Determination of the quality of renovation layers in tribological conditions

Janette Brezinova[1,*], Henrich Sailer[1]
Technical university in Kosice, Letna 9 Kosice 04001, Slovakia[1]
janette.brezinova@tuke.sk

Abstract: *Molds designed for high-pressure casting of aluminum are exposed to very intense thermal, mechanical but also chemical stress during their operation. This stress leads to a synergistic effect of a combination of high-temperature corrosion processes in molten metals, under real conditions associated with mechanical wear. High-temperature corrosion in the environment of liquid metals occurs in the foundry industry, when casting molten metal most often into steel molds. Repair of worn parts of molds by welding, which can be performed even after their irreversible surface degradation, is a very efficient, cost-effective and envi-ronmentally acceptable form of their maintenance, while the chemical and physical properties are welded layers if they exceed the properties of the original material.*
KEYWORDS*: DIE CASTING, DAMAGE SURFACE, CASTING DIES, MOLTEN ALUMINIUM, CLADDING, HIGH-TEMPERATURE CORROSION, LASER, MIG PULS*

1. Introduction

High Pressure Die Casting (HDPC) 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 forced into the cavities of the molds at filling speeds of 30-100m/s, under pressures ranging from 40-80 MPa [1]. This-loading, in combination with the corrosive properties of liquid aluminum, leads to alu-minization or oxidation of them old surface, which results in thermal fatigue of the sur-faces followed by cracking, soldering and erosive wear. The service life of die matrices-made of steel alloys is approximately 100,000 cycles and can be increased either by heat-treatment, thin coating or welding [2-4]. At present, the issue of surface treatment of va-rious materials is becoming more and more important. It offers savings in strategic ma-terials and at the same time enables the production of components with specific surface and volume properties. Because resources are limited by conventional technologies, it is becoming increasingly difficult to meet more advanced customer needs [5-6]. There are many methods for substrate treatment, but coatings developed, for example, by elec-trostatic, chemical, physical deposition techniques, have lower bond strengths or verylow reproducibility than surfacing. Refurbishing worn parts of machines is a very efficient and environmentally friendly form of their maintenance. This option can reduce the en-vironmental impact over the whole lifecycle 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 recoverd efects in worn parts of the surface and base layers of components. Due to the high energy density and relatively small heat affected area, this method is suitable for-processing a wide range of materials. It is mainly used in th eautomotive, aerospace, me-dical, nuclear and oil industries. In the aero space industry, the welding of layers to alu-minum alloys has an increasing potential to improve their surface properties [8-10]. This technology uses highly concentrated waves of light, concentrated at a certain point. In the area affected by the laser beam, atomic bonds disintegrate, causing it to heat up. The three most common types of lasers used in laser welding equipment are gas, se-miconductor and fiber. The laser beam is guided into the welding device by one or more optical fibers concentrated at one point. With each fiber added, the intensity of the laser beam also increases [11-14].Before the laser beam leaves the welding device, a combination of collimator and focusing lenses is often used to direct this radiation to a very small area. An important part of the laser welding equipment is also the nozzle supplying the protec-tive atmosphere gas, most often CO2. this gas prevents contact between the weld pool and the atmosphere. Another possibility is laser welding without a protective atmosphere, for example when welding plastics. Vacuum welding is possible but difficult to use, due to the high demands on the construction of the welding equipment[13].

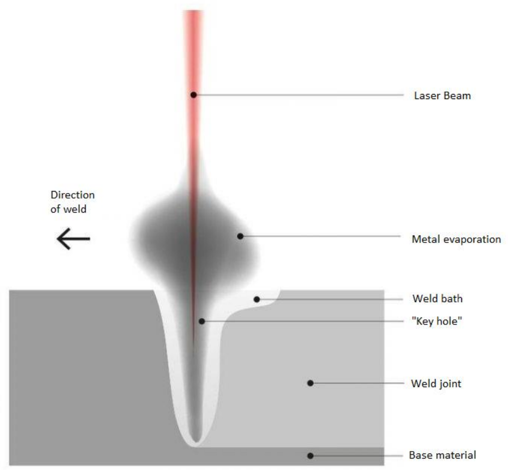

Figure 1. Schematic representation of laser beam welding [13]

TIG (Tungsten Inert Gas)

Non-melting tungsten electrode (TIG) welding technology, otherwise known as Gas Tungsten Arc Welding (GTAW), is a welding method in which the gas protecting the welding bath and the non-melting electrode is usually argon fed to a welding nozzle at the end. The additional material is fed to the welding bath in the form of a wire [15].

The TIG method also enables welding without additional material. The advantage of this technology is the welding of a wide range of materials such as stainless steel, aluminum and its alloys, copper or magnesium, while good weldability is guaranteed in all welding positions. Its main advantage is the welding of thin materials from 0.3 to 5 mm. The main disadvantage of this technology is low productivity, which limits it to smaller-scale work. The welding torches used in the TIG method are divided into two types. The first type is an air-cooled burner used for smaller operations, loaded with a current of up to 200 A. At a high current density of up to about 400 A, burners are used which are cooled mainly by water [16-98].

The non-melting welding electrode material must have a high melting point, good electrical, thermal conductivity and low electrical resistance. Tungsten with a melting point of 3370 ° C meets these requirements. Pure tungsten electrodes are used in predominantly alternating current welding of light metals, but more often, electrodes with an admixture of thorium oxide, cerium or zirconium are used, which improves the stability of the electric arc and improves its ignition. Another parameter of the welding electrode is its shape. When welding with direct current, its tip is sharpened at an angle of 45 °, but when alternating current they are not ground, instead they melt slightly with increasing current until they are rounded [20].

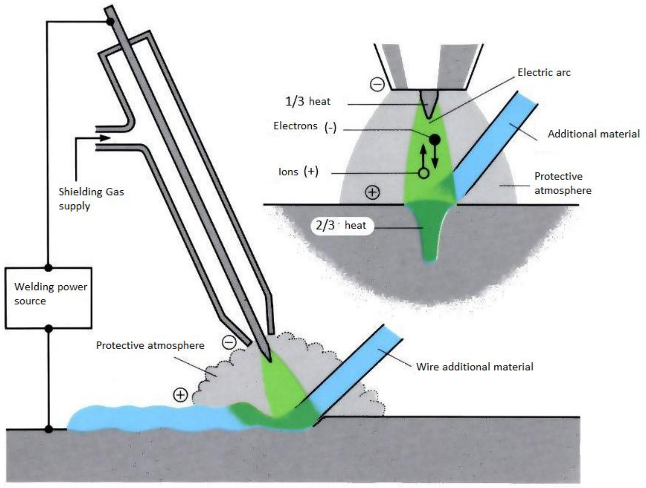

Fig. 2 *Schematic representation of the MIG / MAG method [18]*

2. Materials and Methods

Two different technologies were used for the production of the samples below, while the aim of the work was to determine the impact of individual technologies not only the quality but also 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 is reflected not only in the quality of the weld but also in the degree of mixing of the base material with the weld metal.

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

The welds were applied to samples of two base materials. On base material made of nickel - chrome - molybdenum vanadium steel 1.2714, DIN - 56NiCrMoV7, with hardness 44 HRC Tab. 1.

Table 1. *Chemical composition of the base material*

Element	Wt. [%]
C	0.397
Mn	0.72
Si	0.238
P	0.004
S	0.002
Cr	0.969
Fe	95.76
Ni	1.253
Mo	0.438
V	0.089
W	0.12

Table 2. *Chemical composition of the additive material [36]*

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

Uddeholm Deivar 1.2344 welding wire, DIN-X40CrMoV51 with a diameter of 1.2 mm and a hardness of 51 HRC was used as an additional material for the formation of welding layers [36].

Table 3. *Parameters of welding*

Welding technology	**Disc laser welding**		**MIG Pulse Welding:**
Welding equipment	The TruDisk 4002 solid-state disk laser with BEO D70 focusing	Welding equipment	Fronius TPS600i welding power source
Focal length	200 mm	Welding current	196 A
Laser power	1.8 kW	Welding voltage	23.8 V
Optical fiber diameter	400 μm	Wire feed speed	6.5 m. min^{-1}
Welding speed	10 mm. s^{-1}	Welding speed	8 mm. s^{-1}
Focusing	- +6 mm	Arc length correction	3
Wire feed speed	70 cm. min^{-1}	Pulse/dynamics correction	0.0
Shielding gas flow rate	Ar 30 l. min^{-1}	Shielding gas flow rate	Ar 30 l. min^{-1}
		Pre heating of base material	base material was preheated to 300 ° C before welding
			5 mm
		Distance burner - sheet metal surface	19 mm

3. Results

For structural analysis of the welds, Tescan Vega-3 scanning electron microscope (SEM) images were selected, capturing the interface of the base material and the weld as well as the heat affected area. The chemical analysis of the individual welds was evaluated for each sample from the base material area, the mixing zone and the weld pool.

Weld 01 (disk laser)

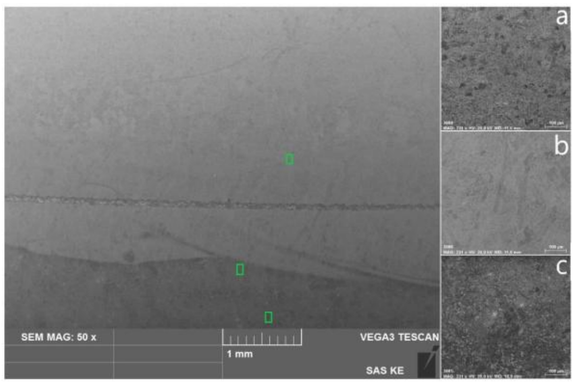

Fig. 3 *Weldment 01. Electron microscope image, capturing the interface of a) weld metal, b) heat affected area, c) base material*

Based on the chemical analysis of the weld metal 01 formed by the disk laser, it is possible to evaluate that due to the mixing of the base material and the weld metal, the original value of chromium in the upper weld metal layer was not reached. Another element for which a visible increase can be observed is vanadium.

Weld 03 (TOPTIG)

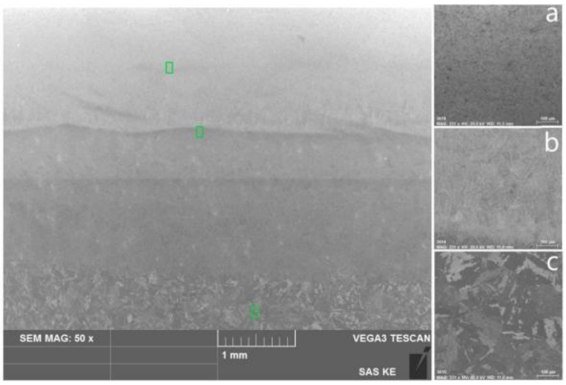

Fig. 4 *Weldment 03. Electron microscope image, capturing the interface of a) weld metal, b) heat affected area, c) base material*

During the chemical analysis of the weld marked 03 made by the TOPTIG technology, the smallest decrease of the elements, especially chromium in the weld metal, is visible, in comparison with the elements contained in the additional material.

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.

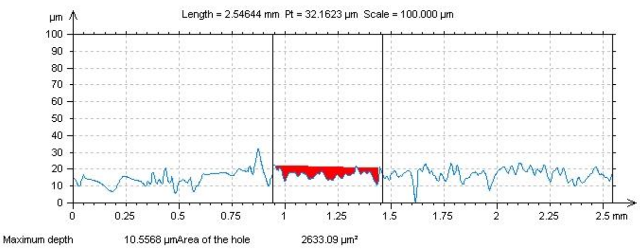

Fig. 5 *Scheme of the tribo wear track on sample 01 produced by the Pin-on-Disc test*

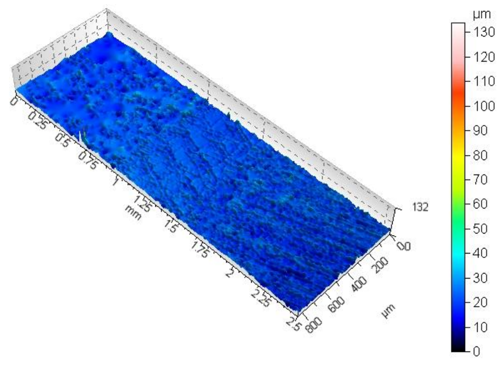

Fig. 6 *3D picture of the tribo wear track on sample 01 produced by the Pin-on-Disc test*

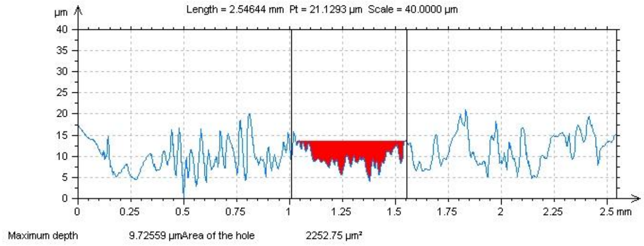

Fig. 7 *Scheme of the tribo wear track on sample 03 produced by the Pin-on-Disc test*

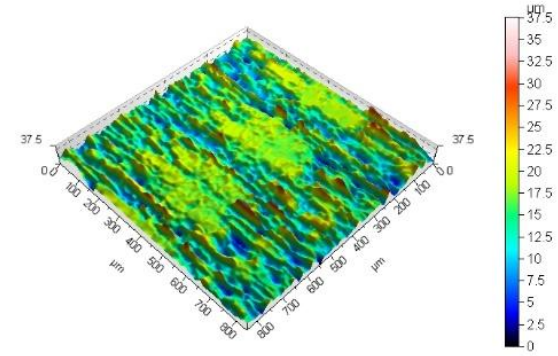

Fig. 8 *3D picture of the tribo wear track on sample 03 produced by the Pin-on-Disc test*

4. Conclusions

The presented article is focused on the analysis of the quality of two types of welds in-tended for the renovation of molds in high-pressure aluminum casting. Two different welding and disk laser welding technologies and MIG Pulse welding were used to pro-duce the test specimens. Uddeholm Dievar 1.2344 welding wire was used as an addi-tional material in all samples due to the fact that this material is used in the renewal and renovation of functional parts of molds, for die-casting of aluminum. In the theoretical part, the problems and mechanisms of wear of die matrices for high-pressure aluminum casting are characterized, together with an overview of welding technologies used in the formation of welding layers in various industries. The experimental part was focused on determining the quality of the above welds. 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. Tribological parameters of the welds were investigated using the Pin-on-disc test. From the measurement of the hardness of individual samples, it is possible to deduce that the narrowest heat-affected area had a weld marked 03, created by the TOPTIG method. The widest heat affected area was recorded on a sample labeled 01, created by a disk laser. Based on the Pin-on-disc test, it is possible to use that sample 03 is much smoother and the shift of the coating material from the center to the wear sides was less pronounced. Based on the implemented experimental work, it is possible to recommend these technologies in practice in order to renovate the molds. Better results were obtained with a sample of weld 3 marked TOPTIG.

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