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Z. PIROWSKI[1], A. BITKA[1], M. GRUDZIEŃ-RAKOCZY[1], M. MAŁYSZA[1],
S. PYSZ[1], P. WIELICZKO[1], D. WILK-KOŁODZIEJCZYK[1,2*]

SELECTION OF CASTING MATERIALS FOR WORKING PARTS OF MACHINES FOR THE FORESTRY SECTOR

The article was created as a result of the work TECHMATSTRATEG 1 program "Modern Material Technologies" as part of the project with the acronym INNOBIOLAS entitled "Development of innovative working elements of machines in the forestry sector and biomass processing based on high-energy surface modification technologies of the surface layer of cast elements"; agreement No. TECHMATSTRATEG1/348072/2/NCBR/2017.

The article discusses the procedure for selecting casting materials that can meet the high operational requirements of working tools of mulching machines: transfer of high static and dynamic loads, resistance to tribological wear, corrosion resistance in various environments. The mulching process was briefly described, then the alloys were selected for experimental tests, model alloys were made and perform material tests were carried out in terms of functional and technological properties. The obtained results allowed to select the alloy where the test castings were made.

Keywords: mulching; forestry tools; tribological wear; abrasion-resistant cast steel; hardfacing surface

1. Introduction

According to accepted international standards, the forest area in Poland is over 9.35 million hectares. Recently in Poland and in the European Union countries, the need for new afforestation and wasteland reclamation processes has been increasing. This is due to the need to care for the natural environment, to reduce the greenhouse effect, as well as to further improve life, especially in urbanized areas [1].

Proper management of forest resources requires the use of specialized equipment and devices with a service life significantly exceeding the standards for other machines. In particular, it is necessary to significantly increase the quality and durability of the working elements of these devices. Tools of the forestry sector should be characterized by high strength and plastic parameters, especially high impact toughness, as well as excellent tribological properties and corrosion resistance.

The aim of the project is to use casting technology in combination with the technology of surfacing the working layer in the production of tools for the forestry sector. One of the most important forest work is mulching. Mulching is a conservation procedure aimed at protecting the soil against degradation and maintaining its productivity by creating the so-called mulch, i.e. a protective soil cover placed on its surface in order to reduce the adverse impact of climatic factors [2]. For example, the authors of [17] in their research stated that with the use of appropriate heat treatment allowing to obtain a nanobainite matrix, increasing the carbon content up to 0.58% compared to typical boron steels resistant to abrasion and additional introduction of vanadium at the level of 0.1% significantly improves the tribological resistance under dry friction conditions: three times in relation to steel containing less than 0.47% C and as much as fifteen times in relation to steel containing less than 0.27% C and up to 2.5% Ni.

In this work, there is no information on the possibility of using the tested alloys at high dynamic loads, which is a condition for the possibility of their use for tools of machines and devices operating under such operating conditions, especially for cast tools, and such are the subject of interest of the authors of the presented article.

The research on the wear intensity of selected steel grades intended for operation under dynamic loads was carried out by, inter alia, P. Kostencki [18]. He found that under the conditions

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[1] CENTER OF CASTING TECHNOLOGY, ŁUKASIEWICZ RESEARCH NETWORK – KRAKOW INSTITUTE OF TECHNOLOGY CONTRIBUTION, POLAND
[2] AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF METALS ENGINEERING AND INDUSTRIAL COMPUTER SCIENCE, AL. MICKIEWICZA 30. 30-059 KRAKÓW, POLAND

[*] Corresponding author: wilk.kolodziejczyk@gmail.com

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of field tests, with an increase in soil pressure on the tools from 5.7 kPa to 12.0 kPa, the unit wear of the steel thickness used by the Lemken company increased from 0.0014 to 0.0028 mm km^{-1}, and of the ZBWTR BM Woro-na steel – from 0.0012 to 0.0044 mm km^{-1}. In the case of Lemken steel, this corresponds to a 2-fold increase in wear intensity, and for B. W. Woron's ZBWTR steel – approximately 3.7 times. The advantage of the performed tests is the determination of the intensity of material consumption in field conditions, typical for the operation of agricultural tools.

Operating conditions similar in nature, but much more dynamic, occur in the case of forestry sector tools, for which a casting material for hammer heads of forest and meadow mulchers was developed as part of the research project. Examples of the results of the work carried out in this area are presented in this article. On the one hand, the implemented tools must meet the design requirements in terms of significant dynamic operational loads, which forces the appropriate plastic properties such as impact strength, elongation or yield point, and on the other hand, they are required to have appropriate hardness giving resistance to abrasive wear of the working layer of the tool, which in this case, it may exceed a thickness of 1 mm. In such cases, the working surface is often covered with a layer of a special, wear-resistant alloy, e.g. by hardfacing. It is a very broad issue that is the subject of many researchers' work, especially in terms of the selection of the surfaced material [e.g. 19-21].

The study [19] compares the microstructure and abrasion resistance of surfacing alloys reinforced with primary chromium carbides, complex carbides or tungsten carbides. The surfacing alloys were deposited onto ASTM A36 carbon steel plates by coated metal arc welding (SMAW). The authors concluded that the wear resistance depends on the size, shape, distribution and chemical composition of the carbides and the matrix microstructure. The best abrasion resistance was obtained for microstructures composed of a eutectic matrix and M_7C_3 or MC primary carbides, while greater weight losses were measured in fully eutectic matrices. The main wear mechanisms observed at the surface included matrix microcracks and brittle carbide fractures.

In the work [20], the authors presented the results of tests of abrasive wear resistance of overlaid materials containing various amounts of WC/W_2C carbides. These materials are intended for use in mining tools exposed to intense abrasive wear. Despite the higher content of WC/W_2C carbides, the wear intensity of the padded material containing 90% of these carbides was higher than that of the padded material containing only 60%.

The authors of the work [21], after testing over 30 different hardfacing materials, concluded that the knowledge of these alloys and their influence on abrasive wear does not allow to effectively predict the durability of machine and device parts. Therefore, it is necessary to experimentally test the material proposals. Research is usually influenced by many parameters, so it can be difficult to transfer the results of experiments to another situation. The experimental results of laboratory tests can only help designers and technologists in selecting the optimal material and technology of manufacturing machine parts working in abrasive conditions.

This article discusses the selected casting alloys for the tools for flail mowers (mulchers and shredders) implemented in the new design. These tools include, among others, hammer heads for meadow, forest and roadside mulchers, as well as hammer heads for forest mulchers.

Why casting alloys?

The casting technology makes it much easier to model and construct elements, even of very complex shapes. Such material and technological conversion allow for:

- decreasing of technology costs (replacement of welded and forged elements with cheaper castings),
- increasing durability and quality,
- increase of modernity and competitiveness of domestic products on the European market,
- reduce the operating costs of machines and devices by improving the quality of the final product, making it more competitive.

Examples of this constructional and material-technological conversion has been described in a number of publications [e.g. 3-7] being the result of cooperation between PIMR (*pol.* Przemysłowy Instytut Maszyn Rolniczych, ang. Industrial Institute of Agricultural Engineering constructors (currently SBŁ-PIMR ang. ŁUKASIEWICZ Research Network – Industrial Institute of Agricultural Engineering) and FRI (ang. Foundry Research Institute) technologists (currently SBŁ-KIT, *ang. Łukasiewicz Research Network – Krakow Institute of Technology*) as part of the implementation of joint research and development projects.

The works described in this article relied on selecting, producing and testing modern casting materials in terms of optimizing their technological and functional properties. Obtaining a casting alloy in terms of its application for the new tools implemented in the project required at the initial stage of implementation to conduct research on alloys previously used for this type of tools.

2. Selection of alloys for tests

The selection of casting material for elements of various machines and devices has been the subject of research work carried out for many years in Łukasiewicz – Kraków Institute of Technology (formerly the Foundry Research Institute). Examples of such activities related to the constructional and material-technological conversion have been described in [1,3-7,12-16]. Realizing this project, the mechanical properties of 15 different grades of steels resistant to tribological wear from the most common groups of alloys for this purpose were analyzed: Raex, Hardox and SAAB Boner. On the basis of the normative mechanical properties of these materials (yield point, elongation, hardness and impact toughness), it was found that the most favourable parameters for working of abrasive wear in impact conditions has Hardox 450 steel [1], which was assumed as a reference for the selection of appropriate alloy cast grades.

According the intentions and aim of the project, the developed tools are cast tools. By analyzing the relevant Polish and European standards for abrasion-resistant cast steel grades, 11 such alloys were selected for the evaluation of their properties. Carrying out the evaluation of these materials similar to that described in [1] in the case of standardized steel grades, two grades of cast steel performing the assumed criterion of mechanical properties ($YS_{0,2} \geq 800$ MPa, Elongation ≥ 7%) were selected. For this alloys designated for experimental tests a point value higher than the **Hardox 450** point value (32,22 assigned points). These are cast steel from the French standard [8]: **30MCDB64-M-I** and **30NSCDV86 M-I**. The selection criteria were the mechanical properties (Rp0.2 ≥ 800 MPa, A ≥ 7%), for which the point value was higher than the point value of Hardox 450 steel. The standard chemical composition of these alloys is shown in TABLE 1.

In the design assumptions, the implemented cast tools must, in terms of strength and usability, at least match the forged and welded tools used so far. For comparative material and operational tests were purchased from the national leaders distributors currently on the market: Mader Serwis – Wrocław, AGROMAREK – Skrzyszów, GRANIT PARTS – Poznań and PHU P. CZYŻ – Łubowo, over 30 items of various types of tools (hammerheads) for the forestry sector. Their chemical composition was analyzed using the Thermo Scientific NITON XL3t 900S GOLDD device, and the average results obtained from this analysis are presented in TABLE 2.

3. Material research

In the following part of the work, model melts of selected test alloys were made in laboratory conditions. All metallurgical operations were carried out in the shortest possible time, resulting from the technical conditions of the devices that we have at our disposal. Model alloys were melted in an open RADYNE induction furnace with a crucible capacity of 100 kg of metal charge. A compacted, dried, and sintered crucible made of a refractory neutral ceramic mass was used. Commonly available charge materials, deoxidizers and modifiers were used for the melts. During the smelting of the metal, its temperature was controlled by periodic measurements with a platinum "B" type thermocouple (PtRh30-PtRh6), which allowed the temperature to be measured up to 1800°C. The tip of the thermocouple immersed in the liquid metal was protected with self-made covers. The chemical composition of the alloy was analyzed at individual stages of the melting process. During each melt, the chemical composition of the alloy was examined with the spectrometric method by taking analytical samples of the starting metal immediately after melting the charge in order to make an appropriate correction of the content of alloying elements, after making this correction, and then after carrying out the final technological treatments (deoxidation and modification). The results of the final analysis are summarized in TABLE 3. The analyzes were

TABLE 1

Standard chemical composition of cast steel grades selected for testing [8]

Alloy	The content of alloying additions; wt%									
	C	Si	Mn	P	S	Cr	Ni	Mo	V	B
30MCDB64-M-I	0,23 0,33	max. 0,60	1,30 1,80	max. 0,040	max. 0,035	0,40 1,00	—	0,40 0,60	—	0,003 0,006
30NSCDV86-M-I	0,26 0,33	1,45 1,80	0,60 1,00	max. 0,040	max. 0,035	0,65 0,90	1,65 2,00	0,30 0,45	0,05 0,15	—

TABLE 2

Average chemical composition of the reference tools

Parameter	The content of alloying additions; wt%				
	C	Si	Mn	Cr	B
average	**0,35**	**0,41**	**1,23**	**0,34**	**0,004**
minimum	0,28	0,21	0,70	0,07	0,000
maximum	0,57	0,82	1,36	0,54	0,006
stand. dev.	0,080	0,162	0,168	0,094	0,0017

Parameter	Contents of admixtures; wt%								
	Cu	Ni	V	Mo	Ti	Nb	Zr	Zn	Sn
average	**0,115**	**0,044**	**0,005**	**0,018**	**0,031**	**0,000**	**0,001**	**0,005**	**0,002**
minimum	0,000	0,000	0,000	0,002	0,000	0,000	0,000	0,000	0,000
maximum	0,249	0,117	0,009	0,151	0,058	0,006	0,003	0,029	0,019
stand. dev.	0,079	0,049	0,003	0,025	0,020	0,001	0,001	0,007	0,006

TABLE 3

The obtained chemical composition of the made model alloys

Alloy	The content of alloying additions; wt%									
	C	Si	Mn	P	S	Cr	Ni	Mo	V	B
30MCDB64-M-I	0,25	0,37	1,41	0,023	0,023	1,54	0,05	0,440	—	0,007
30NSCDV86-M-I	0,47	1,76	0,72	0,017	0,012	0,94	1,740	0,570	0,140	—

carried out using the ARL MA optical emission spectrometer with spark excitation, designed for simultaneous determination of the content of several elements in low-alloy and high-alloy steels, cast steel and cast iron in a wide range of analytical ranges.

A separate research problem was to develop a method of carrying out the necessary thermal treatments of the model alloys (selection of temperature and time parameters of these processes) ensuring obtaining the structurally required properties of the material itself. The material is intended for the further part of the design work consisting in combining this native material of casting tools with the hardened layer of working surfaces [10].

The tested alloys were subjected to multi-variant thermal treatments. Annealing treatments were carried out in an electric resistance furnace POK73.1. The austenitization treatments were carried out in an electric Multitherm N41/M resistance furnace under an argon atmosphere. The tempering treatments were carried out in the Multitherm N41/M electric resistance furnace (for a temperature of 600°C in an argon atmosphere, and for a lower temperature in an air atmosphere). The following thermal treatments were used for individual alloys:

- cast steel 30MCDB64-M (designation of the cast condition not taking into account normative thermal treatments):
  - variant 1: water quenching; low tempering,
  - variant 2: water quenching; high tempering,
- cast steel 30NSCDV86-M (designation of the cast condition not taking into account normative thermal treatments):
  - variant 1: water quenching; tempering,
  - variant 2: preliminary annealing; water quenching; double tempering,
  - variant 3: preliminary annealing; quenching in oil; double tempering.

The heat treated model alloys were subjected to a static tensile test, impact strength and hardness measurements as well as density measurements. TABLE 4 shows the average values of the obtained parameters from the three tested samples, with the exception of the NSCDV86-M alloy, which was not pre-annealed. Samples of this alloy broke during testing and the results are indicative of one sample selected for testing. The remaining results are from the three samples. All cast model alloys were heat treated. The following thermal treatments were used for individual alloys:

- Stop No. “0”:
- preliminary annealing: 930°C/1 h/with a furnace;
- austenitization: 910°C/1 h/water;
- tempering: 250°C/1 h/air;
- Stop No. “2”:
- preliminary annealing: not used;
- austenitization: 950°C/1 h/water;
- tempering: 250°C/1 h/air;
- Stop number “4”:
- preliminary annealing: 930°C/1 h/with a furnace;
- austenitization: 890°C/1 h/oil;
- tempering: 310°C/1 h/air + 310°C/1 h/air.

Annealing operations were carried out in an electric resistance furnace POK73.1., Austenitization in an electric resistance furnace Multitherm N41/M in an argon atmosphere, and tempering also in an electric resistance furnace Multitherm N41/M, but for a temperature of 600°C in an argon atmosphere, and for lower temperature in the air atmosphere.

Mechanical properties were also tested on the reference material taken from the purchased mulcher flail hammers, and

TABLE 4

Mechanical properties and density of the manufactured model alloys

Alloy	Designated parameter									The heat treatment
	UTS (MPa)	$YS_{0,2}$ (MPa)	Elongation (%)	Neck (%)	HB (-)	KV (–40°C) (J)	E (GPa)	ν (-)	ρ (g/cm^3)	
30MCDB64-M	1514	1415	8,4	25,1	409	15,3	188	0,27	7,81	water quenching low tempering
	965	861	13,4	47,1	299	20,5	—	—	7,80	water quenching high tempering
30NSCDV86-M	brittle alloy (samples break during testing)				586	2,9	—		7,66	water quenching tempering
	1674	1486	0,8	0,5	362	6,2	202	0,29	7,68	preliminary annealing water quenching double tempering
	1683	1537	2,5	4,4	349	7,8	197	0,27	7,67	preliminary annealing quenching in oil double tempering

TABLE 5

Test results of the mechanical properties of the forged commercial (reference) hammers material

Material	Designated parameter						
	UTS (MPa)	$YS_{0,2}$ (MPa)	Elongation (%)	Neck (%)	HRC (-)	HB (-)	KV (–40°C) (J)
steel type Hardox 450	1282	1120	8,6	43,6	35,0	325	15,8

the results are presented in TABLE 5, shows the average for three castings with one sample each.

The manufactured alloys were subjected thermal characteristics of thermophysical properties, which are necessary for numerical analysis of pouring and solidification processes in the virtual development of the casting technology of the implemented tools were prepared.

Based on the results of the laboratory tests, the 30MCDB64-M-I cast steel was selected for technological tests.

4. Numerical analysis

Numerical analysis includes all properties describing the alloy i.e. specific heat, thermal capacity, density etc. The properties are in the temperature function. Database curves are presented in the figure xa. The initial pouring temperature was set to Tini = 1610°C, temperature of ceramic mould was set to Tf = 900°C. Additionally the ceramic material database was implemented.

Within the project, the construction of many types of the mulching hammerhead, forestry mulchers was developed. Six of them were selected for realization and implementation, as shown in Figure 1.

Using numerical analysis methods was developed the foundry technology of for the these tools production. This article only discusses examples.

Based on the geometry of the constructed tool, the concepts of casting technology were proposed, which were then used in computer simulation to determine the area of possible shrinkage porosities.

Examples of various concepts for the location of the wax model of the RM806 hammer in relation to the gating system and the evaluation of the effect of changes in this orientation on the contraction porosity in the model-gating system are shown in Figure 3.

The numerical analysis of the solidification process showed that in this case the orientation of the model did not affect the possibility of shrinkage defects. This is due to the gating system's much larger hot spot than the casting.

The construction of the RM806 hammer is discussed in detail in the patent application under the name "Mulcher hammer and its manufacture" dated October 25, 2019 The patent application was marked with the number: P.431587 [11].

In the case of the UTS4 mulcher, two technological concepts were analyzed, for three and four models in the gating system, shown later in the article in Figure 7. Both cases give the positive results of compact structure castings. For economic reasons a four-element concept was chosen. Due to the very similar shapes of the other tools, the casting technology for them was designed in a very similar way.

The only detail that differs in shape from the others is the tool marked RB OTL, characterized by a wide base. Two possible concepts of its casting technology were analyzed: one or four castings in a set. The concept of one casting is dictated by the fact that the casting cross-section requires an appropriate feeding of the casting. The second concept is more economical, but technologically more difficult in terms of making foundry moulds.

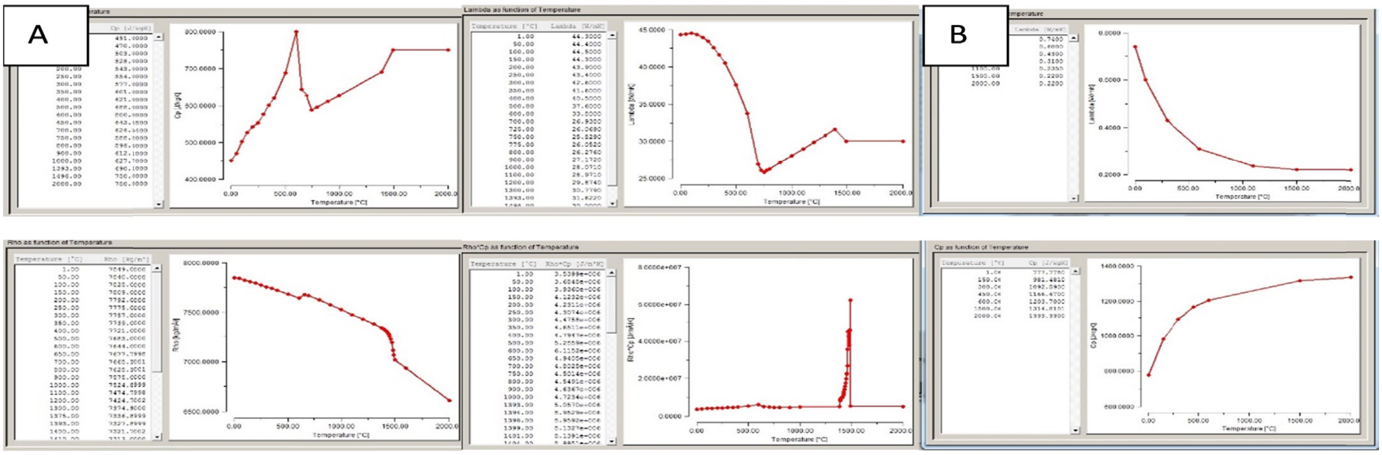
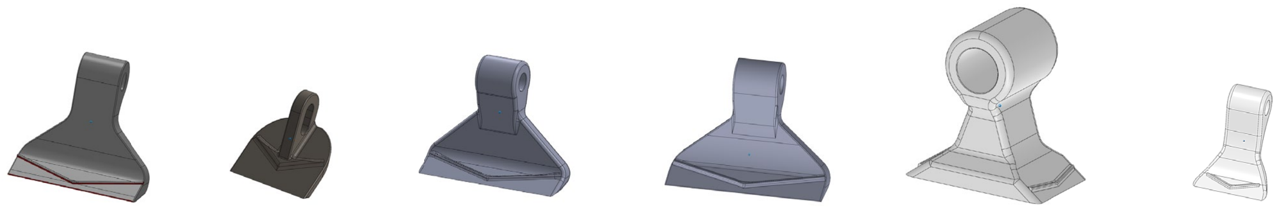


Fig. 1. A) Properties of the alloy in the temperature function, B) Properties of ceramic material



RM4 RM806 RM30 version 6 RM30 version 3 RB OTL (manufacturere's name.) RBR OTL (manufacturere's name.)

Fig. 2. CAD drawings of the developed constructions of hammerheads selected for the implementationt

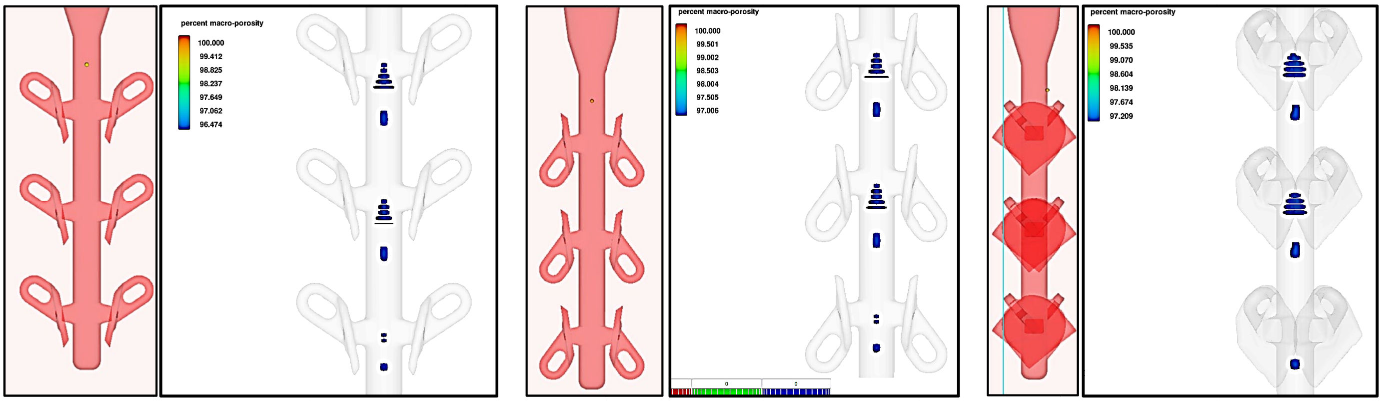


Fig. 3. Analysis of various variants of the mulcher RM806 model positions

Using the numerical analysis method, an attempt was made to virtually evaluate the microstructure of the casting and to estimate the basic mechanical properties of the cast alloy.

Cast steel 30MCDB64-M-I intended for casting of implemented tools is characterized by a YS0.2 / UTS ratio. The virtual solidification curves of this alloy, (example shown in Fig. 4), in the thicker and thinner wall of the RM4 hammer casting show that the solidification rate at these points is significantly different, which influences on the differences in the final strength properties. The tensile strength (UTS) can change from 600 to 800 MPa depending on the wall thickness.

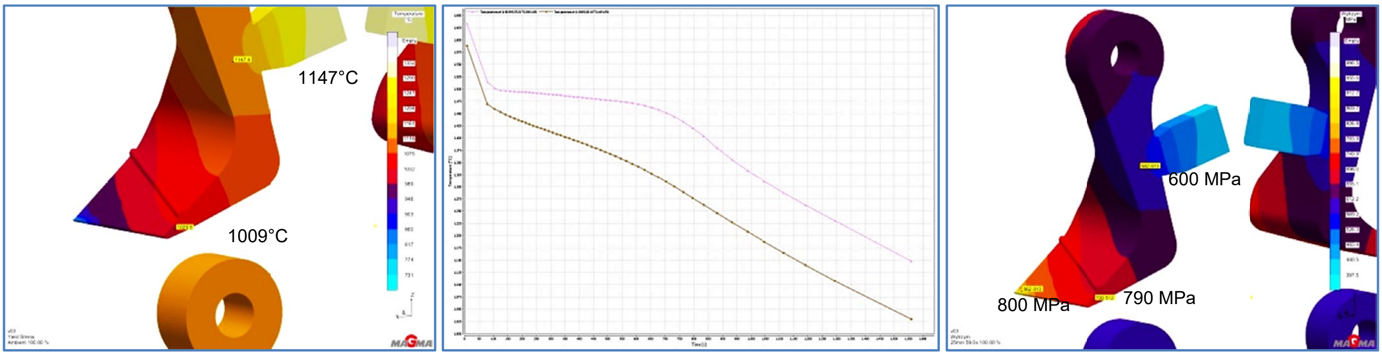


Fig. 4. Measurement points(left), kinetics of temperature changes during solidification (center) and strength values at various points of the casting (right)

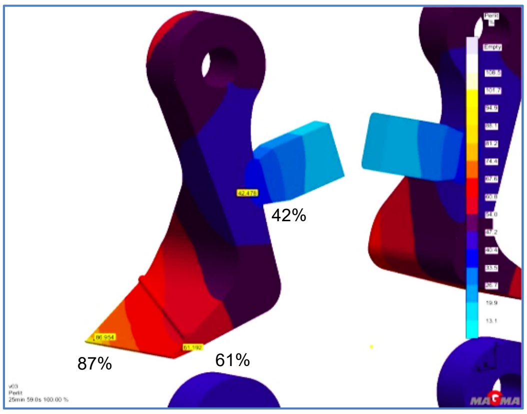


Fig. 5. Virtual evaluation of the amount of perlite in the cross-section of the casting

At the end of (thin-walled) zone is occurring in the tendency to form an increased amount of perlite as shown in Figure 5. The hammer blade has a very thin wall at the end of the tool. This can cause the formation of carbides, which will greatly increase strength, but will significantly reduce plasticity. The heat treatment compensates for such large differences in properties in the cross-section of the casting.

The performed numerical analysis on the example of the RM4 mulcher casting also allowed for a virtual evaluation of the size and distribution of residual stresses can result from in the solidification and cooling process of casting. For this purpose, creates CAD solids in the SolidWorks program were used, which were also used to prepare the concept of the casting technology and to evaluate the porosity. The MAGMASoft software was used for evaluating the size and distribution of stresses. Technological assumptions prepared for precision casting process were analyzed. The computational iteration includes the properties of the ceramic mass, which is a layered casting mould containing the gating system and castings. The aim of this analysis was to virtually evaluation the size and distribution of residual stresses of the selected cast steel grade (30MCDB64-M-I) for solidifying casting on the example of an RM4 mulcher.

Figure 6 illustrates, respectively: the selected tool, the technological concept and the virtual layered ceramic mould for one of the analyzed technological variants.

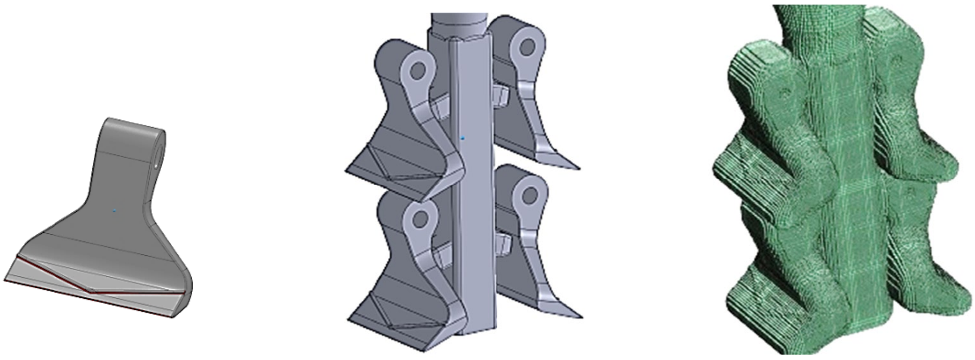
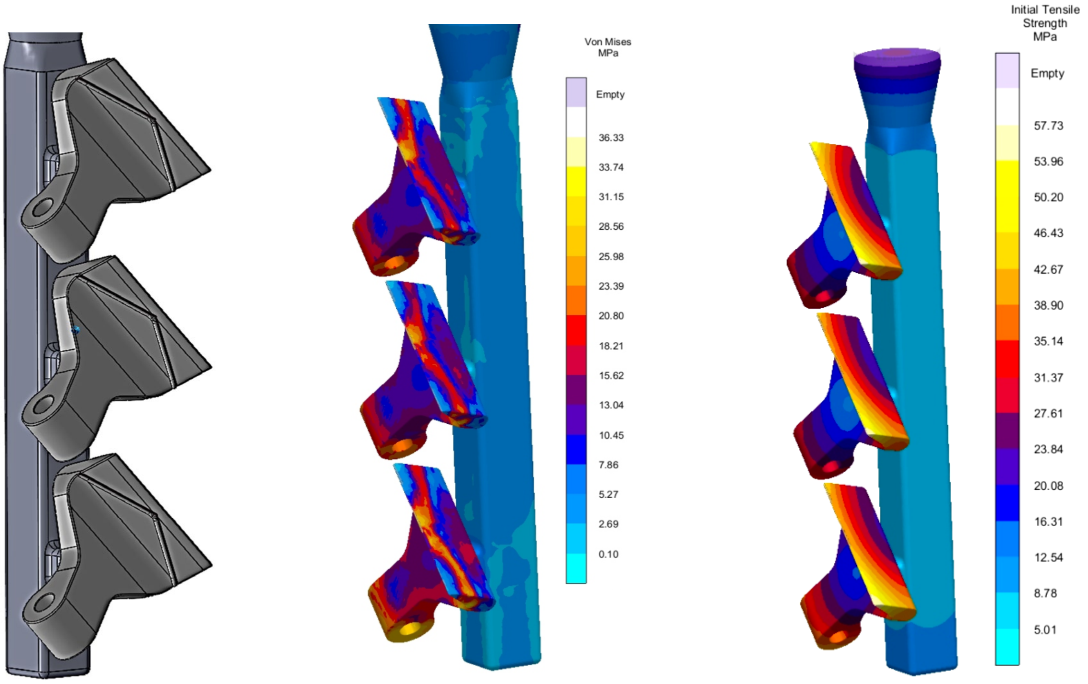

CAD model technological variant virtual mould

Fig. 6. The RM4 type mulcher selected for the numerical analysis of the casting residual stress

Based on the of the geometry of the constructed tool, the previously mentioned two concepts of casting technology were proposed, which were used for evaluating the size and distribution of residual stresses that result from the casting process. The advantage of using computer programs to simulate technological processes is the possibility of predicting stresses occurring during solidification, which may cause deformation or cracking of castings. On the example of the RM4 mulcher, the influence of the change in the orientation of the casting in the gating system set was analyzed, what has been presented in Figures 7 and 8.

Visualization of stress simulation results shows the areas exposed to excessive stress concentration. Simulations A1 and B1 show the picture of reduced stress (Von Mises) for two technological concepts. In the case of the A concept, these stresses do not exceed 37 MPa, which for the analyzed alloy is significantly below its yield point. For the B concept, this value reaches a much higher value, i.e. 100 MPa, but it still does not affect the formation of cracks, because the material has a much higher yield point.

Another feature presented in Figure 7 is the distribution of tensile stresses in the initial stage after the metal solidification (Initial Tensile Strength) – simulations A2 and B2. Its presents in which areas deformations can occur in the process of cooling the casting. For the technological concept A, the danger of deformation rises at the ends of the tool and reaches a maximum value of about 57 MPa. The material characteristics show that this value is also lower than the properties of this alloy. It's similar to the concept B. In such an arrangement, this value reaches about 64 MPa and is also located on the protruding parts of the tool. Such a stress location for this tool is due to its geometry, as there is a significant diversification of the cross-sections in the



A A1 A2

Fig. 7. Variant A. Set with three models of the RM4 mulcher and visualization of the stress simulation results: A1 – on the Von Mises scale – the reduced stresses value; A2 – on the Initial Tensile Strength scale – tensile stresses during solidification of liquid metal

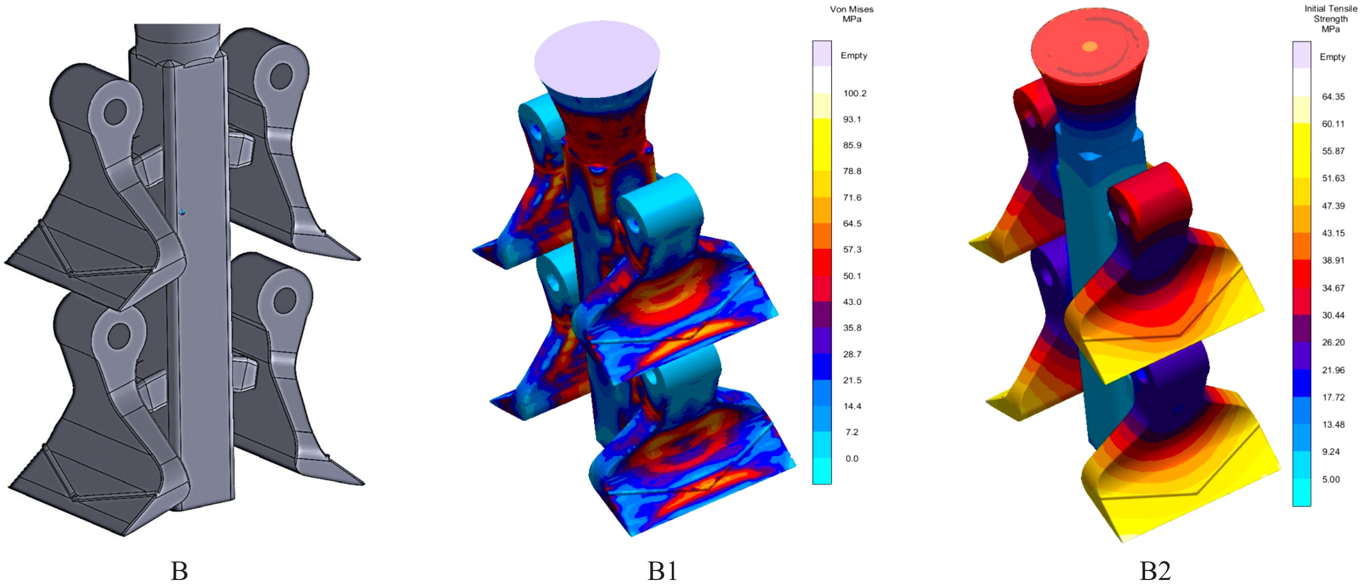


Fig. 8. Variant B. Set with four models of the RM4 mulcher and visualization of the stress simulation results: B1 – on the Von Mises scale – the reduced stresses value; B2 – on the Initial Tensile Strength scale – tensile stresses during solidification of liquid metal

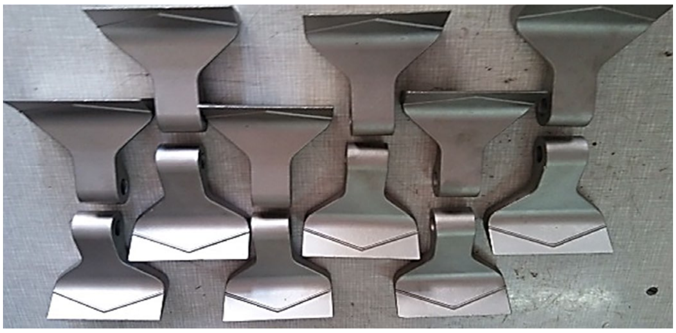


Fig. 9. Manufactured casts of RM4 mulchers

adjacent areas of the casting (the smallest cross-section passing from a much larger one).

Perform the operation of removing the gating system will reduce the value of residual stresses, i.e. those arising in the technological process. The application of heat treatment will cause relaxation and elimination of stresses arising after the solidification casting process (stresses resulting from the essence of the solidification process and the resistance of the ceramic mould).

Control castings made according to the developed technology (Fig. 9) were evaluated using a 3D scanner to determine the

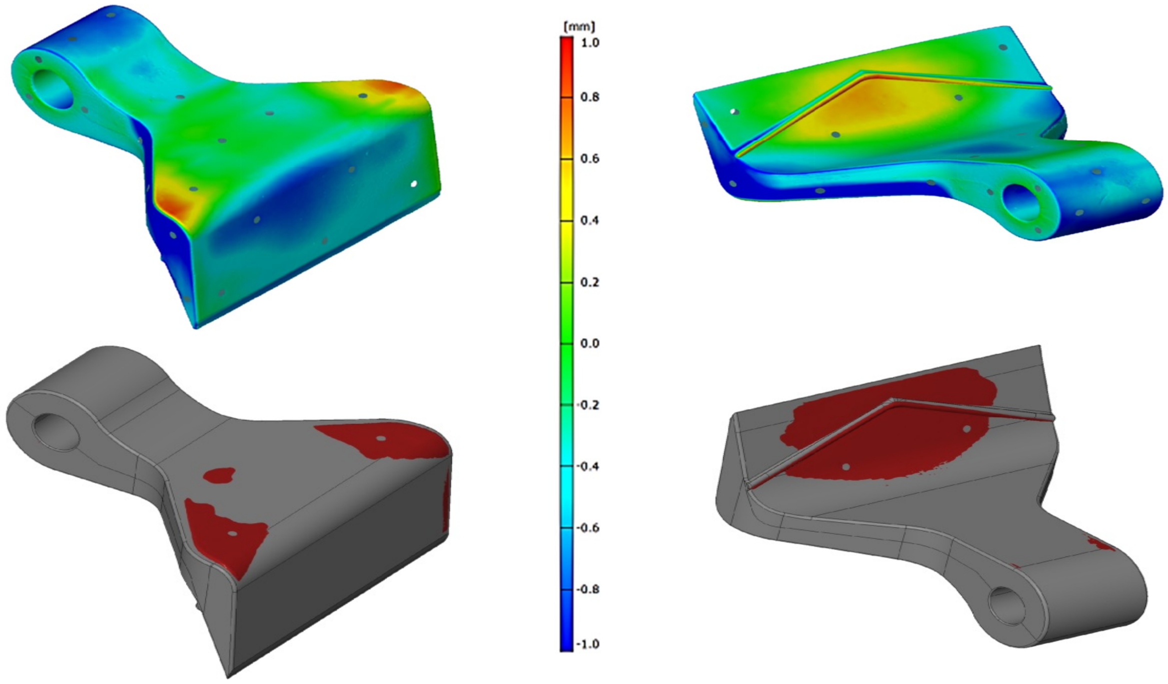


Fig. 10. Measurements of dimensional deviations of the RM4 mulcher castings and matching the casting scan to the CAD model with the best fit method

dimension accuracy with the design CAD drawings, as shown in Fig. 10.

The observed slight dimensional deviations in places important from the operational point of view, which were shown by the performed measurements, do not have a significant effect on the functional features of the tool.

5. Conclusions

1. Realizing the project work described in the article, the main goals were achieved, namely:
   - an analysis of the design and operational requirements for foundry materials for the production of new tools for the forestry sector,
   - properties necessary for the development of virtual and real casting technology have been determined for the selected casting alloys,
   - temperature and time parameters of thermal treatments were determined in order to optimize the mechanical and functional properties of alloys recommended for new, cast working parts of machines and devices used in forestry.
2. Comparing the obtained results of laboratory material tests, it was found that the 30MCDB64-MI cast steel, after a properly selected heat treatment process, does not differ in its properties from the forged steel of reference tools. Technological process of its production is less expensive than the other selected for the tests of cast steel grades (30NSCDV86-M). This alloy, apart from good tribological resistance and high strength parameters, does not meet other design requirements (high brittleness) and operational requirements (poor corrosion resistance). Therefore, cast steel 30MCDB64-M-I was selected for further work. In order to obtain the appropriate balance of strength and plasticity, its chemical composition and technological parameters of the necessary thermal treatments were slightly modified. These parameters slightly different from those specified in the relevant standards, which, apart from the construction of the hammerhead, was included in the submitted patent application [11].
3. Measurements of the geometry of selected hammer heads showed that the stresses that arise during the solidification and cooling process for the analyzed manufacturing concepts of the implemented tools are below the yield point of the material used and do not cause its deformation.
4. Quality assessment, including the lack of significant dimensional deviations in the areas of constructionally significant for mulchers castings, confirmed of the numerical analysis results carried out in the field of virtual technology development, both in terms of shrinkage porosity and not exceeding the admissible casting stresses causing excessive deformation of the casting.
5. The manufactured test series of mulchers (6 types, over 250 examples), after laser surfacing by the Project Consortium (SBŁ-PIMR) of the working layers with the special mixtures of metallic-ceramic powders, were sent for operational tests as spare parts for the of forestry machinery.

The material properties obtained such as conform to the standards. In the available literature, no research has been found on cast tools specific to the forest sector, but only on acute and welded tools. The work is aimed at comparing the properties ... for the forestry sector. Until now, they are exclusively produced as forged and welded. These castings are designed for surfacing with materials with high abrasion resistance.

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