at force $F = 6.5 \text{ kN}$ it will be calculated by formula $R_m\% = x100$ and cross-section area $S = a.b$, we will obtain the following values:

Table 3: Simulation of tensile strength calculation

Measured with:	S, mm	Rm, Mpa
micrometer and caliper	19.2096	338
3D CT	19.8693	327

The results show that the values of the samples measured with a micrometer and a caliper differ from those measured with a 3D computed tomography.

Figures 6 and 7 show images from a 3D computed tomography of the scanned test specimens of thickness and width.

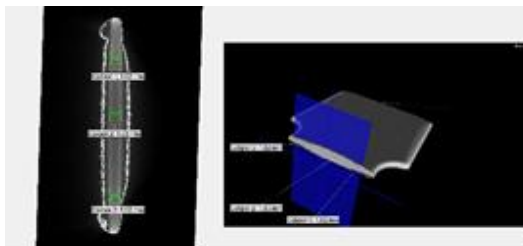


Fig. 6 Measured thickness with a 3D CT.



Fig. 7 Measured width with a 3D CT.

When cutting the test specimen by punching, during prolonged operation, the blades wear out. This phenomenon is observed in fig. 8. The height of the observed defect (sharp edge on the

surface) was measured using a 3D CT. The size of the resulting defect is 0.18 mm. After the analysis by the computed tomography it is seen that on both sides of the test body, the thickness is significantly less than the real one, which is a consequence of the worn blades during punching (fig. 9 a) and b).

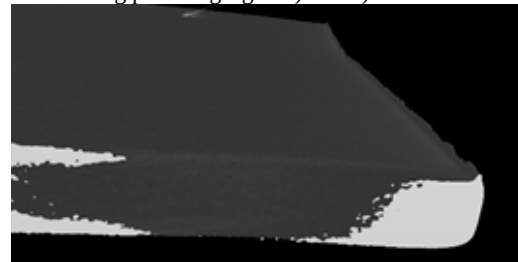
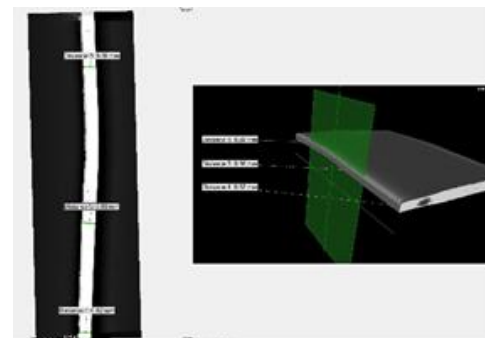


Fig. 8 3D Scanned test body with a defect after punching.

6. Conclusion

As a result of the developing world, the analysis equipment is being modernized. Therefore, it was chosen to compare the measurement of linear quantities using standard measuring instruments - caliper and micrometer and the modernized 3D computed tomography, which provides more detailed information about what problems may acquire in the preparation of a test body for tensile strength testing. The analyses show that despite the discrepancy in the measurement by the two methods, the dimensions of the sample meet the ISO standards for width and thickness. However, a simulation to calculate the tensile strength with the values measured with a micrometer and caliper and with a 3D computed tomograph shows that different values are obtained. If you need to calculate accurate results, the error of incorrect measurement would create a problem. But the analysis with the 3D computed tomography shows detailed defects after cutting off the test body after punching. The thickness on both sides of the sample is crushed from 1.02 mm average thickness in the middle to 0.90 mm. The other defect that is visualized is the appearance of an edge also due to the worn blades of the punch.



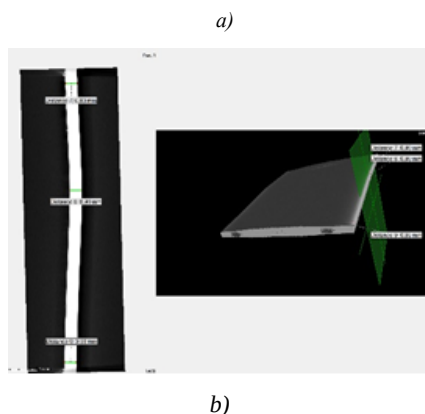


Fig. 9 3D Scanned test body – middle - a) left, b) right.

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Investigation of the properties of Ce dopant titanate ceramics prepared by sol-gel method

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Abstract: The research in this article focuses on the synthesis of Ce donated BaTiO_3 needed to make a target for magnetron sputtering. Synthesis is BaTiO_3 by sol-gel method with a certain concentration of a modifying additive of Ce. The process of the sol-gel method is considered and the obtained results are characterized. Additional thermal treatment of the obtained samples was performed at $T^\circ\text{C} = 900^\circ\text{C}$ in a muffle furnace in Ar / H_2 medium and in a laboratory furnace in air. Physicochemical methods by XRD analysis and Raman spectroscopy were used to characterize the results obtained.

Keywords: SOL-GEL, BaTiO_3 MODIFY, XRD, RAMAN SPECTROSCOPY

1. Introduction

Nowadays, the development of materials for electronics is intensifying more and more. Interest in new advanced materials obtained by low-temperature synthesis methods has grown significantly in recent years. New lead-free titanium materials used in electronics have become a desirable product for various branches of industry. [1]

Traditional ceramics and glass-ceramics are materials that are obtained by high-temperature synthesis methods. The obtained samples have a dense structure after the determined temperature treatment. High temperature solid phase synthesis produces materials with controlled particle size.

Low-temperature synthesis methods are one of the methods that contribute to the development of new materials with different applications. [1-3]

The chemical reactivity of metal alkoxides offers a wide range of possibilities for modifying different materials. The process of hydrolysis and condensation can be completely different, leading to new products. An analysis is provided on some of the most common chemical additives used in the sol-gel process. The most important characteristics are the reactivity of the new ligand to hydrolysis, the charge distribution in the new molecular precursor and the coordination numbers of the metal atom.

It is known that very high values of the dielectric permittivity can occur in ferroelectrics [4,5]. Approximation of the ferroelectric phase transition at T_c (Curie temperature), $\epsilon(T)$ (relative dielectric permittivity) increases sharply, usually at Curie temperature and begins to decrease again below T_c . In addition, ferroelectrics have pronounced nonlinear dielectric properties, for example showing characteristic hysteresis circuits of polarization dependent on the electric field [6-18]. Both phenomena are related to the inability to apply in electronic devices. This can be partially overcome by doped and special treatment, thus regulating the microstructure and the internal arrangement of the particles in the cell. Well-known barrier layer ceramic materials use a combination of polarization effects and ferroelectrics such as BaTiO_3 to achieve high values of capacity with temperature and voltage that are suitable for different applications [6-15].

Many transition metal oxides show very high ("colossal") dielectric constant values and thus have huge potential for modern microelectronics applications and for the development of new capacity-based energy storage devices. In the present paper, we discuss the mechanisms of sol-gel technology, modification of ceramic materials that can lead to colossal values of dielectric constant. In addition, we offer an overview and discussion of the properties of Ce subsidized BaTiO_3 , which emerges as a material with colossal dielectric constant.[12-24]

2. Experimental

$\text{Ba}_{0.945}\text{Ce}_{0.055}\text{TiO}_3$ ceramic was synthesized by the sol-gel method. The starting materials used were $\text{C}_4\text{H}_6\text{BaO}_4$ (barium acetate), $\text{C}_{16}\text{H}_{36}\text{O}_4\text{Ti}$ titanium butoxide and $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ (cerium

nitrate) in certain stoichiometric ratios. CH_3COOH was used as a complexing agent. The solutions are mixed and homogenized on a magnetic stirrer model for 3 hours. The resulting sol was stabilized by the addition of DEA (diethanolamine). The solution is gelled at room temperature. The resulting gel was dried in an oven at 100°C . The annealing is performed in an air laboratory furnace and in a muffle furnace in an environment of $\text{Ar}/5\% \text{H}_2$. The obtained phases are characterized by XRD and Raman spectroscopy, which are explained in the next part of the discussion.

3. Results and Discussion

X-ray phase analysis of the experimental samples was performed using an automatic powder X-ray diffractometer Bruker D8 Advance with Cu K radiation. In laboratory conditions, ceramic samples with desired properties are synthesized by the described technological methodology.

X-ray phase analysis of the obtained experimental samples revealed the presence of a predominant crystalline phase of tetragonal BaTiO_3 . Figure 1 shows a diffraction pattern with a predominant phase of $\text{Ba}_{0.945}\text{Ce}_{0.055}\text{TiO}_3$. The intensity of the peak is marked in red. The annealing was performed at 900°C in a laboratory furnace. In FIG. 2 shows a monophase of pure BaTiO_3 at 900°C in an Ar/H_2 medium. The size of the crystallites was also determined by the Atoms program. The crystallites of the $\text{Ba}_{0.945}\text{Ce}_{0.055}\text{TiO}_3$ phase are 37 nm in size, while the BaTiO_3 monophase shows a size of 19 nm.

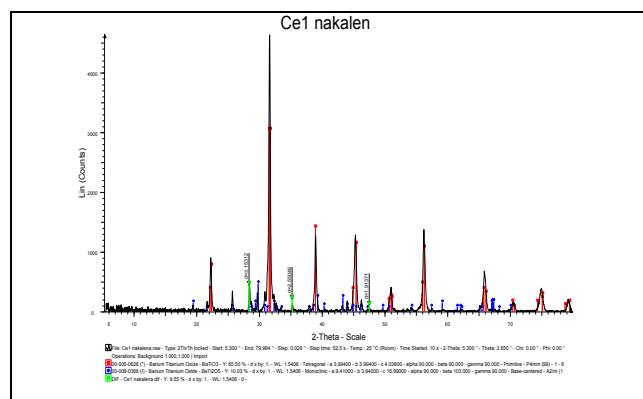


Fig. 1. XRD of BaTiO_3 doped with Ce in air

The Raman spectra were collected using Lab RAM HR Visible Raman spectrometer. For excitation the 633 nm line of a He-Ne laser was used. As some of the investigated powder samples are dark ones and strongly absorbing, a laser power test was done and the laser power not causing local overheating effects on the sample surface was determined as $30\mu\text{W}$. An objective X50 was used both to focus the incident laser light onto a spot with diameter about $4\mu\text{m}$ and to collect the scattered light in backscattering geometry. Several spectra

from different arbitrary spots from each sample were collected. The investigated spectral range was $70\text{ cm}^{-1} - 1290\text{ cm}^{-1}$.

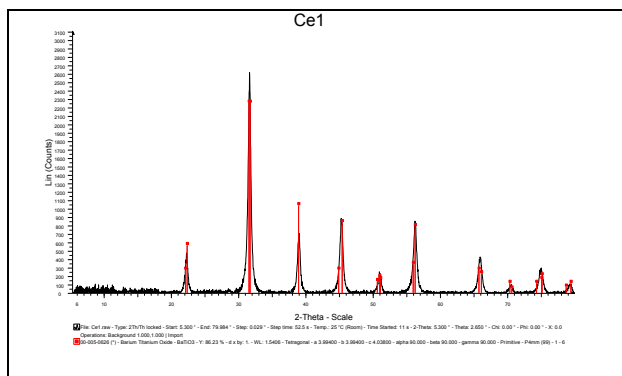


Fig. 2. XRD of BaTiO_3 doped with Ce in Ar/H_2

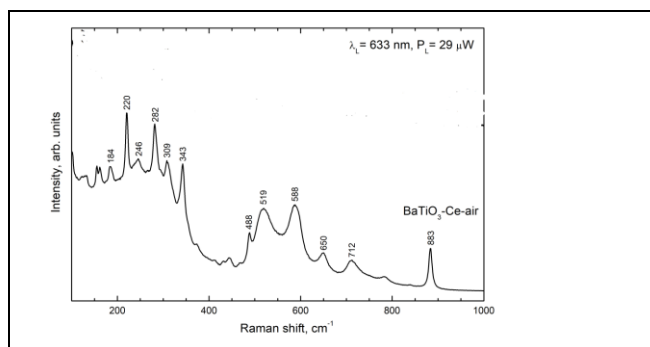


Fig. 3 Raman spectroscopy of the Ce doped BaTiO_3

The Raman spectra of BaTiO_3 -Ce-air samples were shown in Fig. 3. The light (transparent) BaTiO_3 - Ce-air sample. By this reason its Raman spectrum is about 10 times less intensive. For better comparison this spectrum is multiplied by a number of 10.

The lines observed at 246 , 309 , 519 , and 712 cm^{-1} (in spectrum of BaTiO_3 -Ce-air) correspond to Raman-active modes in the tetragonal BaTiO_3 . All other observed lines correspond to impurity phase(s).

4. Conclusions

According to the above results, it can be concluded that a phase of BaTiO_3 with Ce modifier has been synthesized. Sol-gel technology was used for the synthesis. The heat treatment was carried out in two ways: by annealing in a laboratory furnace in air and in a stream of Ar / H_2 .

X-ray diffraction patterns prove the presence of a monophase of BaTiO_3 in an argon and hydrogen medium, and the presence of a $\text{Ba}_{0.945}\text{Ce}_{0.055}\text{TiO}_3$ phase is also proved. Raman spectroscopy proves these results. At 883 cm^{-1} we have a characteristic peak for $\text{Ba}_{0.945}\text{Ce}_{0.055}\text{TiO}_3$. The lines at 246 , 309 , 519 , and 712 cm^{-1} determine the presence of tetragonal BaTiO_3 .

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Structure and composition of innovative porous composite material

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Abstract: The subject of this article is a study on the composition and structure of innovative Porous Composite Material (PCM). The latter is obtained from powders of glass waste and heat-treated rice husks. The PCM is non-flammable, non-combustible and has high heat and sound insulation properties. The structural elements made of it are lighter and stronger than the ones made of foam glass. It is expected that PCM is to find wide application in construction and as an absorbent of heavy metals and oil from polluted water.

Keywords: HEAT INSULATION, SOUND INSULATION, ABSORPTION, NON-FLAMMABLE, NON-COMBUSTIBLE, STRONG, LIGHT-WEIGHT

1. Introduction

Household, construction and industrial glass waste as well as rice husks are dumped worldwide in huge quantities – more than 130 million tons per year [1]. Many research teams in different countries work on methods to utilize these two types of waste materials. Rice is one of the most consumed crops in the world, with China being the largest consumer. Rice husks are a by-product of rice production. Their use as a source of energy is only a partial solution to the problem of their utilization. The valuable ingredient, in the seemingly useless residue after heat treatment of rice husks, is the silicon dioxide, whose content in the resulting ash varies from 90 to 97 weight %. It is important to note that the silicon dioxide is in an amorphous (active) form and with a large specific surface area [2 & 3].

2. Prerequisites and means for solving the problem

Different technologies have been developed for the production of light-weight ceramic materials in the form of bricks and blocks for the utilization of powders from glass waste and rice husks [4]. Another common use is in the production of boards, panels and chips (we have all heard of the Silicon Valley...). Of no less ecological importance is the use of rice husk powder for the production of silica used in construction as a component of cements or for the production, under certain conditions, of silicon carbide [5].

3. Solution of the examined problem

The innovativeness of the porous composite material created by us stems from its higher strength compared to foam glass as well as its non-flammability, non-combustibility and high thermal and sound insulation performance. Besides as construction material, PCM is also valuable as an absorbent of heavy metals and oil from polluted waters. Regarding the broader scientific importance it can be pointed out that the current research contributes to solving a long-standing problem namely utilization of huge amounts of waste materials coupled with the production of useful new material. From a scientific point of view, PCM's composition and structure are of particular interest hence the current study.

4. Results and discussion

4.1. Optical microscopy (OM)

In Fig. 1a and Fig. 1b images from PCM sample examination using an optical microscope are presented. The high degree of porosity is clearly visible (low magnification image – Fig. 1a). The main part of the pores have sizes ranging from 200 to 600 μm . It is worth noting the presence of micro-pores in the walls separating the main pores (see low magnification image – Fig. 1b). The dimensions of the micro-pores are mainly in the range of 5 to 50 μm . As a result of the above observations it is concluded that PCM has a pronounced cellular structure. The difference between PCM's structure and the structure of cellular foam glass is the formation of micro-pores in the cell walls of PCM. These micro-pores effectively

increase the specific surface area of the material thus further stimulating its absorbing ability by creating "breathing" cell walls.

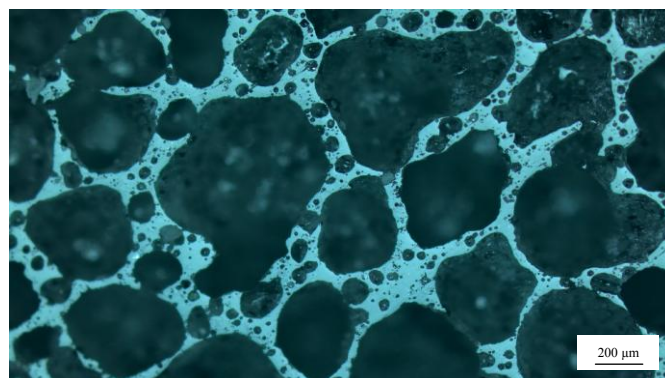


Fig. 1a. Low-magnification OM image of PCM sample

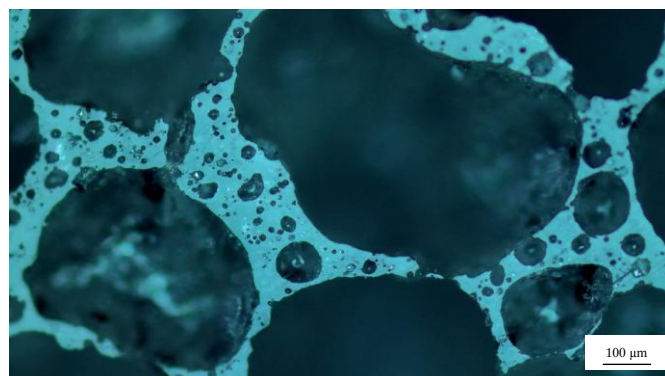


Fig. 1b. High-magnification OM image of PCM sample

Images of the same sample taken with a stereo optical microscope (Fig. 2a and Fig. 2b) give a better spatial picture of PCM's cell structure. The pores are formed as a result of the combustion of the foaming agent, in this case, the carbonized biomass from the rice husks remaining after the heat treatment. The large foaming particles form the large pores and the small ones form the micro-pores in the cell walls.

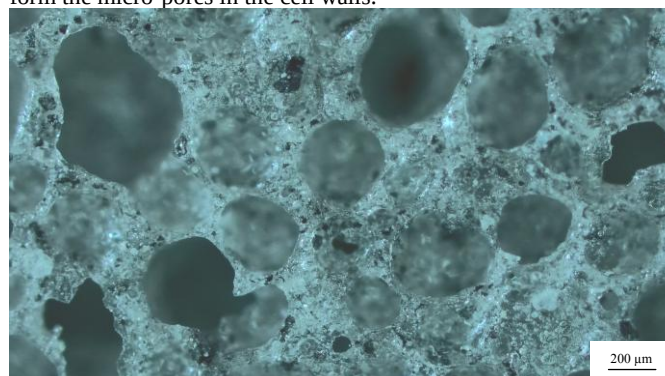


Fig. 2a. Low-magnification stereo OM image of PCM sample

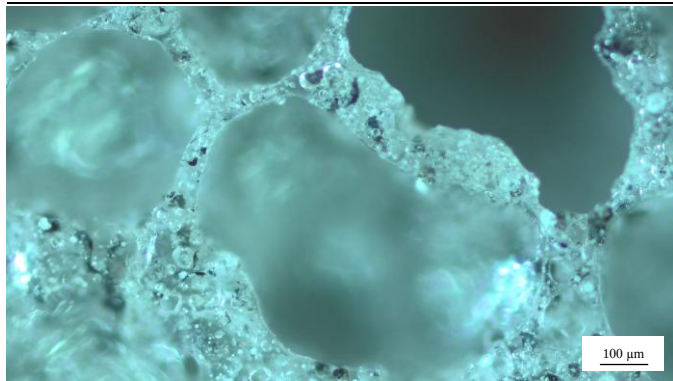


Fig. 2b. High-magnification stereo OM image of PCM sample

4.2. Scanning electron microscopy (SEM)

In Fig. 3a and Fig. 3b images from PCM sample examination using a scanning electron microscope are presented. The images confirm the results of the study with optical microscopes, namely: a high degree of porosity and presence of micro-pores in the walls separating the main pores. The dimensions of the main part of the two types of pores are also confirmed with Fig. 3b showing in detail a micro-pore.

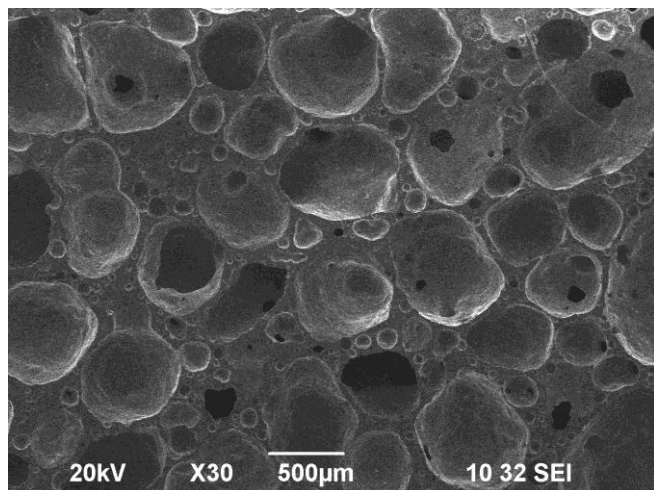


Fig. 3a. Low-magnification SEM image of PCM sample

The high level of porosity of the material is a prerequisite for its low thermal conductivity and high sound insulation capacity; these two properties will be the subject of another study.

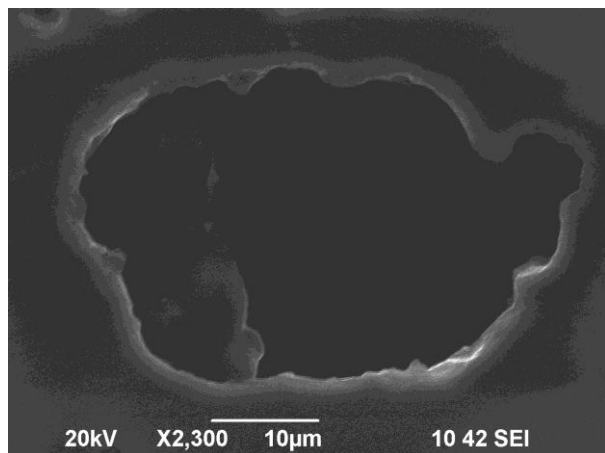


Fig. 3b. High-magnification SEM image of PCM sample

Table 1 shows the average results of chemical analyses (EDS) in five randomly selected sample points. The presence of 4 oxides was detected, namely: SiO_2 , Na_2O , CaO and MgO . The high content of SiO_2 is due to its accumulation from the two raw materials – powders of waste glass and active amorphous silica from heat-treated rice husks.

Table 1. Chemical composition of PCM sample (EDS analysis)

Element	Atomic %	Weight %
Si	20,72	29,44
Na	7,41	8,84
Ca	2,69	5,49
Mg	1,77	2,26
O	67,41	53,97

4.3. Three-dimensional micro Computed Tomography (3D micro CT)

A PCM sample with a roughly parallelepiped shape (approximate dimensions: 15 x 12 x 9 mm) was examined using a 3D X-ray micro-tomographer “SkyScan 1272” from Bruker (*see last page). Fig. 4 shows the sample at the start of the examination, the so-called preview or projection.

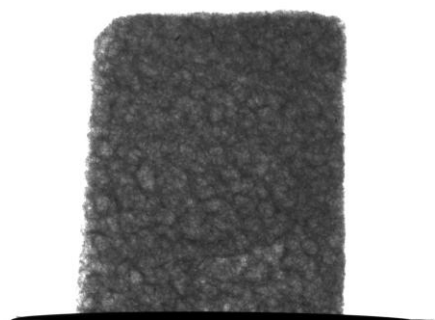


Fig. 4. PCM sample preview/projection

After initial settings, the following radiation parameters were selected:

- resolution: 2452 x 1640 pixels;
- pixel size: 10,8 μm;
- no filter;
- distance from sample to X-ray source: 200,4 mm;
- source voltage: 50 kV;
- source current: 200 μA;
- radiation step: 0,2°;
- 360° radiation (full rotation of the sample).

The sample radiation (examination) with the selected parameters had a duration of 02h 38m 28s.

After completion of the radiation, the so-called “3D reconstruction” was performed by processing the obtained graphic images with NRecon software (v. 1.7.4.2). After that CTVOx software (v. 3.3.0r1403) was used to visualize the 3D models in different spatial orientations (shown in Fig. 5a – 5d). PCM’s highly porous structure is clearly visible in all orientations; now and then some of the pores merge to form channels such as the one that can be seen in Fig. 5c.

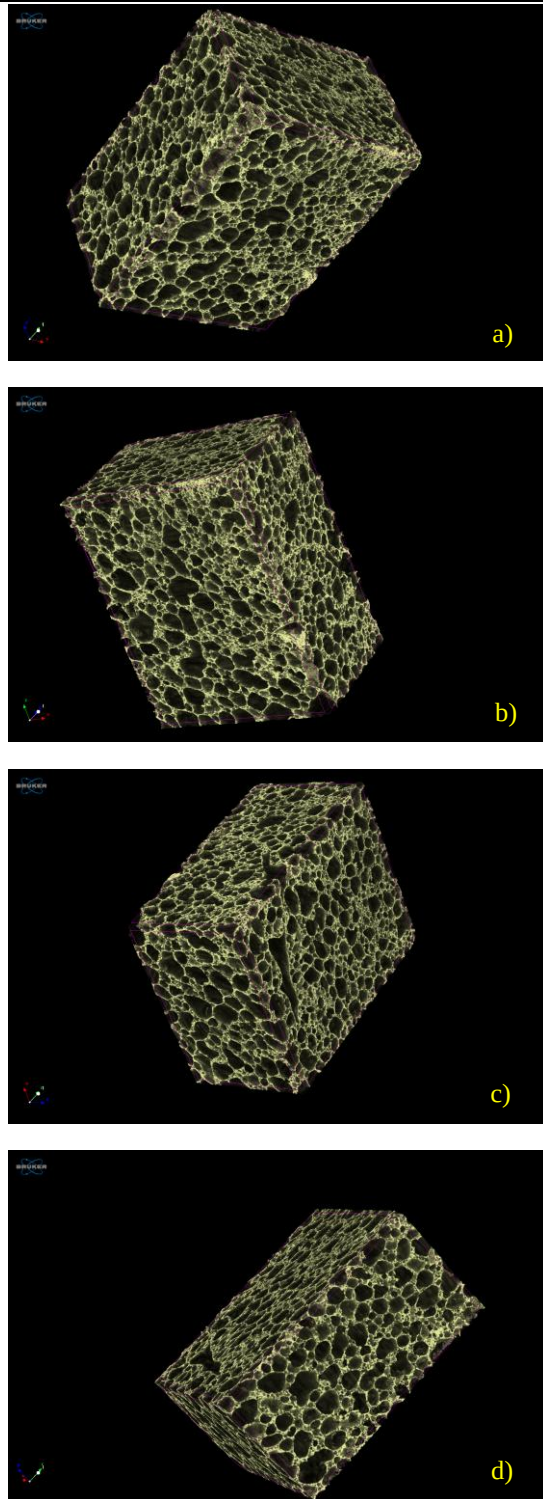


Fig. 5. 3D views of PCM sample

The software has a number of useful functionalities; two of them are demonstrated in Fig. 6 and Fig. 7. The first functionality allows the operator to make a spherical section with a variable size in any part of the sample – so-called “cutting”. This is demonstrated in Fig. 6 (a & b) by making sections in two corners of the sample thus revealing the inner structure in depth customizable by the operator.

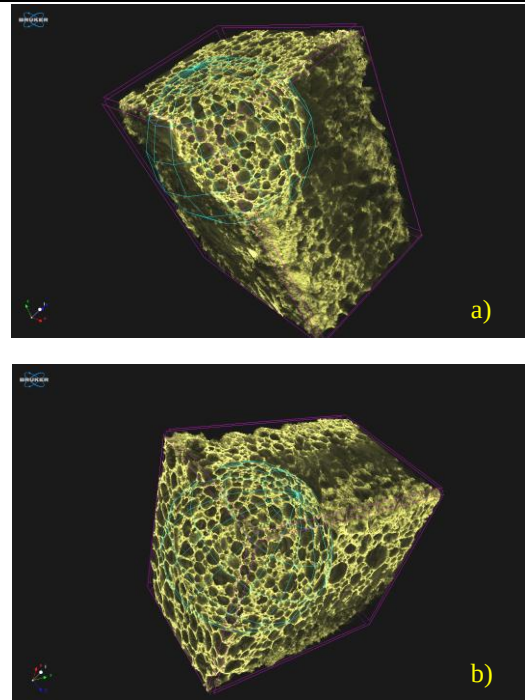


Fig. 6. Spherical sections in two corners of PCM sample

Another functionality allows the operator to insert a sphere in any part of the sample and then remove all surrounding material thus leaving visible only the part which is inside the sphere – so-called “clipping”. This functionality is demonstrated in Fig. 7 (a & b).

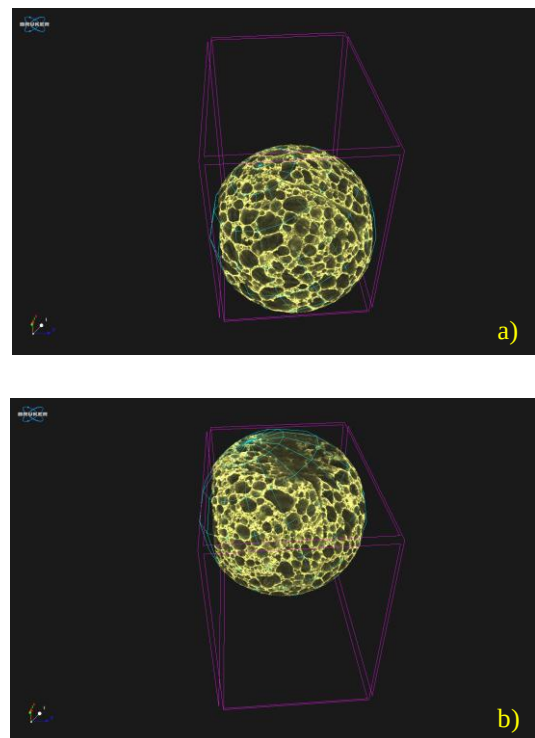


Fig. 7. Spherical inserts in two parts of PCM sample

Using CTAn software (v.1.18.8.0) additional processing of the 3D model was performed in order to obtain quantitative characteristics of the sample. The porosity of the sample was calculated and the results show that the total porosity is 80,45 %, with the percentage of closed pores being only 0,15 % while the percentage of open pores being 80,30 %.

5. Conclusions

As a result of the conducted research it was established that the studied porous composite material has a pronounced cellular structure with a very high degree of porosity (80,45 %) and almost all of its pores are open. This is a prerequisite for very low density and high heat and sound insulation capacity. The last two properties will be the subject of another study and when quantitatively determined will open the door for wide application of the material in construction especially in the renovation of buildings as well as in the production of light-weight concrete and new composite mixtures. Due to the high specific surface area it can be expected that PCM will also find application as an absorbent of harmful substances from various fluids (for example, of heavy metals and oil from polluted water).

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Glass forming ability and crystallization behaviour of amorphous and nanosized rapidly solidified $(\text{Al}_{75}\text{Cu}_{17}\text{Mg}_8)_{100-x}\text{Zn}_x$ alloys

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Abstract: The rapidly solidified $(\text{Al}_{75}\text{Cu}_{17}\text{Mg}_8)_{100-x}\text{Zn}_x$ ($x=0,1,2,3$ at. %) alloys were obtained by melting in an induction furnace and then rapidly quenched by the planar flow casting (PFC) method in installations, created at the IMSTCA-BAS. By TEM and X-ray analyses were obtained data, that the microstructure of the alloys is an amorphous matrix with nanosized particles with dimensions $16\div 90$ nm. The obtained amorphous alloys have relatively good glass forming ability. With increasing content of Zn the amount of the amorphous phase and glass transition temperature T_g also increase.

Keywords: Al-Cu-Mg-Zn, AMORPHOUS ALLOYS, NANOSIZED ALLOYS, GLASS METALS

1. Introduction

The Al-Cu-Mg system is selected as the starting system for the synthesis of relatively new, not so well-studied alloys, because aluminum alloys are widely used in the aviation and automotive industries. In addition, this system also contains commonly used and acceptable as a price metals.

The obtaining of amorphous aluminum-based alloys is traditionally based on multicomponent systems containing aluminum (80–92 at.%), rare earth metals (3–20 at.%), transition metals (1–15 at.%) etc. [1-3]. All these compositions are expensive and this limits their application. The main challenge for scientists today is to obtain new aluminum alloys without rare earth elements, which have a high glass-forming ability (GFA).

The aim of the present investigation is to avoid the aforementioned disadvantages and to obtain alloys with compositions $(\text{Al}_{75}\text{Cu}_{17}\text{Mg}_8)_{100-x}\text{Zn}_x$, $x = 0; 1; 2; 3$ at.%, which are near to the ternary eutectic of the Al-Cu-Mg system.

2. Experimental

An alloy with the composition: Al-61 % mass (75 at. %), Cu-33 % mass. (17 at. %), Mg-6% mass. (8 at. %) was synthesized.

The composition of the alloy is selected on the basis of the available literature data [4] and well known facts that eutectic alloys are more easily amorphized and that the aluminum-copper ligature could contain from 33% (eutectic composition in the Al-Cu system) to 50% copper. The most commonly prepared Al - ligatures contain up to 35% Cu. These ligatures have a low melting point (575°C) and are chemically homogeneous. The preparation of Al-Cu ligature is relatively easy and a good quality of the casting could be achieved.

Purity metals Al-99.99%; Cu- 99.99% and Mg- 99.8% were used to prepare the alloys. The synthesis of Al-Cu-Mg alloys is performed in an installation created at the IMSETHAC-BAS. It consists of a resistance electric furnace, powered and controlled by a programmable thermostat RT 1800. The resistance electric furnace is installed in a water-cooled, pneumo-vacuum chamber in an argon atmosphere, with a purity of 99.998%.

The synthesis results in an ingot with a diameter of about 20 mm and a height of about 30 mm. Four ingots were obtained. To three of the obtained ingots is added high purity zinc, respectively 2, 5 and 7% mass, as described below.

The resulting Al-Cu-Mg ingot was placed in a cold double corundum crucible. under a backfill of equimolar layer flux, which is a mixture of chloride salts 50% NaCl - sylvinit and 50% KCl - sylvin.

The corundum crucible is heated in a tigel cantal electric furnace at a speed of 12 degrees / min. It is found that at a temperature of 500 °C, measured near the surface of the melt, the ligature is still solid under the flux powder. Melting of the ligature begins at a temperature of about 550 °C. At this temperature, the

required amount of zinc granules (for compositions containing Zn) is added under the flux bulk and the melt under the flux is stirred with a quartz stirrer. At a temperature of 670 °C, measured near the surface of the melt, the flux begins to melt and the melt is stirred again. One hour after the start of the synthesis, at a temperature of about 700 – 720 °C, the melt is stirred for the last time, the crucible is removed and placed on a refractory plate to cool to room temperature and the alloy to crystallize.

The alloys obtained after the addition of 2, 5 and 7 mass. % zinc are designated as 2'r, 2''r and 2'''r, respectively.

The planar flow casting (PFC) method was used to obtain the rapidly solidified ribbons. The installation scheme of PFC equipment is shown in figure 1, and figure 2 shows the laboratory installation for rapidly solidification by melt, established in IMSETHAC-BAS.

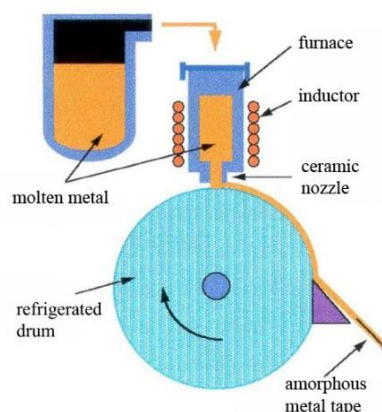


Fig.1. Scheme of Planar Flow Casting instalation

The alloys are placed in a quartz nozzle with a tube diameter of 18 mm. The nozzle opening is about 8-10 mm long and 0.5 mm wide. The melting of the alloys is performed in an inductor to a temperature exceeding the melting temperature of the respective eutectic alloy by 80-100°C.

After melting the alloys, the melt is fired under argon pressure of 0.4-0.5 atm. on a copper disk with a diameter of 140 mm. The linear speed of rotation of the disk in the obtaining of the alloys is in the range of 33,5-35,7 m / s. The resulting ribbons were about 10 mm wide and 110-120 μm thick.

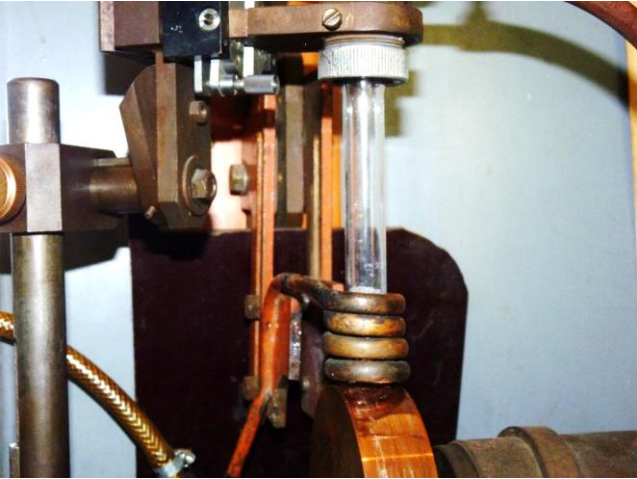


Fig. 2. Laboratory installation of melt spinning.

2.1. Test methods

The chemical compositions of the rapidly solidified ribbons are determined by EDS analysis on a scanning electron microscope HIROX 5500 with EDS system BRUCKER at a magnification of 100x in 10 fields with a field area of 2.5 mm².

The microstructures of Al-Cu-Mg-Zn rapidly solidified ribbons are observed by transmission electron microscope (TEM) JEOL 1011 with accelerated voltage 100kV .

X-ray diffraction analyses are performed to characterize the amount of amorphous and phase composition of the crystalline part of the studied ribbons with a Bruker D8 Advance powder X-ray diffractometer with CuK α radiation (Ni filter) and LynxEye recording in a solid-state position-sensitive detector. The qualitative phase analysis is performed using the PDF-2 (2009) database of the International Data Diffraction Center (ICDD) using the DiffracPlusEVA software package.

The DSC analyses are performed on an STA 449 F3 Jupiter calorimeter connected to a QMS 403 Aëolos Quadro mass spectrometer

3. Results

The chemical composition of the rapidly solidified ribbons by synthesis in atom. % and mass. % and the results of the chemical composition tests of the ribbons by EDS analyses are presented in Table 1.

The diffractograms of the tested alloys show a halo, which is better formed in rapidly solidified ribbons 2r, 2``r and 2 r```` and confirms the existence of an amorphous structure. The sharp peaks characterize the crystalline phases, the composition and dimensions of which were obtained by X-ray analysis and are presented in Table 2.

The X-ray analyses results are presented on figure 3 and in the Table 2.

Table 1. Chemical composition of the rapidly solidified (Al₇₅Cu₁₇Mg₈)_{100-x}Zn_x alloys (ribbons)

Designation of ribbons (r) / Method of analysis	Al [%] at./mass.		Cu [%] at./mass.		Mg [%] at./mass.		Zn [%] at./mass.		Linear disk speed [m/s]
2r-by synthesis	75	61	17	33	8	6	0	0	-
EDS analysis	-	57,0	-	36,4	-	6.6	-	0	35.7
2r ^{''} -by synthesis	75	61	17	33	8	6	1	2	-
2r ^{''} - EDS analysis	-	63,4	-	29,3	-	5,4	-	1,9	34.4
2r ^{'''} - by synthesis	75	61	17	33	8	6	2	5	-
2r ^{'''} - EDS analysis	-	60,9	-	29,6	-	5,1	-	4,4	35.2
2r ^{''''} -by synthesis	75	61	17	33	8	6	3	7	-
2r ^{''''} - EDS analysis	-	59.8	-	28,8	-	5,1	-	6.3	33.6

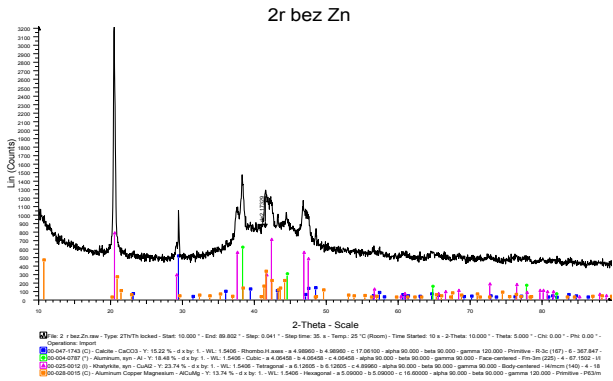


Fig.3a. X-ray diffractogram of the ribbon 2r

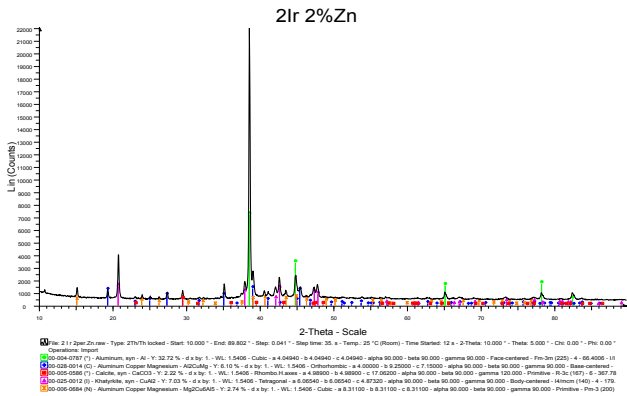


Fig. 3b. X-ray diffractogram of the ribbon 2r

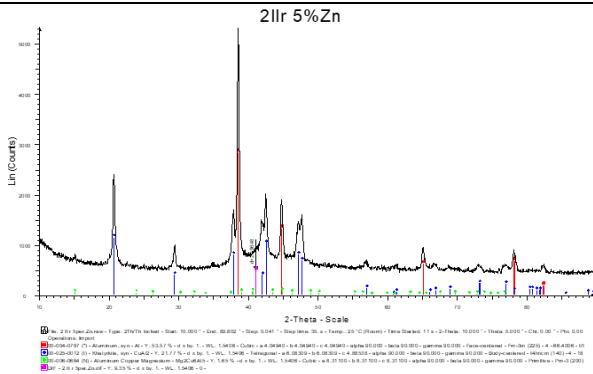


Fig. 3c. X-ray diffractogram of the ribbon 2`r

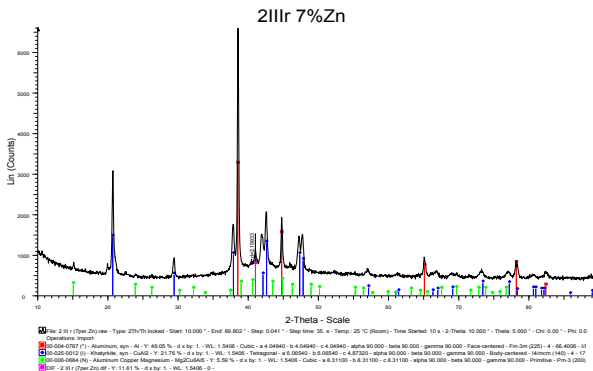


Fig. 3d. X-ray diffractogram of the ribbon 2'''r

Fig.3. X-ray diffractograms

The diffractograms of the obtained alloys show a halo, which is better formed in rapidly solidified ribbons 2r, 2`r and 2'''r and confirms the existence of an amorphous structure. The sharp peaks indicate the presence of crystalline phases, the composition and size of which were obtained by X-ray analyses and are presented in Table 2.

The results obtained by X-ray analyses about the presence a both of amorphous and crystalline part in the microstructure of the rapidly solidified ribbons were confirmed by observations by TEM and electron diffraction (Fig. 4). The microstructure of the tested specimens, both from the ribbons, not containing Zn, and from rapidly solidified ribbons with 2, 5 and 7 mass. % Zn, represents the amorphous matrix with nanocrystals of several types of phases located in it. The type and size of phase crystals, identified by XRD analyses, are presented in Table 2.

Table 2. XRD analysis of the rapidly solidified Al-Cu-Mg-Zn ribbons

Designation	Amorph. part	Cristal part			
	[%]	[%]	phases / [%] / size [nm]		
2r	48	52	Al	36 %	16
			CuAl ₂	64 %	30
			AlCuMg	<1 %	--
2`r	45	55	Al	40 %	90
			CuAl ₂	24 %	62
			Al ₂ CuMg	21 %	62
			Mg ₂ Cu ₆ Al ₅	12 %	62
2''r	55	45	Al	42 %	40
			CuAl ₂	58 %	23
			Mg ₂ Cu ₆ Al ₅	<1 %	--
2'''r	63	37	Al	37 %	71
			CuAl ₂	57 %	35
			Mg ₂ Cu ₆ Al ₅	6 %	60

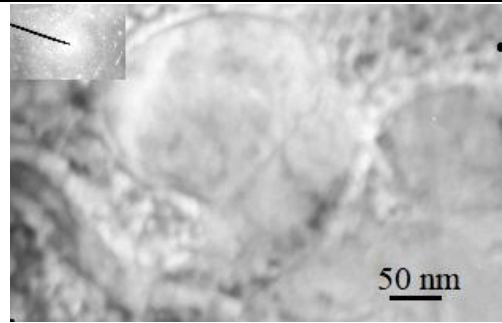


Fig. 4a Rapidly solidified alloy 2r - Al₇₅Cu₁₇Mg₈

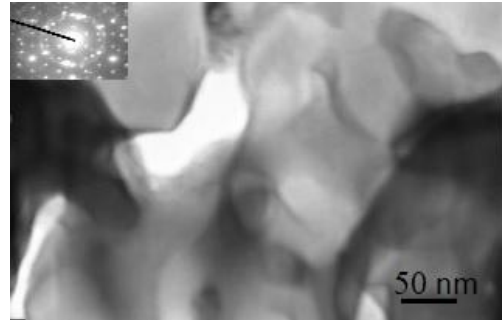


Fig. 4b Rapidly solidified alloy 2`r - (Al₇₅Cu₁₇Mg₈)₉₉Zn₁

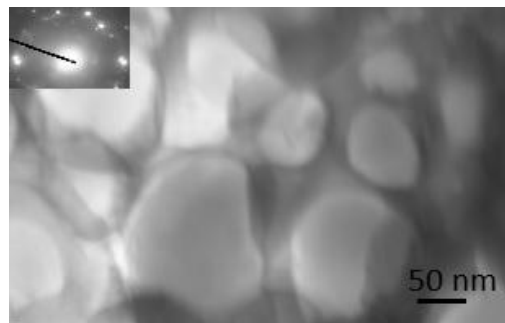


Fig. 4c Rapidly solidified alloy 2''r - (Al₇₅Cu₁₇Mg₈)₉₈Zn₂

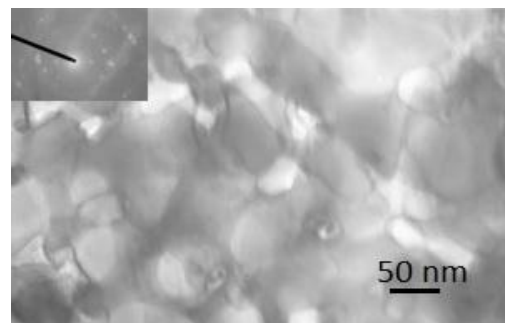


Fig. 4d Rapidly solidified alloy 2'''r - (Al₇₅Cu₁₇Mg₈)₉₇Zn₃

DSC analyzes were performed to study the crystallization behavior of the rapidly solidified ribbons. The results of the DSC analyzes are presented in Figure 5 and Table 3.

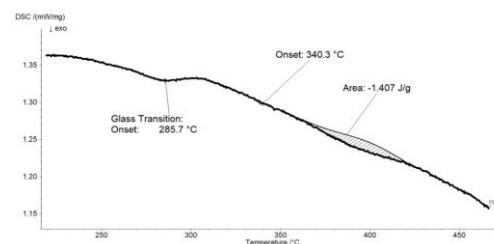


Fig. 5a Alloy 2`r with 2 mass.% Zn

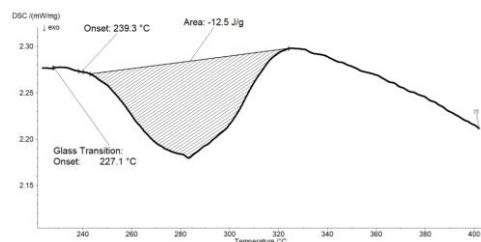


Fig. 5b Alloy 2'r with 5 mass.% Zn

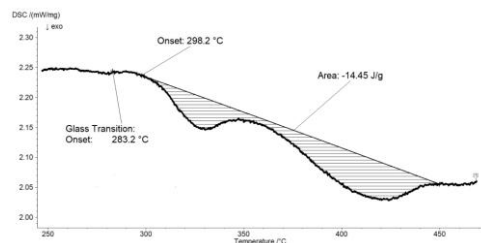


Fig. 5c Alloy 2'''r with 7 mass.% Zn

Fig. 5 DSC thermograms of the rapidly solidified ribbons

Table 3. T_g/T_l assessment of glass forming ability (GFA) of the amorphous ribbons

Amorph. Alloys (ribbons)	T _l [K]	T _g [K]	T _g /T _l	ΔH [J/g]
2r - Al ₇₅ Cu ₁₇ Mg ₈	803.2	423.2	0.53	-
2'r - (Al ₇₅ Cu ₁₇ Mg ₈) ₉₉ Zn ₁	923.2	558.7	0.60	-1.41
2''r - (Al ₇₅ Cu ₁₇ Mg ₈) ₉₈ Zn ₂	923.2	501.4	0.54	-12,5
2'''r - (Al ₇₅ Cu ₁₇ Mg ₈) ₉₇ Zn ₃	923.2	557.7	0.60	-14,45

In ribbons 2'r, 2''r and 2'''r with increasing content of Zn crystallization of the amorphous phase is observe. The amount of the amorphous phase and glass transition temperature T_g increase. change with increasing content of Zn.

In the above designations, following Tammans rule we apply, in general, the notation T_g for the specification of the lower boundary of the glass transformation range. However, the notation T_g is mostly applied, when a standardized method of solidification is used (as in the present investigation), giving more or less reproducible values for the temperature of vitrification T_g.

For typical one-component glass-forming melts and normal cooling rates the value of the glass transition temperature, divided by the melting temperature T_m, is usually of the order T_g/T_m ≈ 2/3.

This is the so-called two-third rule of Tamman - Beamen and Kauzmann [5,6,7,8].

The Beamen – Kauzmann rule was generalized by Sakka and Mackenzie [9] to multicomponent systems. In this case, T_m is to be replaced by the respective liquidus temperature T_l of the system. However, for glass-forming metallic alloys the value of the ratio T_g/T_l may be considerably smaller, e.g., T_g/T_l ≈ ½, or even T_g/T_l < ½ [9,10].

So, glass forming ability (GFA) of good oxide glass formers is characterized by T_g/T_l ratio ≈ 2/3. By contrast to this in glass-forming metallic alloys the value of the ratio T_g/T_l may be

considerably smaller, e.g., T_g/T_l ≈ ½ [10]. As it is seen from Table 3., the investigated amorphous alloys (Al₇₅Cu₁₇Mg₈)_{100-x}Zn_x, x=0, 1, 2, 3 at. % have relatively good GFA, considering that for typical glassy metals T_g/T_l ≤ ½.

4. Conclusions

Amorphous and nanosized rapidly solidified (Al₇₅Cu₁₇Mg₈)_{100-x}Zn_x alloys were obtained by melting in an induction furnace and then rapidly quenched by the planar flow casting (PFC) method in instalations, created at the IMSETHAC-BAS.

It was found that the microstructure of the rapidly solidified (Al₇₅Cu₁₇Mg₈)_{100-x}Zn_x alloys consists of an amorphous matrix and separated nanocrystalline phases in range 10 ÷ 70 nm.

The obtained amorphous alloys (Al₇₅Cu₁₇Mg₈)_{100-x}Zn_x, x=0, 1, 2, 3 at. % have relatively good glass forming ability, considering that for typical glassy metals T_g/T_l ≤ ½. The glass transition temperatures T_g and temperature onsets of crystallization T_{on} are in the range 400 – 660 °K. Enthalpies of crystallization in the interval of 1 -15 J/g are obtained.

Acknowledgements

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