Repairs of Damaged Castings Made of Graphitic Cast Iron by Means of Brazing

M. Mičian *, R. Koňár

University of Žilina, Faculty of Mechanical Engineering, Univerzitná 1, 010 01 Žilina, Slovakia
*Corresponding author. E-mail address: milos.mician@fstroj.uniza.sk

Abstract

The article summarizes the theoretical knowledge from the field of brazing of graphitic cast iron, especially by means of conventional flame brazing using a filler metal based on CuZn (CuZn40SnSi – brass alloy). The experimental part of the thesis presents the results of performance assessment of brazed joints on other than CuZn basis using silicone (CuSi3Mn1) or aluminium bronze (CuAl10Fe). TIG electrical arc was used as a source of heat to melt these filler materials. The results show satisfactory brazed joints with a CuAl10Fe filler metal, while pre-heating is not necessary, which favours this method greatly while repairing sizeable castings. The technological procedure recommends the use of AC current with an increased frequency and a modified balance between positive and negative electric arc polarity to focus the heat on a filler metal without melting the base material. The suitability of the joint is evaluated on the basis of visual inspection, mechanic and metallographic testing.

Keywords: Castings defects, Casting repair, Brazing, TIG electric arc

1. Introduction

Extending the life span of cast iron parts damaged due to occurrence of cracks, fractures or other damages is one of important tasks in the engineering industry. Cast irons as a construction material are not primarily designed for welding or brazing. In this case welding and brazing represent repair tasks. If we lay stress on the fact that the weld metal has similar or approximate mechanical, structural and physical properties than basic material, the repair is very specific, time consuming and financially challenging [1-3].

While repairing damaged machine parts during the operation or breakdown other indicators are taken into consideration, namely joint strength and tightness, how easy the repair is, undemandingness for the staff and finally economic aspects of the repair. In this case, in addition to so-called ultra-cold welding using Ni or Ni-Fe electrodes, brazing is also applicable. It should be noted that brazed joints are, as compared to welded joints, limited by the maximum operating temperature (with Cu-based alloy filler metal, up to 200 - 260 °C, Cu filler metal with Ni alloying tolerate higher temperatures) [4-8].

The first choice in the field of brazing methods is the use of a flame, whereby the filler metal could be a CuZn brass alloy, e.g. B-Cu60Zn(Sn)(Si). When repairing castings of greater dimensions and weight the material pre-heating temperature is an important factor for a successful repair realization. The most suitable temperature to brazing cast irons is 650 - 750 °C. It is the minimum temperature for a proper wetting of the basic material during manual brazing using this filler metal. The most suitable shape of a joint is a V-joint or an X-joint with a included angle of 90°. With the right brazing procedure we may achieve the joint strength of approx. 280 MPa, which in certain cases may exceed the strength of the basic material. During the brazing process it is necessary to proceed quickly because after a longer exposure of the temperatures above 500 °C the cementite in the cast iron disintegrates and its volume increases. We call cast iron expansion.

Arc brazing is a relatively well-known technology, the currently-known outputs of the research direct its usability mainly towards the automotive industry (robotic brazing using a process MIG-brazing). However, the use of the electric TIG arc heat for brazing of graphitic cast irons is a little explored field. A brazers must be really skilled to direct the arc to a filler metal and to braze edges so that these do not melt. The effect of ionized argon to ensure surface cleaning from graphite and other non-metallic inclusions is estimated, which may improve the conditions for a proper wettability of the molten filler metal [4,5,9-8].

2. Brazeability of graphitic cast irons

Brazeability of graphitic cast irons is influenced by several factors. If the brazing temperature is higher than the temperature of eutectoid conversion of the basic material, structural changes will occur, and the occurrence of cementite (harder) structures is estimated. Low thermal conductivity, considerable thermal expansion and low plasticity together with an inappropriate temperature cycle will generate intensive thermal tension in the joint area. The casting surface is usually covered with oxide layers together with impregnated particles of moulding compounds. This surface does not meet the brazeability conditions. Despite removing this layer free graphite remains on the brazed edges surface. As a non-metallic compound it considerably impairs the wettability of the surface using a filler metal [5, 10].

The influence of the above-mentioned factors should always be minimized in order to achieve a successful brazed joint.

2.1. Filler metals for brazing

For flame brazing we can find the use of brass (CuZn) and silver (Cu-Ag-Zn) filler metals in the recommendations of the manufacturers of cast irons repair filler metal. With silver filler metal containing approx. 40% of silver we can achieve the filler metal liquid temperature below 700°C, which is lower than the eutectoid transformation. For arc brazing of graphitic cast irons we cannot find this specification in data sheets, whereby the above-mentioned filler metal containing zinc are not suitable for arc brazing. That is because zinc evaporates considerably by effect of the electric arc temperature to produce a great splash of the filler metal and the evaporating metal impairs the electric arc itself, which then burns in a very unstable manner.

For arc brazing application filler materials with a high proportion of Cu appear to be the most suitable. In general these are silicon, aluminium or tin bronzes (e.g. CuSi3Mn1, CuSn6P, CuAl7, etc.). Even though these materials are used primarily for brazing galvanized sheets (e.g. CuSi3Mn), or welding copper, their use for TIG arc brazing field seems permissible and fundamentally innovative in theory. The fact that should be considered is that the temperature of filler metal liquid with a high proportion of Cu is more than 1000°C, thus there is a little difference between the temperature of the basic material melting and the filler metal. When melting these filler metals there is a high probability of melting the base material (LGG melting

temperature is approx. 1295 °C and the basic material (e.g. CuAl10Fe) melting temperature is in the range 1030-1040°C). We also must consider the knowledge about copper welding.

The basic operational problems include high thermal conductivity and a typical property of copper in the temperature range from 300 to 750 °C. In this temperature range copper ductility decreases from approx. 40% (at the room temperature) by approx. a half. Low plastic properties of copper in this solidifying interval create a possibility of cold cracks [11, 12].

3. Experimental tasks

Plates cast in a sand mould were used as experimental samples. The following element composition was determined by a chemical analysis of the cast plates: C=3,66%, Si=2,28%, Mn=0,23%, P=0,065%, S=0,008%, Mg=0,036%.

Based on the metallographic evaluation it was concluded that it is a ferrite-perlite cast iron with vermicular (compacted) graphite. The basic material classification according to EN 16079 was *EN-GJV-300-2* (guiding value of minimum tensile strength R_m=300MPa). The evaluation of graphite according to EN ISO 945-1 was *80% III 4 + 20%VI 6*.

The plates were formatted by means of milling to the size 150x100x10mm (length/width/thickness). The joint configuration was designed as a butt joint with a 60° „V" bevel for arc brazing and with a 90° „V" bevel for flame brazing. Milled plates with a prepared brazing edge are shown in Fig. 1, left. The simulation of the conditions during a repair, especially oversized machine parts, required strong clamping of a testing sample in a manufactured fixture after stitching (Fig. 1, right).

Fig. 1. Processed plates with a welded V-bevel (left), a fixture with clamped samples (right)

Overall, three testing samples were brazed. The first one by means of flame brazing and the others by means of arc TIG brazing without pre-heating. The classification of brazing methods, for the future purposes of creating brazing technological procedures (BPS) and certificate requirements for brazers, was ISO 4063 – 971 (flame brazing) and ISO 4063 – 974 (TIG – brazing).

Filler metals were selected in terms of the used brazing method. In general, technical and delivery conditions for filler metals intended for brazing are determined in EN ISO 17672 standard. Two ways of designation are used. The first one uses a numerical coding preceded by a symbol of the element prevailing in the filler metal. The other system refers to designating according to EN ISO 3677 standard. The classification of the filler metals used in the experiment is shown in Table 1 and their

guiding chemical composition is shown in Table 2. Practically, we often see that Cu-based filler metals are delivered also according to the classification of filler materials intended for welding copper and its alloys according to EN ISO 24373 (especially filler metals for arc brazing).

Table 1.
Classification of filler metals used in the experiment

Designation acc. EN ISO 17672	Designation acc. EN ISO 3677	Designation acc. EN ISO 24373	Melting temp. (approx.) Solidus [°C]	Liquidus [°C]	Used method
Cu470	B-Cu60Zn(Sn)(Si)-875/895	Cu 4641 / CuZn40SnSi	875	895	Flame brazing (971)
Cu541	B-Cu96SiMn-980/1035	Cu 6560 / CuSi3Mn1	980	1035	Arc brazing (974)
Cu565	B-Cu89AlFe-1030/1040	Cu 6180 / CuAl10Fe	1030	1040	Arc brazing (974)

Table 2.
Guiding chemical composition of the filler metals used in the experiment in mass %

Designation acc. EN ISO 17672	Cu	Al	Fe	Mn	P	Si	Zn	Sn	Total impurities
Cu470	57 to 61	-	-	-	-	-	residue	0,2 to 0,5	-
Cu541	residue	max. 0,05	max. 0,2	0,7 to 1,3	max. 0,05	2,7 to 3,2	max. 0,4	-	max. 0,5
Cu565	residue	8,5 to 11,5	0,5 to 1,5	-	-	max. 0,1	max. 0,02	-	max. 0,5

3.1. Technological parameters of TIG brazing of experimental samples

Before making test joints it was necessary to master the technology and technique of using TIG arc for specific conditions, namely: heating brazing faces of the basic material to the brazing temperature (without excessive melting) and at the same time cleaning them from oxides and other non-metallic inclusions (the graphite itself too). Directing the arc to the filler metal without pre-heating it. The amount of thermal input and its dosing to the joint location influenced the root formation and occurrence of cracks. Thus, to fill the root part correctly we needed more heat, which caused a significant mixing of the filler metal with the basic material and an immediate occurrence of cracks (Fig. 2).

Fig. 2. View of a crack created in the joint root part (a red arrow pointing at the crack)

A better control of the amount of the heat introduced to the joint area was achieved using a pulse arc with a low frequency (approx. 20Hz). Satisfactory conditions and control of the bath during the brazing process was achieved using a modified AC current. During the testing cycle a lot of other factors were found out, which influence the brazing process itself to a great extent and are different from conventional TIG welding of other materials. The technologic conditions of brazing finally stabilized on these parameters bound to the used welding machine - MagicWave 2200 (Fronius):

- a use of AC current with an increased frequency of 100Hz,
- amperage $I_z=100A$, arc voltage $U_z=11V$,
- current balance set to -5,
- shielding gas Ar 4.6, flow rate 12l/min,
- filler metal in form of rods Ø2mm,
- without pre-heating, $T_{ip\ max} = 100°C$,
- brazing using short passes by alternating return step.

The increased AC current frequency meant greater focusing of the electric arc heat effect. Reducing AC current balance (increasing the proportion of direct polarity on the arc to approx. 85% of the time of one AC current period) caused a greater heat penetration into the filler metal while preserving a partial cleaning effect of the arc. These two parameters were critical for mastering TIG brazing of the final experimental samples, which were later subjected to further analyses. To form a root part of V-joint correctly a technique of padding the brazed root edges up to approx. 1/2 of the wall thickness was used and they were then re-ground (Fig. 4). Subsequently the joint root could be formed into a required geometric shape and further filling layers could be laid (Fig. 5).
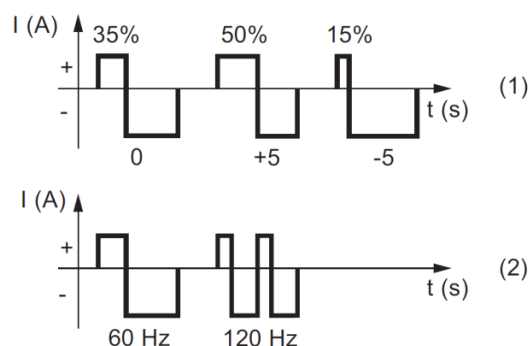

Fig. 3. Effect of the AC parameters on the waveshape
(1) – Balance, (2) – AC frequency

Fig. 4. Pad applied on the root part of the brazing edge (left), pads after grinding (right)

Fig. 5. Pad applied on the root part of the brazing edge (left), filling the joint by means of return alternating step (right)

In Fig. 6 there is a view of test samples after brazing. To compare in Fig. 4 on the right there is a sample carried out by flame brazing with CuZn40SnSi filler metal. In this case the span angle was 90°, brazing was performed at the pre-heating temperature of approx. 450 to 500°C with a slightly oxidizing flame using a backward brazing technique. After brazing this sample was cooled with dry sand to the room temperature.

Fig. 6. View of the front side of the brazed joint, CuSi3Mn1 filler metal (left), CuAl10Fe filler metal (centre), CuZn40SnSi filler metal (right)

4. Testing of brazed joints

The quality of brazed joints was tested by several tests. The main criterion for the joints was their integrity and a satisfactory tensile strength. In case of the joints performed on real castings for pressure applications tightness would be required as well. This colud not be performed on test samples.

Non-destructive tests (NDT)

The joints were first assessed by means of a visual inspection for surface defects and a penetrant colour method for a presence

of cracks connected with the surface. It should be noted that the joints performed by TIG arc way are specific in terms of method selection and defect acceptability criteria values. Even the defect classification itself must regard that this is brazing, but the joint has, due to the used filler material (the melting temperature is close to the melting temperature of the basic material) partly a character of a melted-welded joint too. For NDT several procedures were combined as follows:

- defect classification, EN ISO 6520, EN ISO 5817, EN ISO 18279 standards, quality level D,
- visual testing (VT), EN ISO 17637, EN ISO 12799 standards,
- penetrant testing (PT), EN ISO 12799, which refers directly to EN ISO 3452-1, EN ISO 23277, acceptability level 3.

Destructive tests

The transverse tensile test was carried out according to EN ISO 4136 norm, i.e. welded joint methodology. The flat test specimens before the test are shown on Fig. 7. The results of this test are shown in Table 3 and compared graphically in Fig. 9.
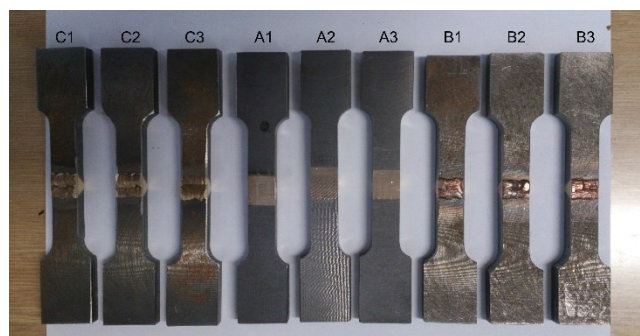

Fig. 7. Prepared test bars

Table 3.
Results of transverse tensile test

Test bars	a [mm]	b [mm]	S [mm²]	F_m [kN]	R_m [MPa]
A1 (CuZn40SnSi)	-	-	-	-	-
A2 (CuZn40SnSi)	8,89	13,85	123,13	7,24	59
A3 (CuZn40SnSi)	9,33	13,79	128,66	4,4	34
B1 (CuSi3Mn1)	8,66	13,8	119,51	16,1	135
B2 (CuSi3Mn1)	7,72	13,88	107,15	9,65	90
B3 (CuSi3Mn1)	-	-	-	-	-
C1 (CuAl10Fe)	8,16	13,6	110,98	29,54	266
C2 (CuAl10Fe)	8,3	13,8	114,54	28,29	247
C3 (CuAl10Fe)	8,45	13,73	116,02	34,72	299
D1 (Base material)	9,88	13,49	133,28	37,3	280
D2 (Base material)	9,94	13,7	136,18	39,02	287

a, b – test sample dimensions, S – test sample cross sectional area, F_m – maximum force, R_m – tensile strength

The brazed joints using CuZn40SnSi filler metal (flame brazing) were not satisfactory. This technology was not mastered. The fracture occured at the interface between the filler metal and the basic material, which was not melted (Fig. 8 left), but it reached significantly low tensile strength values. With arc brazing and CuAl10Fe filler metal we achieved satisfactory results of the

tensile test despite a more significant mixing of the filler metal with the basic material (Fig.8 right).
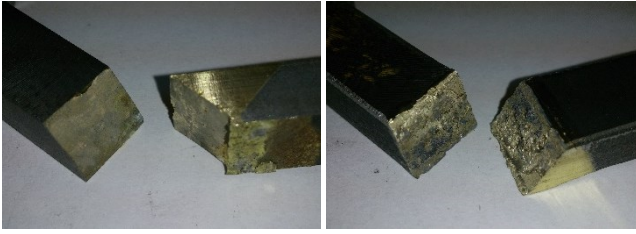

Fig. 8. Fracture surfaces after static tension test, test specimen with CuZn40SnSi filler metal (left), test specimen with CuAl10Fe filler metal (right)

The metallographic assessment was performed on cross sections of the test joints. The whole joint area was assessed macroscopically (the filler metal and an affected area of the basic material). During the microscopic assessment the transition areas (filler metal – basic material interfaces) and structural changes in the affected area of the basic material were assessed. The macrostructure and microstructure pictures are shown in Fig. 10 to Fig. 13.
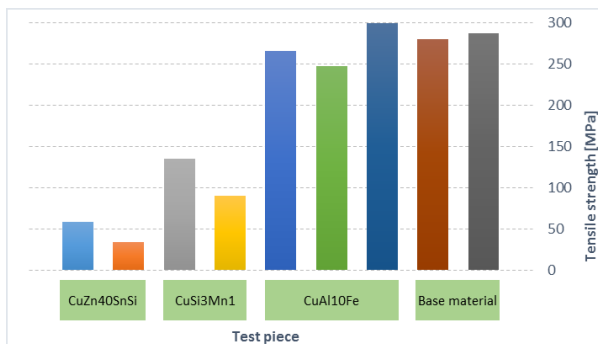

Fig. 9. Graphic comparison of static transverse tension test results of brazed joints

During the brazing process no melting of brazed edges due to the effect of the electric arc was observed. The same was suggested by the results of the fracture surface visual assessment after the static tensile test. However, the macrostructural assessment did not confirm this assumption and a partial and irregular edge melting can be clearly observed. When using CuSi3Mn1 filler metal this melting is more significant. The microstructure of this joint due to the temperature cycle was heated to the temperature above the eutectic temperature (1147°C), which together with a rapid temperature decrease resulted in the creation of ledeburite in the melted part of the joint. Due to another thermal-deformative cycle (application of more passes) in this location we can observe the creation of overannealed ledeburite. In the volume of ledeburitic HAZ we observe isolated micro drops of filler material. With CuAl10Fe filler metal we may see the same character of the transition zone with the presence of ledeburite and transformed ledeburite. We are able to find the areas with the occurrence of a martensitic-perlite structure. B3 area, shown in Fig. 12 is very specific. In this area we notice minimum structural changes of the filler material,

which could be defined as ideal conditions for brazing. With flame brazing using a CuZn40SnSi filler metal, there was no basic material melting, on the macrostructure picture we can observe a substantial transition line corresponding to the original geometry of the brazed edge. We do not observe any considerable structural changes caused by the pre-heating temperature cycle on the brazed metal of the basic material adjacent area. On the microstructure of this joint we can see a creation of a very narrow (sporadically no) diffusion area and solubility zone of the basic material in the filler metal. We can also observe a field richer in the filler metal as a result of the filler metal penetrating into the basic material. This phenomenon occurred in the area of pore creation in the basic material.
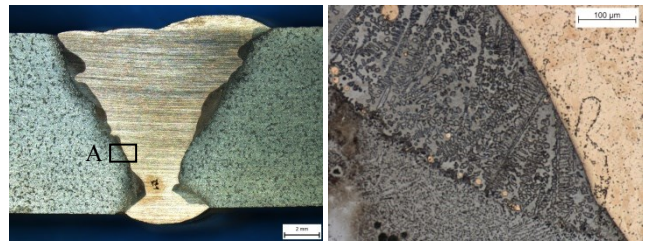

Fig. 10. Macrostructure (left) and microstructure of A location (right) of the brazed joint with CuSi3Mn1 filler metal
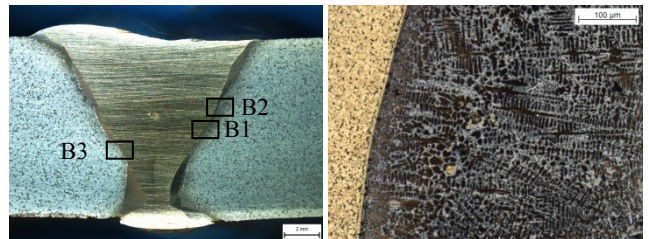

Fig. 11. Macrostructure (left) and microstructure of B1 location (right) of the brazed joint with CuAl10Fe filler metal
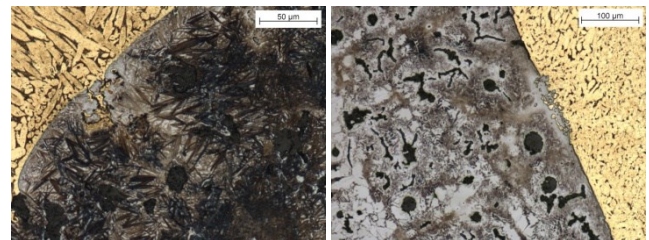

Fig. 12. Microstructure of B2 location (left) and microstructure of B3 location (right) of the brazed joint with CuAl10Fe filler metal
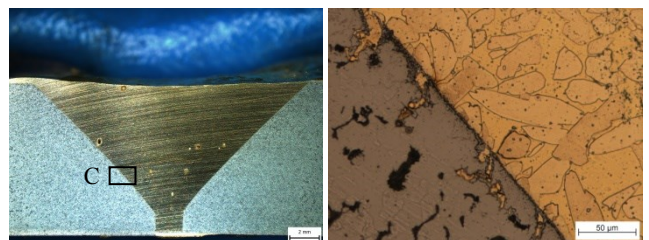

Fig. 13. Macrostructure (left) and microstructure of C location (right) of the brazed joint with CuZn40SnSi filler material

5. Conclusion

Based on the results of the research of the arc brazing technology usability for repairing the castings made of graphitic cast iron we can observe these basic findings:

- a comparative method of flame brazing was not handled properly from a technological point of view, especially non-conforming strength properties of a joint are striking,
- a method of TIG brazing (which was a priority for the research), in view of the requirements imposed on a final joint, was mastered, whereby CuAl10Fe filler metal (aluminium bronze) is recommended as an filler metal for applications up to approx. 250 $^{\circ}$C, pre-heating temperature is not necessary,
- for this method considerable experience of a brazers is needed, it is necessary to use specific settings of the brazing process - electric TIG arc. These must be introduced into the technological process of brazing.

We may state that while observing the recommendations and principles also specified in this article it is possible to carry out repairs of damaged castings of machine parts made of graphitic metals successfully. Cu-based filler materials are perspective materials also for another field of the research for creating heterogeneous joints using „colour" filler material, different from the materials being joined.

Acknowledgments

References

[1] Hrivňák, I. (2013). *Welding and weldability of materials*. 2. vyd. Bratislava : Citadela. (in Slovak).

[2] Dehťar, V.I. (2012). Repair of cast iron parts using welding and welding. *Zvárač*. 4, 22- 23. ISSN 1336-5045. (in Slovak).

[3] Meško, J., Veselko, J. (1999). *Welding and repair of graphite cast iron*. 1. vyd. Žilina: Žilinská univerzita v Žiline. (in Slovak).

[4] Sejč, P. & Kubíček, R. (2015). MIG brazing of 304L type stainless steel using CuSi3 and CuSi3MnAl brazing wire. In *Kovové materiály. Metallic Materials*. 53(5),365-375.

[5] Orłowicz, A.W., Mróz, M. & Trytek, A. (2007). Application of ultrasound in testing of heat-treated cast iron. *Archives of Foundry Engineering*. 7(1), 13-18.

[6] Čep, R., Janasek, A., Čepova, L., Petru, J., Hlavat, I., Car, Z. & Hatala, M. (2013). *Experimental Testing of Exchangeable Cutting Inserts Cutting Ability*. TEHNICKI VJESNIK-TECHNICAL GAZETTE, 20(1), 21-26, ISSN 1330-3651.

[7] BrONčEK, J., Fabian, P. & Radek, N. (2015). Tribological research of properties of heat – treated cast irons with globular graphite. In *Materials Science Forum*. 818, 209-212.

[8] Mohyla, P., Tomčík, P., Veneš, L. & Hlavatý, I. (2011). Effect of Post-Welding Heat Treatment on Secondary Hardening of Welded Joints of Cr - Mo - V Steel. *Metal Science and Heat Treatment*. 53(7-8), 374-378.

[9] Meško, M., Mičian, M. (2000). Cast irons - types, weldability, flux-cored wires and metal transfer in gas metal arc welding. In: Advanced Manufacturing and Repair Technologies in Vehicle Industry. 17th International Colloquium, Zielona Góra – Łagów. P. 85-89.

[10] Pastircak, R., Sladek, A. & Kucharcikova, E. (2015). The production of plaster molds with patternless process technology. *Archives of Foundry Engineering*. 15(2), 91-94.

[11] Sladek, A., Bolibruchova, D. & Bruna, M. (2010). Effect of filtration on reoxidation proceses in aluminium alloys. *Archives of Foundry Engineering*. 10(1), 121-126.

[12] Rózowicz, S., Tofil, S., Zrak, A. (2016). An analysis of the microstructure, macrostructure and microhardness of NiCr-Ir joints produced by laser welding with and without preheat. *Archives of Metallurgy and Materials*. 61(2b), 1157-1162.