Tribological properties of layers created by progressive technologies

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Abstract: *The paper presents the results of research focused on the renovation of worn surfaces. Four progressive welding technologies were used - Cold Metal Transfer, MIG Pulse, TOP-TIG and laser technology. The layers were evaluated by non-destructive tests - visual, capillary and ultrasonic methods. The layers were evaluated under dry-friction adhesive wear conditions by the Ball-On-Disc method. A Si3N4 bead was used. Analyzes confirmed the impact of the renovation method on the quality of the resulting surface.*
Keywords*: DIE CASTING, SURFACE DAMAGE, MOLTEN ALUMINUM, CLADDING, LASER, MIG PULSE*

1. Introduction

High Pressure Die Casting (HDPC), or high-pressure casting, is a technological process widely used for casting complex aluminum castings, mainly associated with the automotive industry. In this process, molten metal with a temperature of 670-710 °C is pushed into the mold cavities at filling speeds of 30-100 m/s, under pressures ranging from 40-80 MPa [1]. This load, combined with the corrosive properties of liquid aluminum, leads to aluminization or oxidation of the surface of the molds, which causes thermal fatigue of the surfaces followed by their cracking, soldering and erosive wear. The service life of mold matrices made of steel alloys is approximately 100,000 cycles and can be increased either by heat treatment, application of thin coatings or welding [2-4]. Nowadays, the issue of surface treatment of various materials is increasingly coming to the fore. It offers the saving of strategic materials and at the same time enables the production of components with specific surface and volume properties [5-6]. As resources are limited by conventional technologies, it is increasingly difficult to satisfy more advanced customer needs. There are many methods for substrate treatment, but coatings developed using, for example, electrostatic, chemical, physical deposition techniques have a lower bond strength with the base material or very little reproducibility compared to those by welding. Refurbishment of worn parts of machines is a very effective and ecologically acceptable form of their maintenance. This option can reduce the impact on the environment during the entire life cycle of the component by up to 63.8% [7].

Laser welding

Laser welding is a technology used to create coating layers with improved properties, or to restore defects in worn parts of the surface and base layers of components. Due to the high energy density and relatively small thermally affected area, this method is suitable for processing a wide range of materials [8]. It is mainly used in the automotive, aviation, medical, nuclear and oil industries. In the aviation industry, the welding of layers on aluminum alloys to improve their surface properties has an increasing potential.

This technology uses highly concentrated light waves, concentrated to a certain point [9]. Atomic bonds break down in the area hit by the laser beam, which causes it to heat up. The three most common types of lasers used in laser welding equipment are gas, semiconductor and fiber [10]. The laser beam is guided to the welding device by one or more optical fibers concentrated at one point. With each added fiber, the intensity of the laser beam increases. Before the laser beam leaves the welding equipment, a combination of a collimator and a focusing lens is often used to direct this radiation into a very small area [11]. An important part of the laser welding equipment is also the nozzle supplying the gas of the protective atmosphere, most often CO2. this gas prevents contact between the weld pool and the atmosphere [12]. Another option is laser welding without a protective atmosphere, for example when welding plastics. Although vacuum welding is possible, it is difficult to use, due to the high demands on the construction of the welding equipment [13].

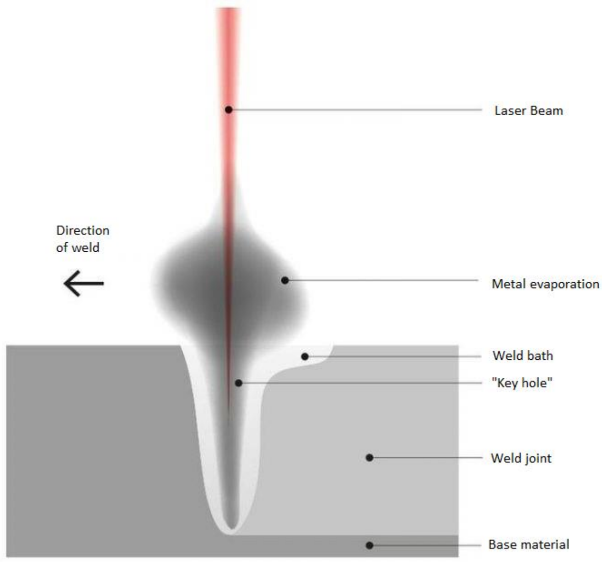

Fig. 1 Schematic representation of laser beam welding [13]

MIG/MAG welding (GMAW)

MIG/MAG welding is currently the leading method in most industries. Gas metal arc welding (GMAW) also referred to as metal inert gas (MIG) if the shielding gas is inert, or metal active gas (MAG) with an active shielding gas [14]. The main advantage of this technology is its flexibility. The construction of the welding equipment allows welding in all positions, to weld surface-treated metals such as zinc-coated steel, as well as all commonly occurring materials such as stainless steel, alloys of aluminum, copper, nickel, and the like [15]. The disadvantage is its limited use outdoors, where the protective gas may be blown off due to air flow [16].

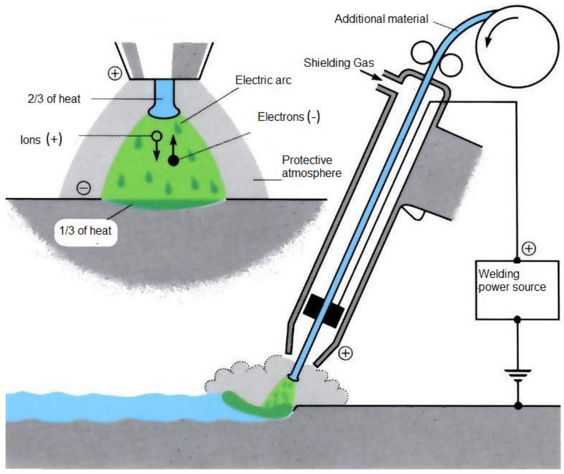

Fig. 2 Schematic representation of the MIG/MAG method

The principle of the MIG/MAG method consists in the burning of an electric arc between a continuously supplied melting electrode and the welded material [17]. The welding wire is wound on a coil, from which it is fed to the welding gun through a system of drive rollers. Electrical voltage is applied to the electrode through the contact nozzle, which is usually connected to the positive pole of the source, while the workpiece is connected to the negative pole. The shielding gas is supplied through a gas nozzle surrounding the contact nozzle. With an increased load of 300-500 A, the welding gun is usually cooled by water. Additional material in the form of wire is divided into 2 basic groups [18]. The first is solid wire intended for welding with inert and active gases in diameters of 0.6-2.4 mm. Such wires, especially if they are of larger diameters, are coated with a thin layer of copper, due to the increased power supply. The second group are wires with a core, which consist of a metal outer shell, covering the flux, or metal powder located in the electrode core [19]. such electrodes are mainly used when welding thicker sheets, for rounded and butt welds, or when welding with robots in a horizontal position. The use of these wires increases the resistance of welds to cracking, they ensure deeper penetration into the welded material, and increase the range of usability of the welding equipment [20]. The disadvantage is the higher price, finishing operations of the weld surfaces and increased production of harmful fumes.

2. Materials and Methods

Two different technologies were used for the production of the samples listed below, while the aim of the work was to determine the impact of individual technologies not only on the quality, but also on the chemical composition of the welds and the minimization of the heat-affected area. Each of the technologies listed below has a different heat input, which, in addition to the quality of the weld, is also reflected in the degree of mixing of the base material with the weld metal.

Two samples of disc laser welding (sample 01), MIG Pulse (sample 03) were applied to the additional material. Sample welds marked 01, 03 were applied to a substrate of nickel-chromium-molybdenum-vanadium steel 1.2714, DIN - 56NiCrMoV7. The welding wire Uddeholm Dievar 1.2344, DIN - X40CrMoV51 with a diameter of 1.2 mm was used as an additional material. Peg tests and hardness curves were performed on the samples.

Coatings were applied to samples of two basic materials. On the basic material nickel - chrome - molybdenum vanadium steel 1.2714, DIN - 56NiCrMoV7, with a hardness of 44 HRC

Tab. 1 Chemical composition of the base material

Element	Wt. [%]
C	0.397
Mn	0.72
Si	0.238
Cr	0.969
Ni	1.253
Mo	0.438
V	0.089
W	0.12

Table 2. Chemical compositon of the additive material [16]

Element	Wt. [%]
C	0.35
Cr	5.00
Si	0.20
Mo	2.30
Mn	0.50
V	0.60

The welding wire Uddeholm Dievar 1.2344, DIN-X40CrMoV51 with a diameter of 1.2 mm and a hardness of 51 HRC [8] was used as an additional material for the formation of welding layers.

Table 3. Parameters of laser welding

Welding technology	**Disc laser welding**
Welding equipment	The TruDisk 4002 solid-state disk laser with BEO D70 focusing
Focal length	200 mm
Laser power	1.8 kW
Optical fiber diameter	400 μm
Welding speed	10 mm. s^{-1}
Focusing	- +6 mm
Wire feed speed	70cm. min^{-1}
Shielding gas flow rate	Ar30l. min^{-1}

Table 4. Parameters of Mig Pulse welding

Welding technology	**MIG Pulse Welding:**
Welding equipment	Fronius TPS600i welding power source
Welding current	196 A
Welding voltage	23.8 V
Wire feed speed	6.5 m. min^{-1}
Welding speed	8 mm. s^{-1}
Arc length correction	3
Pulse/dynamics correction	0.0
Shielding gas flow rate	Ar 30 l. min^{-1}

3. Results

Chemical analyzes have shown that in the heat-affected area, individual materials are mixed, ie. base and additional material in the weld metal. The value of chromium in the weld metal is crucial, which in no case reached the limit of 5.00%, soaked in the additive material. The decrease of this element can be attributed mainly to the thermal influence of the material in the process of welding. The value of mixing the base material and the weld metal is minimal, which is confirmed by the fact that the hardness of all welds evaluated in the previous analysis was around 500 HV0.5.

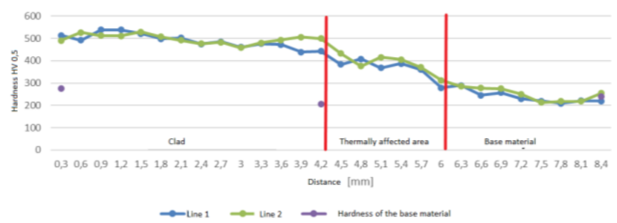

Fig.3 The graph shows individual weld hardness values measured in two lines and the hardness value of the base material on sample 01, created by disc laser welding

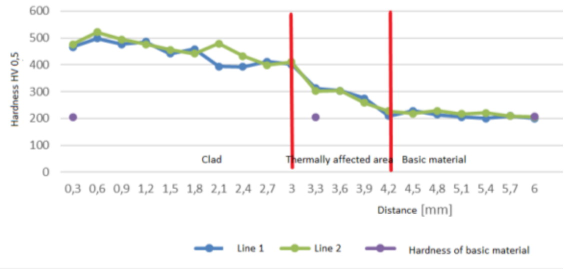

Fig. 4 The graph shows individual hardness values measured in two lines and the hardness value of the base material on sample 03, created by MIG Pulse technology

Since one step was 0.3 mm in the hardness measurement, the weld thicknesses ranged from 2.8 to 4.7 mm. Weld 01 had an average hardness value in the range of 450-500 HV0.5. In sample 03, see In Figure 5, 20 measurements were made, while the average value of the weld metal hardness was in the range of 400-500 HV0.5. From the fact that the hardness of all samples is in the range of 500 HV0.5, it is clear that the mixing of the base material and the weld metal has been eliminated, therefore there is no need to apply an additional layer during welding in either method. In weld 03 (MIG Pulse), the width of the heat-affected zone was around 1.2 mm. a wider heat-affected area was recorded by disc laser welding on the sample marked 01, the width of which was about 1.8 mm.

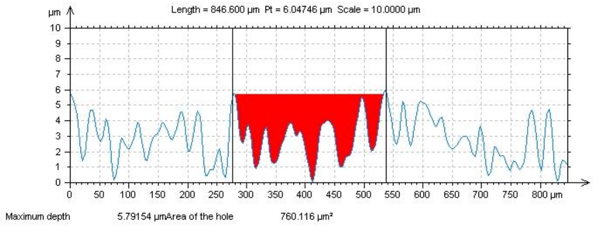

Fig. 5 Schematic of the tribo wear track on sample 01 produced by the Pin-on-Disc test

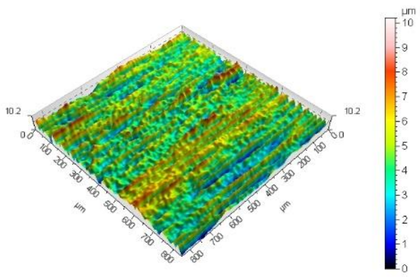

Fig. 6 3D image of the tribo wear track on sample 01 produced by the Pin-on-Disc test

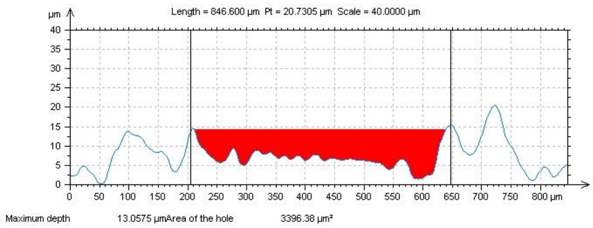

Fig. 7 Schematic of the tribo wear track on sample 03 produced by the Pin-on-Disc test

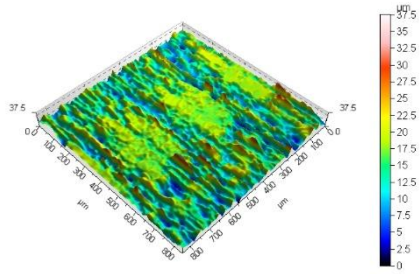

Fig. 8 3D image of the tribo wear track on sample 03 produced by the Pin-on-Disc test

A comparison of the coating surface of sample 01 (see Figure 6) with that of sample 03 (see Figure 8) showed that the wear mark of this coating was much shallower and smoother, and that the coating material moved from the center to the sides of the wear mark was less pronounced.

Weld 01, made by disk laser:

The width of the scanned area in the ultrasonic inspection of the weld marked 01 was 72mm and 6 scanning lines were used. The direction and designation of the scan lines are shown in Fig. 9.

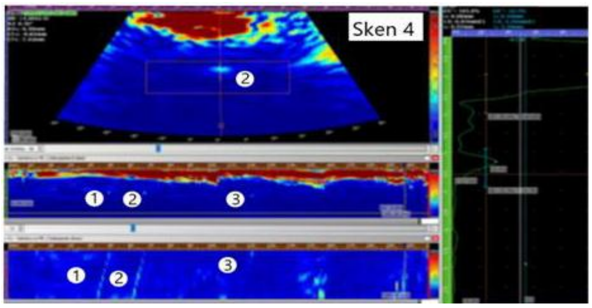

Fig. 9 Top - S-scan, right - A-scan (amplitude in the path), bottom - B-scan (cross section), in the middle - C-scan (area distribution of errors)

On scan no. 1, 2 internal errors were found, differing in depth, which was 3.8 mm at size 1 and 3.3 mm at size 2. On scans no. 2, 5, 6 no relevant internal errors were found, whiles-cans 5,6 are the same as scan 2 without internal errors, therefore they are not in Fig. 9 shown. In scan no. 3, only one relevant internal error with a depth of 3.6 mm was found. On scan no.4, internal defects were found, with depths ranging from 3.2 mm to 3.6 mm.

Weld 03, made by MIG Pulse technology:

The width of the scanned area in the ultrasonic inspection of the weld marked 03 was 82 mm and 8 scanning lines were used. The direction and designation of the scan lines are shown in Fig. 10.

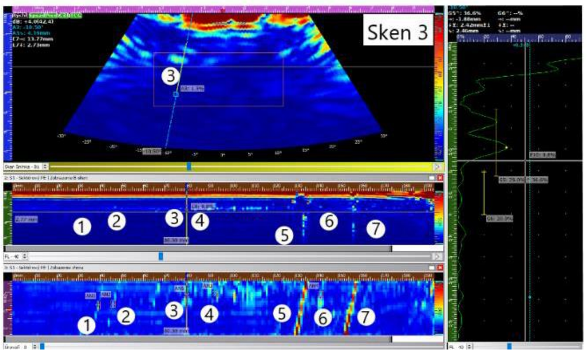

Fig.10 Top - S-scan, right - A-scan (amplitude in the path), bottom - B-scan (cross section), in the middle - C-scan (area distribution of errors)

On scan No. 1, 3 internal errors were found, while the depth of the error varied in the range from 1.7 mm to 1.8 mm. On scan No. 3, 6 internal errors were found, while the depth of the error varied in the range from 1.9 mm to 2.7 mm. No relevant internal errors were found on scans 2, 4, 5, 6, 7, 8, with scans 4, 5, 6, 7 being the same as scans 2 and 8 without internal errors, therefore they are not shown in Fig. 10.

4. Conclusions

The presented article is focused on the analysis of the quality of two types of deposits intended for the renovation of molds in high-pressure aluminum casting. Two different welding technologies and disc laser welding and MIG pulse welding were used for the production of test specimens. In all samples, UddeholmDeivar 1.2344 welding wire was used as a supplementary material, because this material is used in the restoration and renovation of functional parts of molds for aluminum pressure casting. In the theoretical part, the issues and mechanisms of die matrix wear for high-pressure aluminum casting are characterized, along with an overview of welding technologies used in the formation of weld layers in various industries. The experimental part was aimed at determining the quality of the above-mentioned navars. The quality of the welds was assessed on the basis of the heat-affected zone, which was determined from the course of the graphs, when measuring the hardness. The tribological parameters of the welds were investigated using the Pin-on-disc test. From the hardness measurement of the individual samples, it can be deduced that the narrowest heat-affected area had a weld marked 03, created by the Mig Pulse method. The widest heat-affected area was recorded on the sample marked 01, created by the disc laser. Based on the Pin-on-disc test, it can be used that sample 03 is much smoother and the shift of the coating material from the center to the worn sides was less pronounced. Based on the experimental work carried out, it is possible to recommend these technologies in practice for the purpose of renovating molds. Better results were achieved with the sample of weld 3 labeled Mig Pulse.

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3. References

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