METHOD FOR EVALUATING THE DURABILITY OF MOULD SLEEVES FOR HIGH-PRESSURE DIE CASTING OF AL IN MELT

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Abstract

The paper presents the results of research aimed at determining the quality of renovation layers for the restoration of shaped parts of molds for high-pressure casting of aluminum alloys. An analysis of the wear of the shaped parts of the mold was carried out and the dominant degradation mechanisms were identified. A method of modifying the surface of the shaped parts of the molds by creating a stochastic texture with a low-energy laser in combination with duplex PVD coatings on the surfaces of the parts of the molds that are in contact with the molten aluminum alloy was proposed and verified. The methodology of measuring the contact angle for determining the number of sprays with a separating agent - lubricant on the surface of a new or of the renovated shaped part of the mold before the first casting cycle. Dievar, Dratec, UTPA 702 additional materials were verified for the creation of renovation layers. PVD coatings were applied to increase the durability of the layers. The coefficient of corrosion resistance of clads in aluminum alloy was determined.

Keywords: *laser, cladding, layers, Dievar, Dratec, UTPA 702, surface texturing*

1. INTRODUCTION

Technology of pressure casting represents a complex of interrelationships between the properties of the alloy, the construction of the mold and the operation of the pressure casting stand. From the point of view of the efficiency of production and the improvement of the quality of castings, in addition to the technological parameters of metal casting under pressure, the design solution of the mold and its technological life are decisive. Technological lifetime of the mold is limited by the quality requirements prescribed for the casting and the tolerance range of the technological parameters for the pressure casting of the casting [1-3]. Shaped parts of molds and cores for casting aluminum alloys are usually made of chrome, tungsten and chrome molybdenum tool steels. Properties of the materials used for the production of molded parts of molds and cores for aluminum alloy die casting must take into account the stress of the molds in the aluminum alloy die casting itself. These are mainly thermal expansion, modulus of elasticity, mechanical properties at elevated temperatures, resistance to thermal fatigue and chemical stress of shaped parts of molds and cores. In the pressure casting process, the shaped parts of the molds and cores are exposed to intense thermal, mechanical and chemical stress. High melt flow velocities of aluminum alloys (up to 120 $m.s^{-1}$), high pressures (up to 120 MPa) and high maximum temperatures on the surface of shaped parts of molds (up to 550 °C) lead to erosion, abrasion, corrosion and thermal fatigue of the mold. The heat load of foundry cores is even higher (up to 600 °C), because they are not connected to the mold cooling system. Thermal cyclic loading from 80 °C to 550 °C leads to high tensile stresses on the surface of shaped parts of molds/cores and subsequently to the formation and propagation of thermal cracks. Frequent contact of the surface of the shaped part of the mold with the melt causes the formation of growths (sticking) as a result of corrosion due to the influence of molten metals and consequently shortens the life of the shaped parts of the molds and cores. Aluminum alloy die casting molds and mold parts are exposed to abrasion and erosion in the high-pressure metal casting process. These phenomena are intensified in the case of injection of materials with a high Si content. At the same time, a physico-chemical reaction takes place on the surface of the mold to form intermetallic phases based on Fe-Al (melting). Intensity of both phenomena is conditioned by the initiation of surface cracks or cracks during the expansion of oxidized grains and the formation of weakened places responsible for aluminum sticking. Interaction of the Al melt with the steel material of the mold, the kinetics of formation and the morphology of intermetallic phases on the basis of Fe-Al were devoted to works [4-7]. Any degradation change of the shape parts of the molds and cores will also affect the quality and dimensions of the castings.

One of the solutions to extend the technological life of shaped parts of molds and cores on a global scale is their renovation with appropriate surface engineering technologies. Various measures can be implemented to increase the lifetime of the shaped parts of the molds and the resistance of the inner shaped surfaces of the mold, which are often eroded by the flow of molten aluminum. Their purpose is preventive - they are applied to a new form in critical places, or renovation - replenishment of eroded material or material broken by a network of thermal - mechanical cracks [8-9]. The most economical way of renovating shaped parts of molds and cores intended for pressure casting is cladding [10-11]. The main advantages of cladding are short downtimes and economic advantage compared to the production of a new part of the tool. Clad repair generally allows for higher added value in the foundry.

Paper presents the results of research focused on surface modification by texturing and application of PVD coatings. Renovation of shaped parts of molds for high-pressure casting of aluminum alloys was realized by laser cladding.

2. MATERIALS AND METHODS

2.1. Materials

From the group of shaped parts of molds for casting metal under high pressure on cold machines those molded parts (mold inserts) were selected by the filling chamber. Wear analysis was performed on the shaped parts that were discarded after 800 thousand casting of the mold cavity with a melt of aluminum alloy. On the surface of the molded parts, due to repeated impacts of the moving core on the surface of the molded parts of the mold, it caused intense plastic deformation associated with the separation of plastically deformed parts of the surface of the molded part, Fig.1.

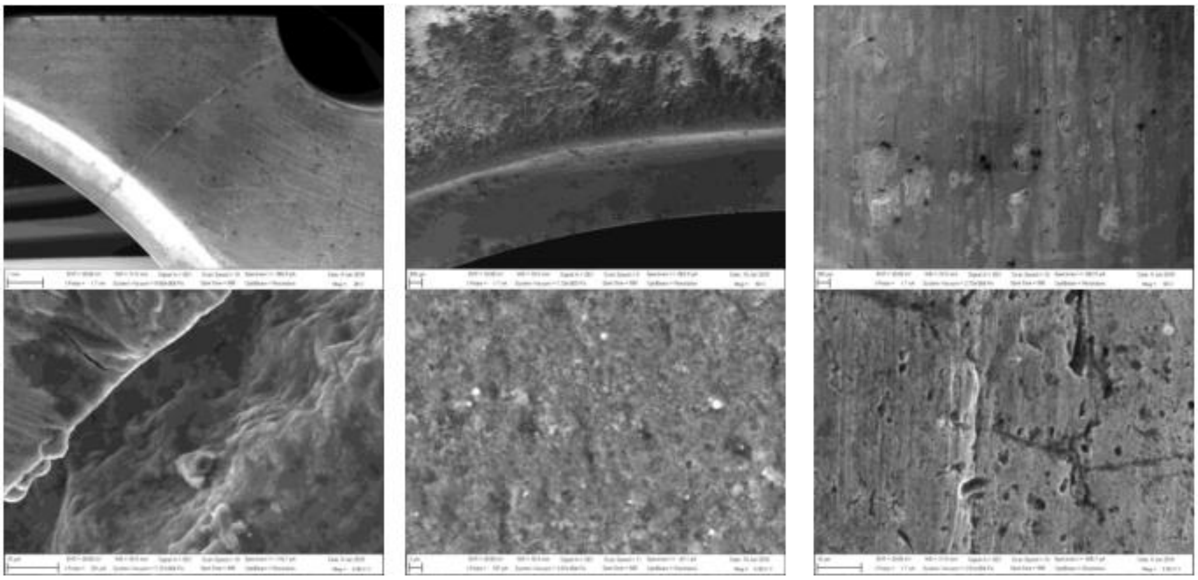


Fig. 1. Degradation of molds during the injection of Al alloys - cracks, adhesion of the separating agent, tearing of material on the surface of the molds

To repair and renovate the mold parts of molds for high-pressure casting of aluminum alloys, samples of experimental clads were prepared on the base material of grade 1.2343 (Dievar) with dimensions of 150 × 130 × 30 mm, which was refined to a hardness value of 44–48 HRC. Chemical composition of the base material is in Table 1, chemical composition of the additive materials is in Table 2.

Table 1. Chemical composition of the base material (wt.%), Fe Bal.

C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu
0.382	0.377	0.914	0.002	0.002	4.893	0.199	1.277	0.499	0.077

Table 2. Chemical composition of the additive material (wt.%), Fe Bal.

Filler Mat.	C	Si	Mn	Cr	Mo	Ni	Co	Ti	Al	Cu
1.2343 (Dievar)	0.4430	0.147	0.423	5.13	2.27	0.067	0.01	0.002	0.008	-
1.6356 (Dratec)	0.0005	0.200	0.50	0.15	4.0	18.0	12.0	1.60	-	-
1.6356 (UTPA 702)	0.0200	-	-	-	4.0	18.0	12.0	1.60	0.10	-

2.2. Methods

In the presented experiment, the production of layers was realized by means of a TruDisk 4002 solid-state disk laser with BEO D70 focusing optics (Trumpf, Ditzingen, Germany). Three types of additive materials were used. Since the process was reimplemented on a robotic workstation, the additive materials used were in the form of wires with a diameter of ø 1.0 mm.

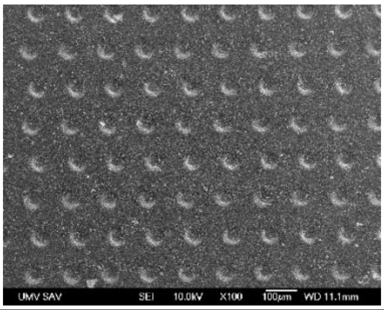
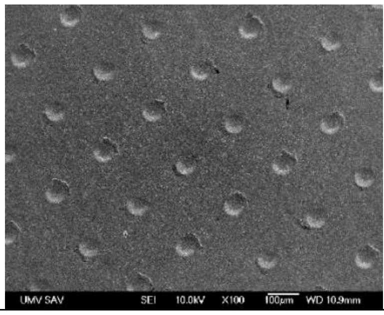
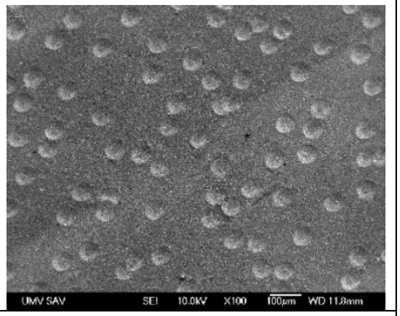
Cladding parameters were selected based on previously performed experiments on a given type of solid-state laser. Following experiments were analyzed:

- light microscopy, (etchant used-3% HNO3 solution);
- microstructure in the area of drilled holes (for the drilling method);
- immersion test in a molten aluminum alloy AlSi, at a temperature of 680 °C – 60, 150 and 300 min

3. RESULTS

Microgeometry of the surface due to radiation - microtexturing. Grid and stochastic textures were created by laser radiation with the diameter of ablation craters of 50 micrometers, the depth of 5 to 8 µm, and the distance between the centers of the craters was modified with a low-energy laser of 100 µm and 200 µm. Integrity of the surfaces of the samples after the formation of ablation craters was checked using the scanning electron microscopy technique, Table 3.

Table 3. Distribution of ablation craters on the surface of the samples

		
texture - grid 100x100 µm	texture - grid 200x200 µm	stochastic texture, maximum mutual distance of ablation craters 100 µm (texture random)

Dimensions of random texture craters on which duplex PVD coatings nACRo[4], AlTiN G and AlXN3 were deposited using LARC technology were controlled by confocal microscopy. Dimensions and distribution of the ablation craters were: diameter 50 µm, depth 5-10 µm, average distance between the craters 200 µm (Fig.2).

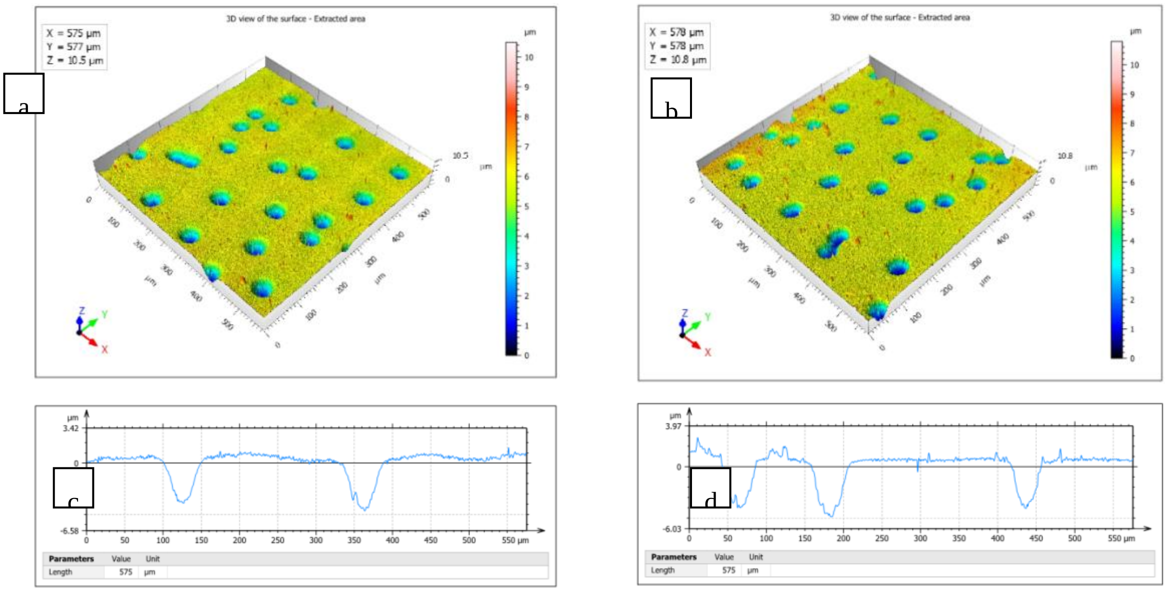


Fig. 2. a) Surface topography with random texture and AlTiN G duplex PVD coating; b) texture topography by random and duplex PVD coating AlXN3; c) random texture profile with AlTiN G duplex PVD coating; d) random texture profile with AlXN3 PVD coating

Analyses of surface integrity were targeted to the area of ablation craters and their surroundings. The topography of the original surface after grinding and polishing was the same at the edges of the ablation craters, on the side of the craters, and in their center. There was no violation of the integrity of the surface of the samples in any crater. Based on the measurements, the creation of textures with a regular distribution of ablation craters is only possible on flat surfaces. Only textures with a stochastic distribution of ablation craters can be created on facially broken surfaces. To create a stochastic texture, also called a random texture, an interval of maximum crater distance of up to 200 µm was chosen. Inspection of the surface integrity of the samples with a stochastic distribution of ablation craters with a maximum mutual distance of 100 µm did not reveal damage to the integrity of the surface in the areas outside the ablation craters, in the crater walls and in their center. Presence of nitrogen was detected on the surface of the samples by semi-quantitative EDX microanalysis.

A multilayered nACRo^4 (a 4th generation nanocomposite layer) was deposited on a part of the samples with a textured surface in the regime of lattice textures and stochastic texture with a diameter of 50 µm ablation craters, a depth of 5 to 8 µm and a distance between the centers of the craters of 100 µm and 200 µm. It consists of nanocrystalline AlCrN grains embedded in an amorphous Si3N4 matrix. The aim of this surface treatment was to analyse the adhesion effect of commercially used lubricants in the technology of treatment of shaped parts of molds when casting aluminum alloys under high pressure on machines with a cold filling chamber. By checking the integrity of the textured surfaces with the deposited duplex PVD coating of the 4th generation nACRo^4, no failure of the integrity of the deposited PVD coating was detected. By semiquantitative EDX microanalysis, the elements forming the PVD coating nitrogen, aluminum, silicon and chromium were detected on the surface.

A stochastic texture of ablation craters was created by a low-energy laser on the surface of a hardened and tempered sample of Dievar material and experimental deposits. Duplex PVD coatings AlTiN G, AlXN3 and nACRo^4 were deposited on such textured surfaces. The temperature of the PVD coating deposition process is higher than 500°C. In this process, the elimination of residual stresses in the area of ablation craters can be assumed. For all samples, the effectiveness of surface protection was investigated by the methodology used in tests of non-textured and laser-textured surfaces. Contact angle measurement criterion was selected as one of the control measurements. Aim was to obtain information about the resistance and effectiveness of the surface protection of the shaped part of the mold with SafetyLube 7815 lubricant in the "run-in" phase of the shaped part of the mold, which is in contact with the molten aluminum alloy. Test consisted of heating the samples to a temperature of 250°C, applying a separating agent by spraying 10 times and 20 times and dipping for 15 seconds into a melt of an aluminum alloy based on Al-Si at a temperature of 680±20°C. With the increase in the number of spray cycles from 10x to 20x, higher values of the contact angle were measured for the laser random+duplex nACRo^4 system. After a short exposure of the treatment samples to the 250°C/10x-spray SafetyLube 7815 and 250°C/20x-spray SafetyLube 7815 treatment regimes and subsequent immersion in the aluminum alloy melt (680°C/15 seconds), a decrease was measured with the laser random+duplex nACRo^4 system contact angle values (Fig.3).

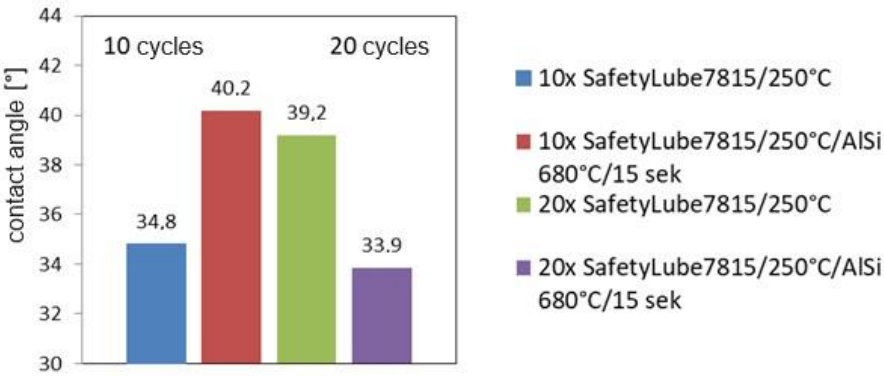


Fig. 3. Contact angle depending on the number of sprays with Safety Lube 7815. Surface Dievar+laser random+duplex nACRo^4

With the laser random duplex AlXN3 system, higher values of the contact angle were measured as the number of spray cycles increased from 10x to 20x, and after a short exposure of the samples treated with the 250 °C/10x-spray SafetyLube 7815 and 250°C/20x-spray SafetyLube 7815 modes in the aluminum alloy melt (680°C/15 seconds) a monotonous increase in the value of the contact angle was measured for the AlXN3 laser random+duplex system. With the laser random duplex AlTiN G system, higher contact angle values were measured as the number of spray cycles increased from 10x to 20x, and after a short exposure of the samples treated with the 250 °C/10x-spray SafetyLube 7815 and 250°C/20x-spray SafetyLube 7815 modes in the melt aluminum alloy (680 °C/15 seconds), a significant drop in the value of the contact angle was measured for the laser random+duplex AlTiN G system after 10 cycles of spraying with a separating agent. Analogous results, as with the laser random+duplex AlTiN G system, were also obtained with the laser random + duplex nACRo[4] system, which was selected for subsequent experiments. Thickness of HAZ (Heat Affected Zone) was max.1.0 mm. Microstructure in the deposit was sorbitic with directed crystallization, without defects integrity. A gradual transition from a ferritic-carbide mixture to a sorbitic one was observed in the HAZ microstructure.

4. DISCUSSION

Control of deposits was focused on identification of defects and incompleteness of clads coating 1.2343-Dievar - HAZ thickness was max. 0.5 mm. The microstructure in the melt is sorbitic with directed crystallization, without defects integrity, a gradual transition from a ferritic-carbide mixture to a sorbitic one was observed in HAZ microstructure. Coating 1.6356 – Dratec - HAZ thickness was max. 1.0 mm. Microstructure in the clad is casting with directed crystallization without integrity defects, the build zone is also without integrity defects, the base material 1.2343 had a sorbitic microstructure without integrity defects. A thickness of HAZ was recorded on the sample with a coating of 1.6356 - UTPA 702 max. 1.0 mm. Microstructure in the deposit is casting with directed crystallization without defects integrity.

Based on the EDX analyses carried out in individual selected spectra, it is possible state that the chemical composition of the coatings corresponds to the chemical composition of the used ones additive materials. Due to the influence of the used cladding technology and parameters, only minimal mixing of the clad metal with the base material, which is in accordance with measured values of HAZ. When using the energy beam method of laser cladding, there was no firing of the elements during their transfer to the clad metal, as occurs with arcs methods. Oxidation was also not observed or contamination of the clad metal due to impact insufficient protection of the cladding site.

For the purposes of determining the resistance of the shell and the material resistance of the shaped part of the molds and cores for aluminum alloy casting based on AlSi under high pressure, the corrosion resistance coefficient is defined as the ratio of the thickness of the intermetallic phase formed on the surface of the clad to the thickness of the intermetallic phase formed on the surface of the material of the shaped part of the mold after immersion into a molten AlSi-based aluminum alloy at a temperature of 680±20°C for 60 minutes and 150 minutes, Fig.4. If the ratio of the thickness of the intermetallic phase on the surface of the plate and the thickness of the intermetallic phase on the opposite side to the clad is less than the number 1, then the clad is suitable for renovating shaped parts of the molds or cores. Given solution to the method of evaluating the resistance of clads in the aluminum alloy melt provides an effective method of selecting the clads for the renovation of shaped parts of molds and cores for casting aluminum alloys under high pressure, Fig.5.

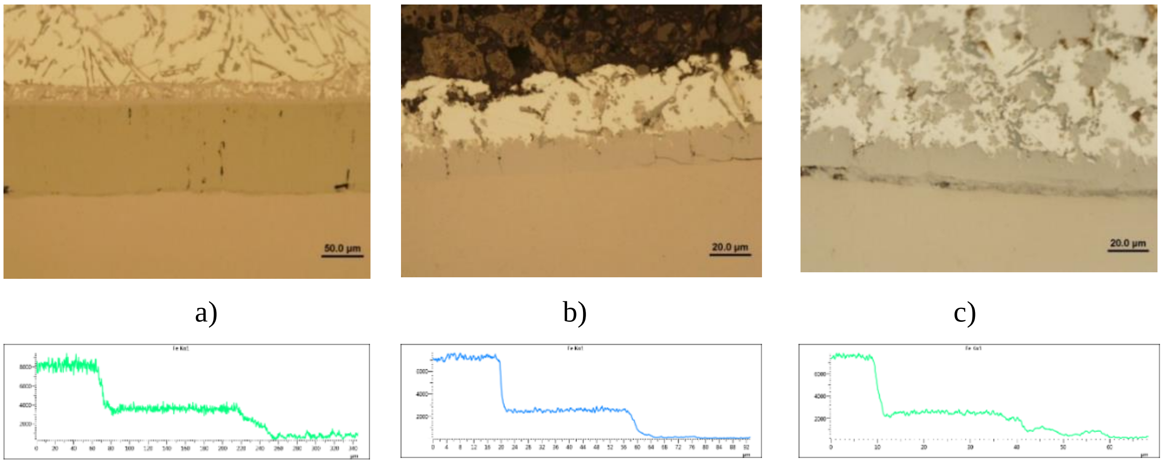
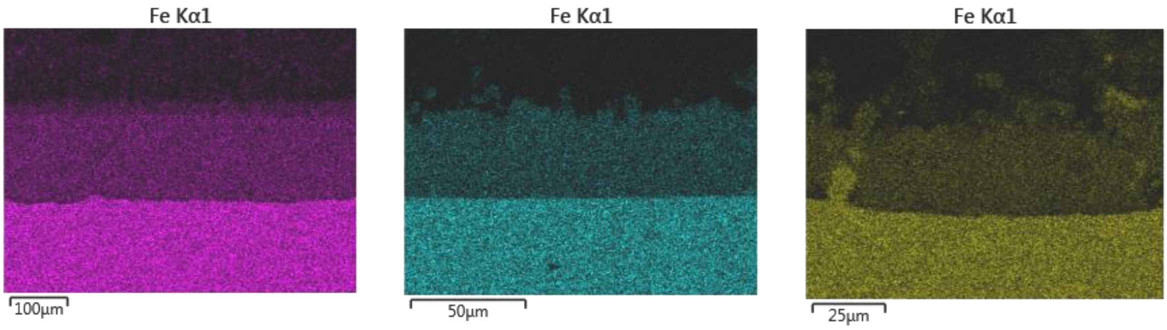


Fig. 4. Appearance of the formed intermetallic phases and the solubility of Fe in the AlSi melt 150 min for deposits a) Dievar, b) Dratec, c) UTPA 702



a) b) c)

Fig. 5. Solubility of Fe in AlSi melt for clads a) Dievar, b) Dratec, c) UTPA 702

After the immersion test, the thicknesses of the intermetallic layers on the deposits were measured, Fig.6. Thickness of the intermetallic phase on the surface provides information about the reaction of the material with the Al-Si aluminum alloy melt. Corrosion resistance coefficient was defined as the ratio of the thickness of intermetallic phase formed on the surface of the clad to the thickness of the intermetallic phase formed on the surface of the material.

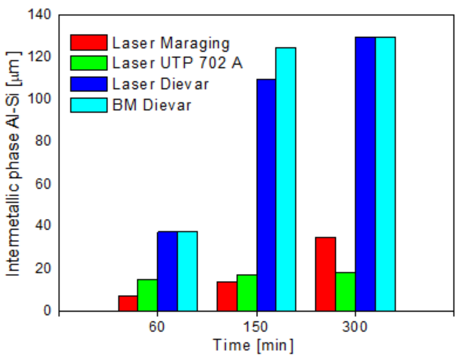


Fig. 6. Size of intermetallic phases depending on the number of cycles

For technological applications, those parts of the mold for casting aluminum alloys under high pressure were selected, which are exposed not only to cyclic thermal stress, contact of the surface with the aluminum alloy melt on the basis of Al-Si, but also to shear force loading. These conditions are met by the cores of slides. Based on the results of previous laboratory tests, a laser random stochastic texture with laser-created ablation craters was selected with the following parameters: max. distance of ablation craters 100 µm, diameter 50 µm and depth up to 5 µm. Three groups of core-slider test samples were prepared. One group was focused on the analysis of the effect of the laser random texture on the technological life of the core-slider. In the second group with laser random surface topography and nACRo[4] duplex coating, the influence of PVD coating resistance compared to only duplex PVD coating on a non-textured surface is investigated. The first group of test samples consisted of the cores of slides with a laser random texture in exposed areas, which are in contact with the aluminum alloy melt and are subjected to shear force loading. In the second group, a duplex nACRo[4] PVD coating with a thickness of ~1 µm was deposited on the topography of the surface prepared in this way by LARC technology. The third comparison group was only with LARC technology deposited PVD coating duplex nACRo[4] ~1 µm thick. Test samples of core-slides were deployed in a real die casting process on machines with a cold filling chamber, Fig.7.

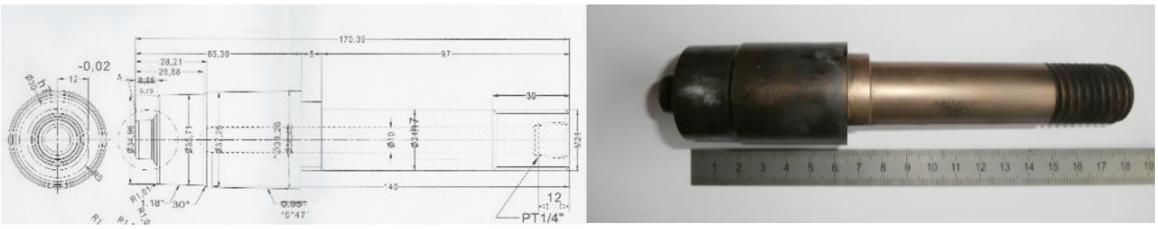


Fig. 7. Core-slider. Test surface Ø38.26x65.39 mm; a) core diagram; b) slide core before texturing and PVD coating

5. CONCLUSIONS

Microgeometry of the surface of the samples was modified by low-energy laser radiation - microtexturing. Grid and stochastic textures were created by laser radiation. Duplex PVD coatings AlTiN G, AlXN3 and multilayer nanocrystalline coating nACRo[4] were deposited on random textures using LARC technology. The contact angle between the surface of the samples and the SafetyLube 7815 lubricant was NaCR determined. The goal was to obtain information about the resistance and effectiveness of the surface protection of the shaped part of the mold in the "run-in" phase of the shaped part of the mold, which is in contact with the molten aluminum alloy. The quality of the clads from Dievar, Dratec and UTPA 702 additive materials, which were produced by a TruDisk 4002 solid-state disk laser with BEO D70 focusing optics, was determined. A method of assessing the resistance of deposits in molten aluminum alloys based on aluminium-silicon based on the assessment of the size of intermetallic phases was proposed. Based on the results of immersion tests in the melt of the Al-Si-based alloy, laser cladding technology with additive material No. 1.6356 – Dratec. A coating was applied to the marked places, which was machined, and the shaped part of the mold was used for operational tests in the serial production of pressure castings.

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