Renovation of moulds for high-pressure casting of aluminium by laser cladding

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Abstract: *The paper presents the results of an investigation focused on the analysis of the wear of moulds for high-pressure casting with Al alloy. In order to repair and refurbish the mould parts of moulds for high-pressure casting of aluminium alloys, samples of experimental welds were prepared on the base material of grade 1.2343 (Dievar) of dimensions 150x130x30 mm refined to the hardness value of 44-48 HRC. A TruDisk 4002 solid-state disk laser with BEO D70 focusing optics was used for surfacing. Mat.No.1.2343 (Dievar), Mat.No.1.6356 (Dratec) and Mat.No.1.6356 (UTPA 702 and NIFIL NiCu7/Dievar) wires were used as additional material. Light microscopy technique was used to inspect the microstructures on the cross-sections of the welds. Microhardness measurements were performed with a Vickers indenter at a load of 500 g and a mutual indentation distance of 0.4 mm between the indenter impressions..*

Keywords*:* LASER CLADDING, DIE CASTING, CASTING DIES, ALUMINIUM, CONTACT ANGLE

1. Introduction

High-pressure die casting is a process that is used in the manufacture of components used mainly in the automotive industry but also in the aerospace industry. The principle of this technology consists in injecting, at a temperature of 670 - 710 °C, aluminium and its alloys into the mould cavity at high speed (30 - 100 m.s-1) and under high pressure (70 - 120 MPa) through complex injection systems. This process consists of several steps, from spraying the release agent on the mould surface, opening and closing the mould, but also the actual solidification of the casting (crystallisation) is important. Before each casting process, a release agent is sprayed on the mould surface to prevent the liquid metal from sticking to the mould surface and to ensure easier removal of the casting from the mould. The mould and its functional parts are preheated to a temperature of 400 °C prior to casting, where a significant temperature gradient occurs as the aluminium hits the mould surface at temperatures of around 700 °C. The layers on the mould surface tend to increase in size due to the natural thermal expansion from 400 °C to 700 °C. This expansion is limited by the other layers beneath them. The situation is then similar to the application of compressive surface stresses, which force the surface layers to be smaller in dimension than would be expected at these temperatures. However, as a consequence, the areas below the surface will be subjected to tensile stresses. Moulds designed for high pressure aluminium die casting are subject to a number of effects, mainly mechanical stresses, temperatures and liquid metal filling rates. These effects result in degradation mechanisms that act on the moulds and cause them to wear, Fig.1. Worn moulds require refurbishment once the condition is considered. One of the options to increase the life of the moulds is by cladding [1-8].

Fig. 1 *Initiation and propagation of cracks due to thermal gradient of the mould surface*

2. Experimental methodology and material

In order to repair and refurbish mould parts of moulds for high-pressure casting of aluminium alloys, samples of experimental welds were prepared on the base material of grade 1.2343 (Dievar) of dimensions 150x130x30 mm refined to a hardness value of 44-48 HRC. A TruDisk 4002 solid-state disk laser with BEO D70 focusing optics was used for surfacing. As additional material, Mat.No.1.2343 (Dievar), Mat.No.1.6356 (Dratec) and Mat.No.1.6356 (UTPA 702 and NIFIL NiCu7/dievar) wires were used.

The winding parameters were:

(a) Dievar additive material, laser power 1500W, crimping speed 6 mm/s, feeding speed feed rate 10 mm/s, focus 20 mm, protective atmosphere Ar (4.6) 7 l/min.

b) Dratec additive, laser power 1600W, winding speed 6 mm/s, feeding speed feed rate 10 mm/s focus 20 mm, protective atmosphere Ar (4.6) 10 l/min/min

c) UTPA702 additive material, laser power 1500W, winding speed 6 mm/s, feeding speed feed rate 5 mm/s, focus 0 mm, protective atmosphere Ar (4.6) 12 l/min.

Table 1: *Chemical composition of the additive materials used [wt.%]*

	Element										
	C	Si	Mn	Cr	Mo	Ni	Co	Ti	Al	Cu	Fe
1.2343 (Dievar)	0,463	0,147	0,423	5,13	2,27	0,067	<0,01	<0,002	0,008	-	Rest.
1.6356 (UTPA 702)	0,020	-	-	-	4,0	18,0	12,0	1,60	0,10	-	Rest.
1.6356 (Dratec)	0,0005	0,20	0,50	0,15	4,0	18,0	12,0	1,60	-	-	Rest.

Light and electron microscopy, EDX microanalysis

Light microscopy technique was used to examine the microstructures on cross-sectional sections of the striae in the magnification range of 25x to 1000x. The inspection of the welds was focused on the identification of defects and non-integrity of the welds. Scanning electron microscopy technique and semi-quantitative EDX microanalyses were used to analyse the distribution of alloys in the 1.2343 Dievar, 1.6356-UTPA 702 and 1.6356-Dratec alloys.

Hardness of cladds

Microhardness measurements were performed with a Vickers indenter at a load of 500 g and a mutual indentation distance of 0.4 mm.

Verification of surface wettability of samples with modified topography by contact angle measurement techniques

Only stochastic texture can realistically be applied to the mould parts of moulds for high-pressure casting of aluminium alloys on cold chamber machines. After each casting cycle, a separating agent - lubricant - is applied to the mould parts in order to form a thin layer on the surface preventing direct contact of the melt with the metal surface of the mould part. At the same time, this layer is also a thermal barrier. When filling the mould cavity with the aluminium alloy melt, this separation layer lubricant may be removed locally and the aluminium alloy melt is in direct contact with the metal surface of the mould. Research in the field of modification of the surface topography of mould parts was aimed at obtaining information on the interaction of separating agents (lubricants) used for the treatment of mould parts with modified surface topography - texturing by low-energy laser radiation. Tests of the interaction of the separating agent SafetyLube 7815 with the laser-textured surface by the "random" mode were carried out. The run-in phase conditions of the new or refurbished mould part were approximately obtained by repeated heating to 250°C (mould part temperature in high pressure die casting of aluminium alloys) and repeated splashing with SafetyLube 7815 release agent.

3. Results and discussion

Material 1.2343-Dievar. HAZ /heat affected zone/ thickness was max.0,5 mm. Microstructure in the coating - sorbitic with directed crystallization, without integrity defects, zone of building - without integrity defects and anomalies in microstructure, in HAZ gradual transition from ferritic-carbide mixture to sorbitic microstructure of the base material, Fig.2.

Fig.2 *Material 1.2343-Dievar, a) disposition; b) detail of the outline; c) background material*

Material 1.6356 - UTPA 702. HAZ thickness was max. 1.0 mm. Microstructure in the coating - casting with directed crystallization (visible in scanning electron microscope in BSE mode), without integrity defects, HAZ - without integrity defects, build zone without integrity defects, base material - sorbitic microstructure without integrity defects, Fig.3.

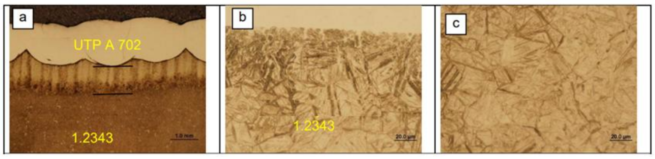


Fig.3 *Material 1.6356 - UTPA 702, a) disposition; b) detail of HAZ and construction material; c) detail of HAZ*

Material 1.6356 - Dratec. The thickness of HAZ was max. 1.0 mm. Microstructure in the coating - casting with directed crystallization (visible in scanning electron microscope in BSE mode), without integrity defects, HAZ - without integrity defects, build zone without integrity defects, base material - sorbitic microstructure without integrity defects, Fig.4.

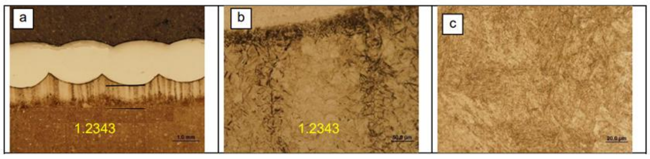
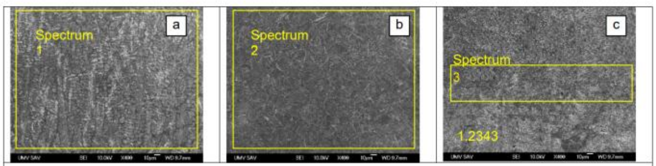


Fig.4 *Material 1.6356 - Dratec, a) disposition; b) TOZ detail and melting zone; c) detail of HAZ*

In both layers of the 1.2343-Dievar deposit, the distribution of alloys was uniform, Fig.5. In the 1.6356-UTPA 702 deposit, no cobalt was detected in the second layer, Fig.6. In the second layer of the 1.6356-Dratec deposit, the concentration of cobalt and nickel was reduced with respect to the first deposit, Fig.7.



Spectrum 1.

Element	Weight%	Atomic%
Cr K	5.35	5.78
Fe K	92.41	92.91
Mo L	2.23	1.31
Totals	100.00	

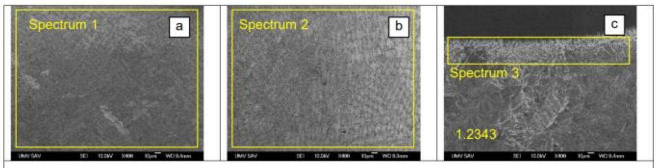
Spectrum 2.

Element	Weight%	Atomic%
V K	1.00	1.10
Cr K	4.72	5.09
Fe K	92.28	92.64
Mo L	2.00	1.17
Totals	100.00	

Spectrum 3.

Element	Weight%	Atomic%
Cr K	5.80	6.29
Fe K	90.56	91.56
Mo L	3.65	2.15
Totals	100.00	

Fig.5 *Microstructure of material 1.2343; a) 2nd layer of clad; b) 1st layer of clad; c) HAZ*



Spectrum 1.

Element	Weight%	Atomic%
Ti K	1.61	1.92
Cr K	1.90	2.09
Fe K	77.39	79.14
Ni K	14.51	14.12
Mo L	4.60	2.74
Totals	100.00	

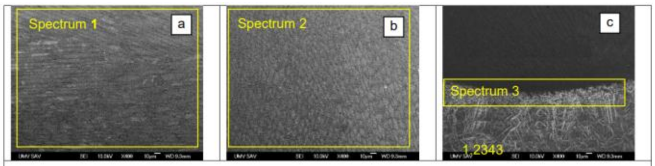
Spectrum 2.

Element	Weight%	Atomic%
Ti K	1.17	1.40
Cr K	1.74	1.91
Fe K	71.56	73.37
Co K	9.14	8.88
Ni K	12.28	11.98
Mo L	4.11	2.45
Totals	100.00	

Spectrum 3.

Element	Weight%	Atomic%
Cr K	5.40	5.86
Fe K	91.47	92.31
Mo L	3.13	1.84
Totals	100.00	

Fig.6 *Microstructure of material 1.6356-UTPA 702; a) 2nd layer of clad; b) 1st layer of clad; c) HAZ*



Spectrum 1.

Element	Weight%	Atomic%
Ti K	1.00	1.20
Cr K	1.26	1.39
Fe K	72.22	73.96
Co K	8.17	7.93
Ni K	13.71	13.36
Mo L	3.64	2.17
Totals	100.00	

Spectrum 2.

Element	Weight%	Atomic%
Ti K	1.43	1.71
Cr K	1.24	1.36
Fe K	67.50	69.21
Co K	10.22	9.92
Ni K	16.08	15.69
Mo L	3.53	2.11
Totals	100.00	

Spectrum 3.

Element	Weight%	Atomic%
Cr K	4.66	5.06
Fe K	92.13	93.06
Mo L	3.20	1.88
Totals	100.00	

Fig.7 *Microstructure of material 1.6356-Dratec; a) 2nd layer of clad; b) 1st layer of clad; c) HAZ*

Material 1.2343-Dievar - At the surface the microhardness value was 600 HV0.5, at a depth of 0.8 mm the microhardness was ~ 700 HV0.5, Fig. 8a. Die 1.6356-Drill and Die 1.6356-UTP702 A - From the surface to a depth of 1.2 mm, the microhardness value was 400HV0.5. At a depth of 1.6-2.0 mm, the microhardness value was locally increased to 600-700 HV0.5 Fig.8 b,c.

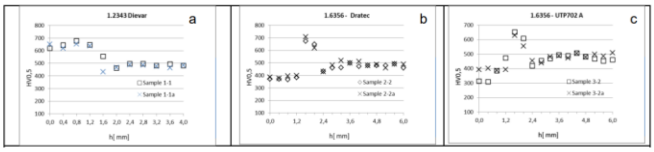
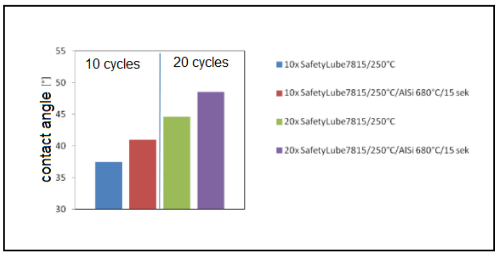


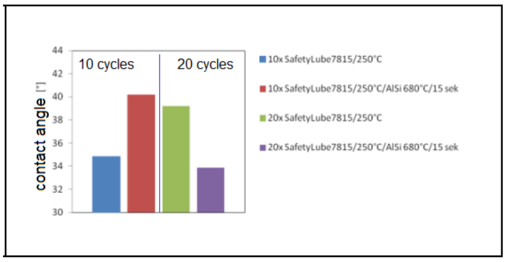
Fig.8 *Microhardness from surface, indentation distance 0,4 mm; a) material 1.2343 - Dievar ; b) material 1.6356 - Dratec; c) material 1.6356 - UTP 702 A*

After ten and twenty cycles of abrasion with the separating agent, the 250°C samples were immersed in an aluminum alloy melt maintained at 680°C. The immersion time was 10 seconds. The ablation craters were coated with a thin layer of Safety Lube 7815 lubricant after ten cycles. After twenty cycles, there was a 2 and 3 times thicker layer of Safety Lube 7815 lubricant in the ablation craters.

The contact angle measurement was targeted to test the methodology designed to determine the number of splashes of the separating agent - lubricant Safety Lube 7815 on the surface of the new or renovated mould part for the first casting cycle. On the textured surface of the Dievar grade material, the increase in the contact angle value with the number of Safety Lube 7815 splash cycles was measured, Fig.9. The contact angle values of Safety Lube 7815 were measured on the PVD coating $NaCRo_4$ deposited on the textured surface (texture random). The contact angle values as a function of the number of spray cycles with Safety Lube 7815 separator were smaller after 20 spray cycles and a 15 second immersion in the aluminium alloy melt than after 10 spray cycles and a 15 second immersion in the aluminium alloy melt.



a)



b)

Fig.9 *Contact angle vs. number of spray cycles lubricant Safety Lube 7815. a) Surface Punch + texture random, b) Surface Dievar + laser random + duplex NaCRo$_4$ coat*

4. Conclusions

The paper presents the results of research aimed at determining the quality of three types of brews. Three types of strands were produced by lasso technology. A TruDisk 4002 solid-state disk laser was used for the surfacing. DIEVAR, DRATEC AND UTPA702. The quality of the overlays was evaluated by light and electron microscopy and the chemical composition of the different regions was evaluated by EDX microanalyses. The distribution of alloys was uniform in the coatings. The blooms showed high structural quality. The use of surface texturing provides the possibility to ensure smooth lubrication of the moulds, especially in the mould run-out. Further research will be focused on the determination of the quality of the welds under the conditions of high temperature corrosion in molten aluminium.

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