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Use of Duplex PVD Coatings to Increase the Life of Moulds and Cores for die Casting of Aluminium Alloys in the Automotive Industry

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Abstract: The paper presents the results of research aimed at increasing the life of moulds and cores for high-pressure aluminium casting. The castings produced are intended for the automotive industry. Local impulse heating was applied to the surface of the base material of the Uddeholm Dievar moulds. Three heating rates were used. After surface treatment, structural analysis was performed. PVD coating nACRo^3 was applied to the surface treated in this way. Coating deposition was performed by Larc technology. The quality of the coating was evaluated on the basis of the Scratch test and the Mercedes test. After laser treatment of the material surface and application of nACRo^3 coating, the surface microgeometry was evaluated according to ISO 25 178. The coated surface was then immersed in an Al – Si-based alloy melt at a temperature of 680 ± 20°C and remaining in the melt for 120 and 300 min. Experimental work has confirmed that the resistance of the mould surface has significantly increased.

Keywords: PVD coatings, laser surface remelting, die casting of aluminium, tribology

1. Introduction

Aluminium and plastic castings are of great importance in the automotive industry. They are usually produced in metal moulds for die casting and injection moulding. Die casting moulds are made of chrome or tool steel and are heat treated to a hardness between 29 and 48 HRC. Mould life is a major factor in the die casting process and this strongly affects the productivity of mass production. Depending on the application of the casting or mould, different types of mould damage occur. Cracking caused by thermal fatigue is the most common mistake in the life cycle of a mould. Thermal fatigue cracking is often observed on the tool surface as a network of fine cracks or as individual and distinct cracks. The formation of thermal fatigue cracks leads to the loss of surface material in the form of small fragments. Other common reasons for damage are tensile cracks caused by structural notches, local adhesion of the casting alloy to the tool, i.e. soldering, and steel erosion supported by the casting of molten metal or plastic. Plastic injection moulds are exposed to lower operating temperatures, while pressure cycles are more demanding, and therefore mechanical fatigue damage and overload failures can occur [1].

The mould parts and mould cores for casting aluminium alloys must have suitable physical and mechanical properties at elevated temperatures. These properties are essentially defined by thermal and mechanical stress, as well as the interaction at the interface between the mould and the aluminium alloy melt. In particular, high rates of turbulent to dispersive filling of the mould cavity with an aluminium alloy

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melt, high hydrodynamic pressures generated by the melt on the mould part and relatively high temperatures on the surface of the mould parts can significantly shorten the life of moulds and cores. All these phenomena cause degradation of the surface of the moulded parts by the mechanisms of erosion, abrasion, corrosion and thermal fatigue of the mould, each of which acts simultaneously. They identified wear (abrasive, adhesive according to the purpose of the mould: casting in a mould or forging in a die), erosion and mechanical and thermal fatigue as the main mechanisms of mould damage. Jhavar identified the factors influencing wear as follows: temperature, atmosphere, contact area, load, material properties, surface finish, speed, lubrication, shape, vibration, sliding distance and type of movement [2]. The material characteristics of the moulds and dies are also important, in particular hardness, yield strength, modulus of elasticity, ductility, toughness, curing characteristics, fracture toughness, microstructure, corrosion resistance and also the use of moulds and dies in high pressure die casting. Abrasive wear can occur in high-pressure moulds due to insufficient cleaning of the mould between injection cycles in the area of the shaped surfaces between the mould parts [3]. During this process, solidified cast metal particles can act as abrasive particles. Depending on the shape and hardness of these particles, one of the following mechanisms of abrasive damage may occur: cutting or fragmentation. In case of insufficient lubrication and at high temperatures and friction speeds, adhesive wear of the moulds can occur. This results in an increase in the surface roughness of the mould and a deterioration in the casting quality and efficiency of the process [4]. The solubility of the old material in the melt can also contribute to this. At high friction rates in the presence of oxygen, oxidation of the moulding material can also occur. Thermal fatigue is the result of a cyclic change in the temperature of the functional surface of the mould compared to the temperature of the material next to the mould surface [5].

Today innumerable companies and enterprises focus on protection and treatment of surfaces of tools, machine parts and equipment by various surface adjustments, but they lag behind in an effort to develop new methods for final finishing of surfaces. Research and development in the field of methods of final surface treatment takes place mostly at colleges, universities and independent developmental units and laboratories established for this purpose [6]. Thus new progressive technologies of surface finishing are developed resulting in better properties and permitting new applications. Before depositing the coating or protective film, the surface should be treated in a way capable of ensuring correct position and depositing of coating and reaching desirable properties (service life and durability) [7].

The wear of tools and moulds for pressure casting of metals occurs particularly due to thermal fatigue and abrasive, erosive, and corrosive action of molten metal on the functional surface of the moulds. This results in changes in surface morphology and sticking of melt to the mould [8]. A potential solution aimed at delaying degradation of the mould surface is based on surface treatment of those parts, which come into contact with the melt aluminium. Due to the adverse conditions during the casting process (thermal and chemical action of melted alloys, etc.) the mould surface is susceptible to damage and the mould life is a demanding subject of concern. One of the solutions aimed at increasing the resistance of PVD coatings deposited to tools and mould parts is laser hardening of previously thermally treated tools (hardened and tempered) under the conditions of required surface topography, leading to better surface adhesive properties as a result of laser pretreatment of the base before coating [9].

A significant part of European car production is provided by car manufacturers in the Slovak Republic. Together with an extensive network of domestic subcontractors, they represent a major employer of the Slovak population. The strategic goal in car development is a lighter, more economical and greener car. One of the possibilities of reducing the weight of cars is the replacement of steel parts with parts made of light metal alloys. The most cost-effective technology for the production of aluminium castings is die-casting technology [10]. Die casting technology is a complex of interrelationships between the properties of the alloy, the construction of the mould and the operation of the die. In terms of production efficiency and improving the quality of castings, in addition to the technological parameters of die casting, the design of the mould and its technological life are decisive. The technological service life of the mould is limited by the quality requirements prescribed for the casting and the tolerance interval of the technological parameters for die casting [11].

Moulded parts of moulds and cores for casting aluminium alloys are usually made of chromium and chromium-molybdenum tool steels. In the die-casting process, the mould parts and cores are exposed to intense thermal, mechanical and chemical loads. High melt flow rates of aluminium alloys (up to 120 m.s-1), high pressures (up to 120 MPa) and high maximum temperatures on the surface of moulded parts (up to 550 °C) lead to erosion, abrasion, corrosion and thermal fatigue of the mould [12]. The thermal load of the foundry cores is even higher (up to 600 °C) because they are not connected to the mould cooling system. Thermal cyclic loading from 80 °C to 550 °C leads to high tensile stresses on the surface of the moulded parts/cores and consequently to the formation and propagation of thermal cracks. Frequent contact of the surface of the mould part with the melt causes the formation of build-ups due to corrosion due to molten metals and consequently to a shortening of the service life of the mould parts and cores. Any degradation change in the shape of moulds and cores will also affect the quality and dimensions of the castings [13].

2. Materials and Methods

a) <u>Concept of surface treatment technology of samples by local pulse heating</u>:

The innovative surface treatment of mould parts consisted of local intensive heating of the surface of Uddeholm Dievar material by laser irradiation in the recrystallization temperature range without melting of the material, finishing grinding to the required geometry of the mould surface and deposition of duplex PVD coatings chemically stable at aluminium casting temperatures.

The manufacturer of the Dievar steel for hot work is Uddeholm. The mechanical properties of Dievar steel, such as its toughness and hot strength, are the reason for its use, especially in the technological processes of die casting, forming, which are carried out at elevated temperatures. Dievar offers the potential to significantly improve tool life, thereby improving tool economy [14]. It is a steel for hot work with high strength at elevated temperatures and resistance to tempering. The steel must be hardenable in oil and air, as well as suitable for nitriding in baths and gases. Requirements for this type of steel include good machinability, good hardenability, good thermal conductivity, high yield strength and low thermal expansion, low thermal expansion, adhesion resistance and dimensional stability during heat treatment [16]. The chemical composition and the latest production technologies predetermine it for a given application. Dievar material has good toughness, good hot strength, satisfactory resistance to heat stress and rough cracking. The die is suitable for applications with requirements for work at high temperatures such as die casting and forging. Thanks to its properties, it is also suitable for other applications. Dievar offers the potential to significantly improve tool life, thereby improving economic indicators [17].

Table 1: Chemical composition of Uddeholm Dievar [15]

Chemical element	*C*	*Si*	*Mn*	*Cr*	*Mo*	*V*
wt. (%)	0.38	0.2	0.5	5	2.3	0.6

The material excels with its excellent mechanical properties such as high tensile strength, yield strength and others. Table 2 shows the values of mechanical properties of the material.

Table 2: Mechanical properties of Uddeholm Dievar [15]

Mechanical properties				
Hardness (HRC)	*Limit of strength (MPa)*	*Yield strength $Rp_{0,2}$ (MPa)*	*Elongation (%)*	*Reduction (%)*
44	1480	1210	13	55
48	1640	1380	13	55
52	1900	1560	12.5	52

A solid-state laser operating in a continuous mode at a power of 400 W with a beam diameter of 3 mm and a beam mode of T00 created three tracks on the surface of each tested core. The diameter of the beam was 3 mm, the focal length was f = 3 mm and the mutual distance of the tracks was 3 mm. The speed of movement of the laser beam was 50 mm/s. Subsequently, the cores were ground so that a layer 2 micrometres thick was removed from the "2" "1" surface. The undercut depth corresponded to the thickness of the deposited duplex coatings so that the final dimension was within the required dimensional tolerances of the mould and the casting. The aim of undercutting was to remove surface defects after laser treatment and to ensure the dimensional accuracy of the cores.

b) Concept of surface treatment technology of samples by duplex PVD coating:

$AlXN^3$ and $nACRo^3$ coatings were used to perform PVD coating.

For the nano-multilayer coating, $AlXN^3$ (X = Cr) is the basic adhesive layer of CrN, followed by Al/CrN nanolayers, and the top layer is AlCrN. It is a tough coating with high resistance to abrasion at high temperatures (up to 900°C)

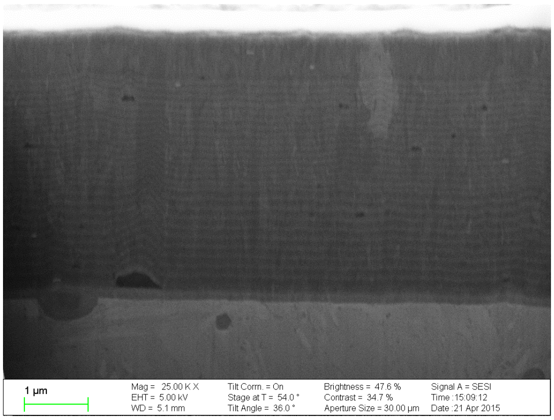

Figure 1: Cross section of $AlXN^3$ coating made on a FIB (Focused Ion Beam) device

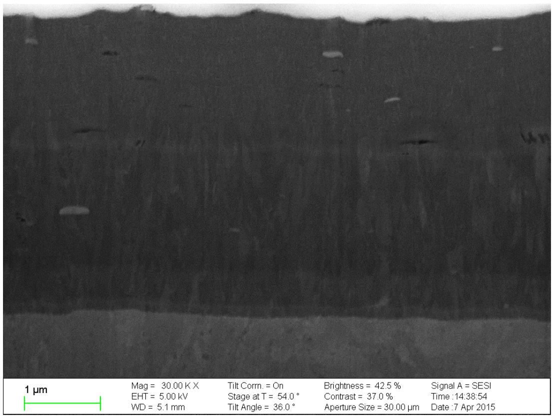

Figure 2: Cross section of $nACRo^3$ coating performed on a FIB device

The $nACRo^3$ nanocomposite coating, called TripleCoatings3, consists of AlCrN nanocrystalline grains that are embedded in an amorphous Si^3N^4 matrix. It consists of three layers: the first adhesive layer consists of CrN, on which an AlCrN layer is deposited, and on this final top layer, formed by a nc-AlCrN/a-Si^3N^4 nanocomposite coating. The coating is very tough, resistant to abrasion to high temperatures (up to 900/1100°C).

In order to determine the adhesive-cohesive behaviour of the substrate-coating system, an indentation method was implemented, the so-called Mercedes test using a diamond cone. The test was performed on a UH 250 universal hardness tester with a Rockwell indenter at a load of 1500 N and the indentation indentations of 10 were evaluated according to DIN EN ISO 18265. The initiated stress causes cracks and defects to propagate to the surface at the coating/substrate interface. Using this method, it is possible to monitor the dimensions, nature and development of cracks depending on the load [18]. The evaluation of the morphology of individual imprints is determined according to Table 3.

The Mercedes test is a penetrating method and is one of the most common methods for testing the adhesion between the layer and the substrate. It is a relatively simple method based on the generation of stress at the interface of the layer-substrate system, which is caused by indentation under static indenter loading with a force of 1500N [20]. Indentor has the shape of a cone (for hard substrates) and a ball (for soft substrates). The initiated stress causes cracks to form at the interface, which propagate to the surface of the layer. The evaluation is performed by assigning it to the appropriate category with the adhesion number HF1 to HF6, which characterizes the degree of cracking resp. peeling layer.

Prior to deposition of $AlXN^3$, $nACRo^3$ duplex coatings, the cores were degreased and ground in a nut shell environment. All parts of the core threads were protected from coating. To control the laser heat treatment and PVD coating process, a set of control samples was prepared, which were of the same quality material as the cores and were with the same laser heat treatment, grinding and PVD coating parameters together with a batch of experimental cores. Deposition of duplex coatings was performed by Larc technology. In the deposition chamber, the surface of the cores was cleaned, plasma nitrided and PVD coated. The nitriding and PVD deposition process was at a temperature of about 550°C. This ensured that the microstructure of the core material was tempered in the laser-heated surface. The surface of the mould inserts was inspected. The light microscopy technique was used. The quality control of the mould surface before renovation

Table 3: Assessment of adhesion by the Rockwell C indentation [19]

Evaluation of coating adhesion by the Rockwell C indentation test			
	HF 1- good adhesion a small amount of cracks		HF 4- reduced adhesion peeling around the edge of the indent
	HF 2- satisfactory adhesion small peeling between cracks		HF 5- insufficient adhesion peeling even at greater distances from imprint
	HF 3- reduces adhesion peeling over more than two cracks		HF 6- unsatisfactory adhesion complete peeling around the indentation

consisted of a visual inspection, which was carried out in accordance with STN EN 13018. The visual inspection was followed by a capillary inspection according to STN EN ISO 23277.

The principle of the scratch test is the continuous loading of the indenter, which moves parallel to the layer-substrate interface. The sample moves horizontally at a constant speed, and the indenter, which is loaded with a constant or continuously increasing force, penetrates the surface of the sample as it moves, creating a scratch. This generates a stress at the layer-substrate interface which, when a critical value is reached, causes the layer to tear off the substrate. The value, at which the layer is damaged, is called the critical load Lc and it is used as a measure of the adhesion of the layer.

During the scratch test, the speed of displacement of the sample dx/dt under loading with a continuously increasing force and the speed of its increase dL/dt are monitored. The normal force can be chosen either constant or linearly increasing in the interval from 0 to 200 N. The maximum values of the scratch, which can be achieved with this device, is the length of the scratch 20 mm and the depth 1 mm. The device records the course of the normal Fn and the tangential force Ft acting on the indenter, the values of the friction coefficient $\mu = Ft / Fn$ and the acoustic emission signal (AE-elastic waves generated by the release of energy internally bound in the material structure).

The coatings were then immersed in the melt of the Al – Si based alloy at a temperature of 680 ± 20°C, the residence time in the melt was without flowing around the surface of the samples with the aluminium melt for 120 and 300 min.

3. Results and Discussion

The capillary test was fixed and movable on the surfaces of the inserts parts of the mould identified by several groups of surface and subsurface defects. There was mostly mechanical pressure at the points of contact of the movable cores with the surface of the inserts. There was a discontinuous layer of release agent on those parts of the surface of the inserts that were in contact with the aluminium melt. Below the separator layer, areas of surface integrity failure by thermal fatigue and mechanical damage were isolated.

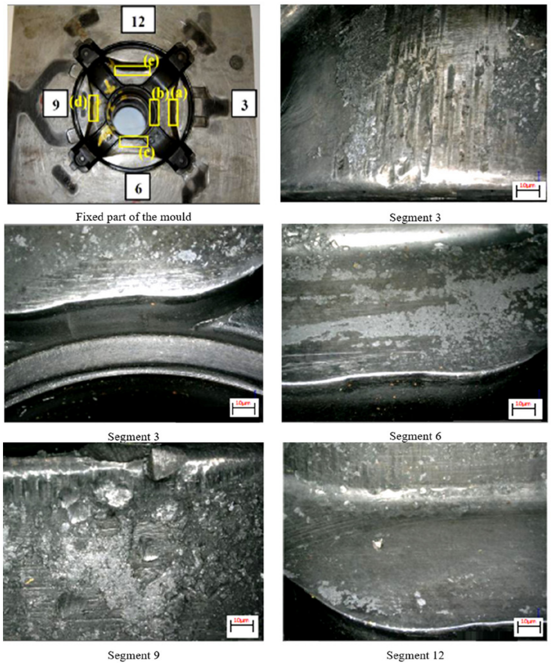

Figure 3: Worn solid half of the mould part - mould insert

Detailed analyses of the wear of the surfaces of the shaped and moving parts of the moulds were performed. Information was obtained on the extent of damage to those areas, which were in contact with the aluminium melt and those parts of the surface, which were outside the zone of contact with the aluminium melt and were mechanically damaged by the moving cores. The capillary test confirmed that several groups of surface and subsurface defects were identified on the flakes of the fixed and movable part of the mould in the area of the ejector casters extending to a depth of 5 mm, Figure 4, Figure 5. The capillary test identified several groups of surface and subsurface defects. There was mostly mechanical pressure at the points of contact of the moving cores with the surface of the inserts. There was a discontinuous layer of release agent on those parts of the surface of the inserts that were in contact with the aluminium melt. Below the separator layer, areas of surface integrity failure by thermal fatigue and mechanical damage were isolated, Figure 6, Figure 7.

Figure 4: Shaped part of the mould after capillary testing

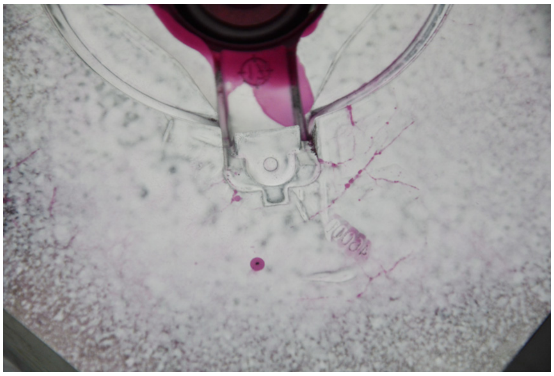

Figure 5: Appearance of cracks at the bottom of the mould

The aim of the laser surface treatment was to determine the parameters of the heat treatment so that the surface of the test specimens was not treated. The 400 W radiation energy at a scan speed of 20 mm/s, 30 mm/s, 40 mm/s, 60 mm/s and a working mode of T00 and a beam diameter of 3 mm determined the heating depth: 160 µm, 90 µm, 80 µm and 75 µm. Below the surface, below the surface, there was a fine-grained martensitic-carbide microstructure, which passed through an incompletely austenitized zone into the sorbitic

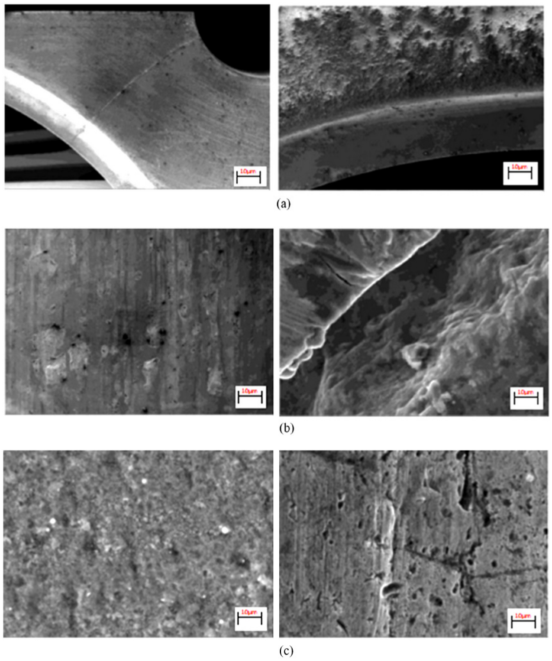

Figure 6: Detail of the worn form; a) Crack around the ejector and the core cavity b) Separating means on the surface of the moulded part c) Contact of the movable core and the moulded part

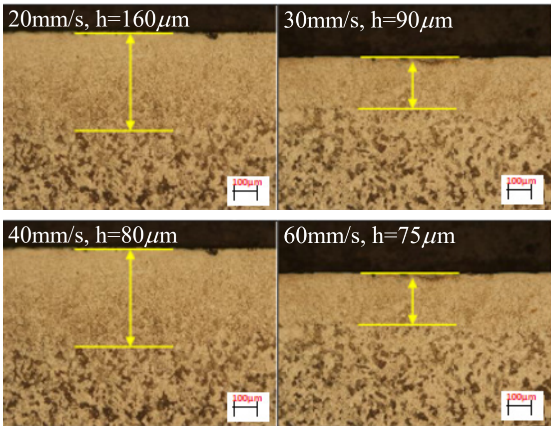

Figure 7: Laser surface hardening

microstructure of the material. A heat treatment mode with a scan speed greater than 60 mm/s assumes that there is no local adjustment of the sample surface. A suitable test is to check the surface of the laser trace by SEM microscopy. In the zone after thermal heating by laser radiation, there was a network of shallow surface cracks on the surface, typical for rapid heating and rapid cooling of the material surface. The trajectories of the cracks crossed the boundaries and through the submicron cubic particles on the surface. On the entire surface, which was pulsed by laser radiation, it was possible to detect the presence of oxygen or a local increase in the concentration of the alloys of the base material.

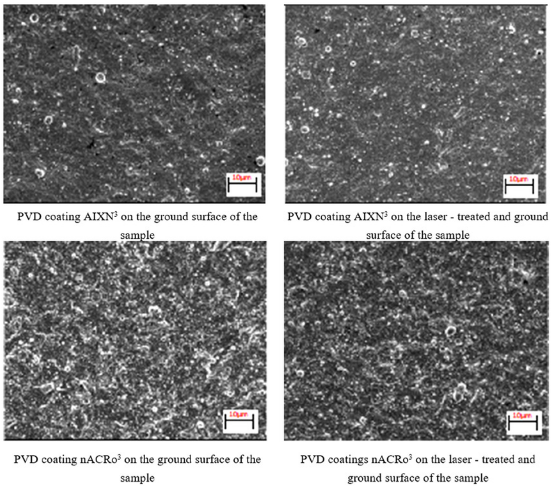

Figure 8: Surface of PVD coatings of control samples and samples after laser treatment and deposition of coatings

Measurement of mechanical properties, local chemical composition by EDX microanalysis, adhesion properties by scratch test and microstructures of individual systems PVD coating - laser heat treated substrate. By evaluating the microhardness in the cross section in the individual bands of the subject materials, an increase of about **18.6 – 25 % HV0.025** compared to the substrate was recorded in the area with the coating on the laser substrate.

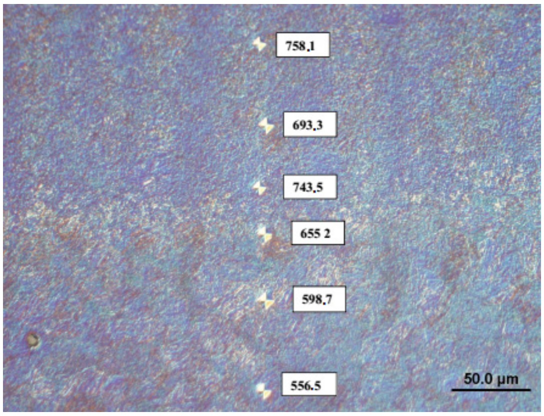

Figure 9: Indents for the nACRo coated sample

Indents 0.025 HVm for the nACRo-coated sample at the interface of the laser zone and the W300 substrate. The HVm values decreasing towards the substrate acquire the HVm value of the substrate W300. Figure 10 presents hardness profile of HV0.025 coatings and shows an arrow from the area of the coatings to the base material.

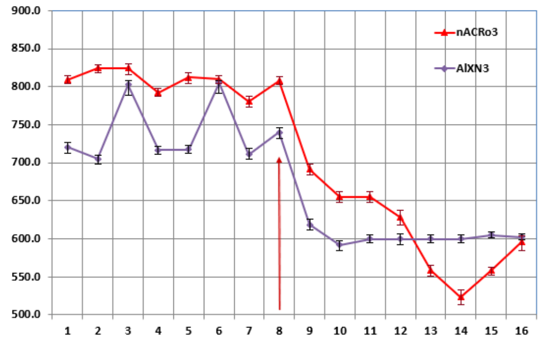

Figure 10: Hardness test HV0.025 from the surface towards the substrate

The depth of the laser-affected zone reached up to 280 µm. The acoustic emission detected in scratch tests of duplex PVD coatings showed a low value for laser heat treated substrate materials, Figure 11.

Scratch tests were performed on an AMI CSEM - Revertest device (feed 10 N/mm, load up to 80 N, track length approx. 8 mm). The device records the course of the increasing normal Fn and the tangential force Ft acting on the indenter, the values of the friction coefficient COF = Ft / Fn and the acoustic emission signal AE. The output is a graphical record of the AE emission signal and the COF coefficient of friction depending on the size of the load. In this test, the value of the critical load Fz at which the substrate is exposed is determined, which is the degree of adhesion of the layer to the substrate. In practice, the value of the critical load Fz = 40 N is referred to as satisfactory adhesion. Satisfactory adhesion was recorded on the subject tested samples with applied coatings, because the failure or detection of the substrate occurred at values of about 50 N. We can evaluate that the chosen surface treatment technology was satisfactory and the test also confirmed the quality of the applied coatings.

Analogous results were obtained in the Rockwell indentation test (Mercedes test). Impressions on the coatings of the control samples were evaluated under a force of 1500N. Good adhesion of PVD

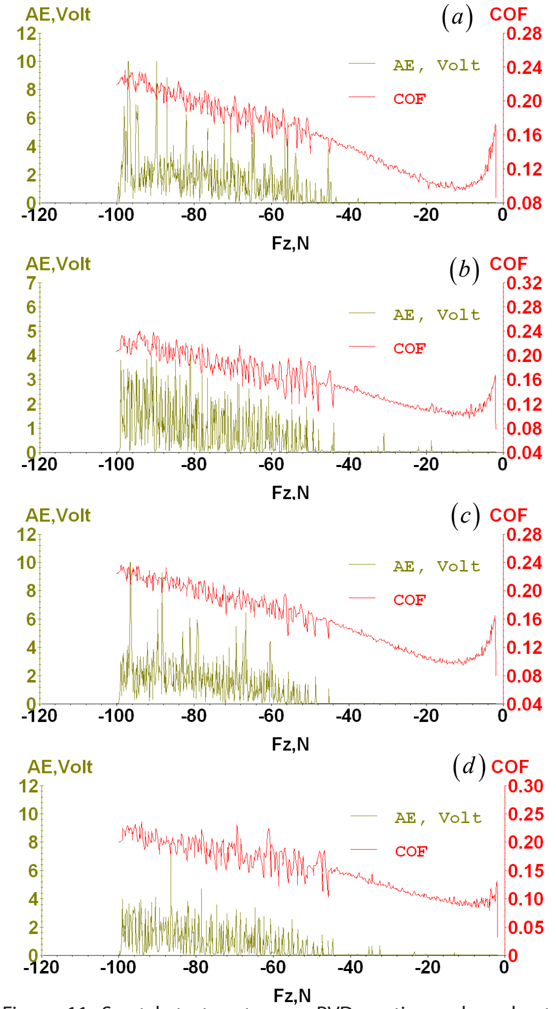

Figure 11: Scratch test systems o PVD coatings - laser heat treated substrate; a) PVD coating duplex AlXN³; b) PVD coating duplex nACRo³; c) PVD coating duplex AlXN³ on a laser terated surface; d) PVD coating duplex nACRo3 on a laser terated surface

layers to the substrate was confirmed, determined by the ratio of cohesive and adhesive number K / A and the degree of H = 1, which was characteristic for the occurrence of only isolated cracks and minimal disruption of the integrity of PVD coatings around the indentations.

Figure 12 and Figure 13 illustrate the morphology of indentation indentations into the coating surfaces, with only isolated radial cracks in both cases reaching a length of max. 200 μm and the appearance of the indents confirms the good quality of the coatings, which was evaluated by the degree of adhesion HF = 1-2. A more detailed description of the methodology is in the works D. Jakubéczyová, M. Džupon [21]. The impressions were evaluated according to Table 3 and characterize the adhesion-cohesion properties of the layer to the substrate, evaluated by a degree of HF from 1 to 6.

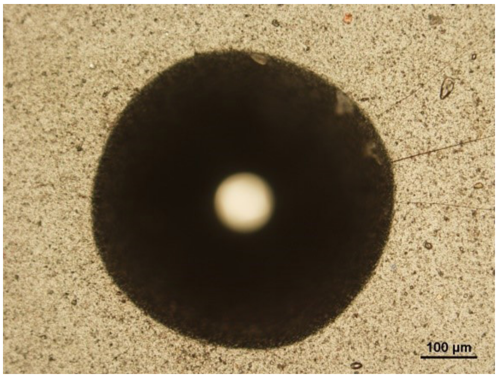

Figure 12: Morphology of indentation impression in AlXN3 coating (X = Cr)

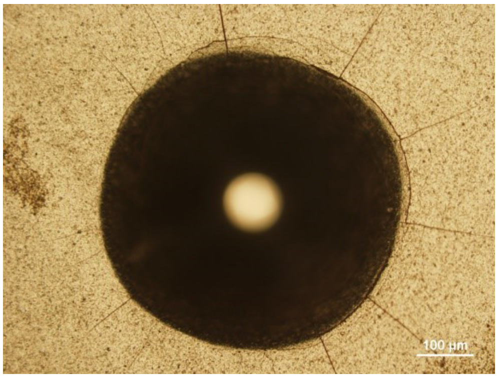

Figure 13: Morphology of indentation indentation into the coating nACRo3, LM

The surface microgeometry of conventional PVD duplex AlXN³ and duplex nACRo³ coatings and coatings deposited on laser treated surfaces was evaluated according to ISO 25 178. The commonly used parameter to evaluate the surface microgeometry on a given test area is the arithmetic mean Sa. It is the parameter that best statistically characterizes the actual surface using experimentally measured surface heights. The parameter Ssk is a statistical parameter characterizing the distribution of the heights of the measured profile on the reference surface around the mean value characterized by the value Sa. If the skew parameter is zero, then the height values of the measured surface are uniform divided around the mean value of Sa. The measured positive value of the skew parameter Ssk can be interpreted in such a way that there are isolated particles on the surface, resp. depressions whose dimension is greater than the value Sa measured on the reference surface and at the same time most of the measured values of the surface heights are smaller than the mean value Sa. A positive value of Ssk indicates the presence of isolated formations on the surface, the size of which is larger than Sa (they shift all statistics to the left). In the case of a negative value of the slope parameter Ssk, it is possible to expect the occurrence of a larger number of measured surface heights, the dimension of which is larger than the mean value Sa. Information on the concentration of surface heights around the mean value Sa is given by the magnitude of the positive value of the parameter Sku (Kurtosis). In the case of a zero value of the slope parameter Sku, the surface height distribution is characterized by a normal distribution. The variance (Sq parameter) is affected by only small probable outliers. In the case of a positive value of the slope parameter Sku, the values of the heights on the surface are close values of Sa and on the surface of the PVD coating there are isolated macroparticles resp. surface depressions. The surface microgeometry parameters of duplex PVD coatings evaluated according to ISO 25 178 were not significantly affected by surface pretreatment by laser heat treatment and grinding with respect to ground surfaces Table 4.

Coatings controlled by immersion in an Al-Si alloy melt at 680 ± 20°C and remaining in the melt without flowing around the surface of the samples with the aluminium melt while remaining at 120 and 300 min, were compact, intact and formed a barrier between the aluminium melt and the coated surface. After evaluating these tests of PVD coatings, cores with deposited PVD coatings $AlXN^3$, $nACRo^3$ and $nACRo^4$ and cores with a heat-treated laser surface on which PVD coatings $AlXN^3$, $nACRo^3$ were deposited were successively installed in the body of a die for casting aluminium alloys under high pressure. After these tests, the nuclei will be analysed by laboratory techniques.

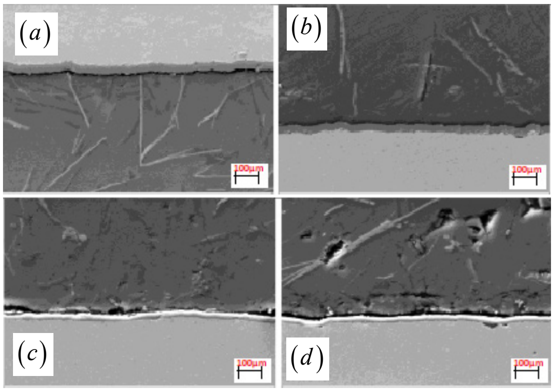

Figure 14: PVD coatings duplex on laser treated and ground surfaces after exposure in Al mel; a) Duplex $AlXN^3$/120 minutes/680+/-20°C/Al-Si; b) Duplex $AlXN^3$/300 minutes/680 +/-20°C/Al-Si; c) Duplex $nACRo^3$/120 minutes/680+/-20°C/Al-Si; d) Duplex $nACRo^3$/300 minutes/680+/-20°C/Al-Si

4. Conclusions

The paper presents the results of research aimed at determining the degradation mechanisms of moulds for high-pressure casting of aluminium and the possibility of modifying the quality of functional surfaces of moulds using PVD coatings of a new generation. Experimental work was focused on verifying the possibility of surface treatment using local intensive heating of the surface by laser radiation in the subsequent combination of PVD

Table 4: Surface parameters of PVD coatings according to ISO 25 178

Height Parameters (µm)	*PVD coating duplex $nACRo^3$*	*PVD coating duplex $AlXN^3$*	*PVD coating duplex $nACRo^3$ on a laser treated surface*	*PVD coating duplex $AlXN^3$ on a laser treated surface*
Sq	1.04	0.78	0.37	0.31
Ssk	0.11	4.78	0.24	3.65
Sku	3.06	167.87	10.43	171.05
Sp	4.47	40.10	24.08	22.81
SV	4.81	13.77	7.55	6.82
SZ	9.29	53.88	31.63	29.62
Sa	0.82	0.57	0.29	0.23

coatings. Two types of coatings were applied, a conventional AlXN[3] coating and a newly designed nACRo[3] coating. The performed experiments confirmed the following conclusions:

– *An innovative method of treatment of shaped parts of moulds and cores was developed, which consisted of local and intensive heating of the surface by laser radiation in the recrystallization temperature range without melting the material with finishing grinding to the required geometry of the shaped surface with deposition of duplicate PVD coatings chemically stable at aluminium gold casting temperatures.*

– *PVD coatings were of high quality, which was confirmed by a scratch test and a Mercedes test. After immersion in the melt of the Al-Si-based alloy at a temperature of 680 ± 20°C, the coatings were compact, intact and formed a barrier between the base material and the melt after the high-temperature corrosion test.*

– *The surface microgeometry parameters of duplex PVD coatings evaluated according to ISO 25 178 were not significantly affected by surface pretreatment by laser heat treatment and grinding with respect to ground surfaces.*

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