High pressure die casting mould renovation by cladding

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Abstract: *The paper presents the results of the research of the evaluation of the overlay layers quality made by the fusible arc methods. By applying arc welding methods, it is possible to significantly extend the life of injection molds and thus significantly reduce production costs. The newly formed layers must meet a number of requirements so as not to degrade the advantages of high-pressure injection technology over conventional casting technologies. High pressure casting solves most of the problems of conventional casting technologies such as: porosity of the casting, high surface roughness, long casting time, inability to produce thin cross-sections and low dimensional accuracy. During exploitation, the mold surface is damaged, mostly by thermal cracking and combined adhesive-abrasive wear. Material used for high pressure die casting permanent mold is a medium alloyed hot tool steel Uddeholm Dievar. Layers were made using three types of filler materials on the Fronius TransTig 4000. To eliminate the effect of mixing, three layers were made. The quality of the deposits was assessed by non-destructive and destructive tests.*
Keywords: *CLADDING, RENOVATION, LIFETIME,*

1. Introduction

Shape mold parts and mold cores for the casting of aluminum alloys must possess suitable physical and mechanical properties at elevated temperatures. These properties are essentially defined by the thermal and mechanical stresses as well as by the interaction at the interface between the mold and the aluminum alloy melt (Fig. 1). In particular, the high velocities of the turbulent to dispersive filling of the mold cavity by the aluminum alloy melt, the high hydrodynamic pressures generated by the melt on the shape part of the mold and relatively high temperatures on the surface of shape parts of molds can significantly shorten the lifespan of molds and cores. All these phenomena cause the degradation of the surface of mold shape parts by mechanisms of erosion, abrasion, corrosion and heat fatigue of the mold, each of which act at the same time [1-2].

As the main mechanisms of mold damage, they identified wear (abrasive, adhesive, according to the purpose of the mold: mold for casting or die forging), erosion and mechanical and thermal fatigue. Jhavar [3] identified wear-influencing factors as follows: temperature, atmosphere, contact area, load, material properties, finish, velocity, lubrication, shape, vibration, sliding distance and type of motion. The material characteristics of molds and dies are also important, especially hardness, yield strength, elastic modulus, ductility, toughness, work-hardening characteristics, fracture toughness, microstructure, corrosion resistance, and in case of molds and dies in high-pressure die casting also resistance against solution in the melt [3].

Abrasive wear can occur in high-pressure casting molds due to insufficient mold cleaning between injection molding cycles in the area of the fitting surfaces between the mold parts. During this process, solidified particles of cast metal can act as abrasive particles. Depending on the shape and hardness of these particles, one of the following mechanisms of abrasive damage can occur: ploughing, cutting or fragmentation.

Adhesive wear of molds may occur in the event of insufficient lubrication and at high temperatures and friction rates. This results in an increase in the roughness of the mold surface and deterioration of the casting quality and process efficiency. The solubility of the mold material in the melt may also contribute to this. At high friction speeds in the presence of oxygen, oxidation of the mold material may also occur.

Thermal fatigue results from the cyclic change in the temperature of the functional mold surface relative to the material temperature next to the mold surface (Fig. 2). These changes cause thermal stresses and lead to the formation of a network of cracks. Chander [4] and Chen [5] developed a thorough analysis of the thermal fatigue and identified the factors that a ect it [6-8]. They have been divided to die temperature cycle-related factors (preheating temperature, surface temperature of the die, holding time at peak temperature, cooling rate), basic die material properties' factors (thermal expansion coefficient, thermal conductivity, hot yield strength, temper resistance, creep strength, ductility) and to stress raisers' factors (fillets, holes and corners, surface roughness) [9-12].

Ansys software can be used to simulate injection molding processes and calculate the temperature distribution on the surface of the mold part and the heat flow into the mold (Fig. 3).

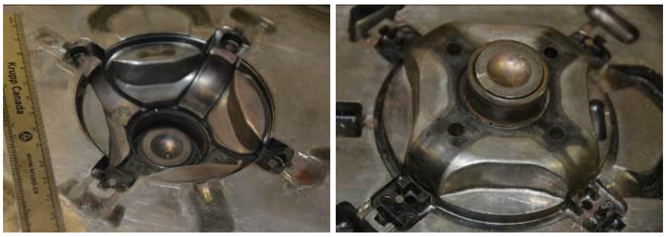

Fig. 1. *Aluminum injection mold*

Fig. 2. *Cracks on the mold surface*

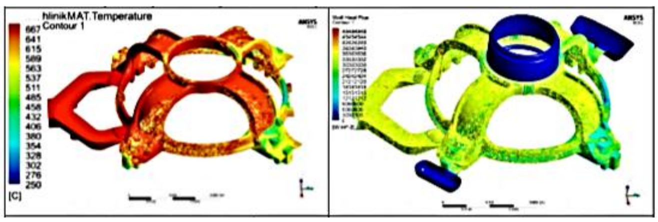

Fig. 3. *Temperature field of the mold at 1.5x10-3s (left) and heat flux density between Al and the mold at 1.5x10-3s (right)*

2. Materials and Methods

The material of the test samples by chemical composition and heat treatment regime was the same as the material used for the molded parts of die casting molds Uddeholm Dievar (Tab. 1). Delivered semi-finished product was soft-annealed. Material of the test samples by chemical composition and heat treatment regime was the same as the material used for the molded parts of the die-casting molds. Test samples 2.5 and 3.5 mm thick were taken from rolled Uddeholm Dievar steel bars with a diameter of ø 50.8 mm and 25 mm. Delivered semi-finished product was soft-annealed.

Chemical elemental analysis of metal samples and welds was determined with a Belec Compact Port spectrometer. All samples were heat treated mode: heating to 650 °C / 15 min / 850 °C / 15min / heating to 1000 °C / 30min / oil, 2x tempering 580 °C / 2 h / on air to a final hardness of 44 HRc and on both sides 49 ground to a roughness of Ra 0.2. GTAW welds were made on the samples with three types of additional materials - chemical composition of which is in Tab.2 to Tab. 4. The weld was made as a single layer. The diameter of the additional materials was ø 1.6 mm. Additive material was fed manually. The flow rate of the inert atmosphere I 1 - EN ISO 14 175 (100% Ar 4.6) was 18 l / min.

***Table 1:** Chemical composition and mechanical properties of steels Uddeholm Dievar*

Chemical composition in (% wt.) / Fe balance/					
C	Mn	Si	Cr	Mo	V
0.338	0.441	0.125	5.041	2.290	0.532
Mechanical properties					
Tensile strenght R_m [MPa]	Yeld strenght $R_{p0,2}$ [MPa]	Elongation A5 [%]	Reduction of area [%]	Hardness [HRC]	
1490	1210	13	55	44	

***Table 2:** Chemical composition filler material W/MSG 3-GZ-45-T – DIN 8555*

Chemical composition in (% wt.)						
C	Mn	Si	Cr	Mo	Ti	Fe
0.25	0.7	0.5	5.0	4.0	0.6	Bal.

Cladded sample A.

***Table 3:** Chemical composition filler material W/MSG 3-60 -T – DIN 8555*

	Chemical composition in (% wt.)						
C	Mn	Si	Cr	Mo	W	V	Fe
0.35	0.4	1.0	5.0	1.5	1.3	0.3	Bal.

Cladded sample B.

***Table 4:** Chemical composition filler material Cronitec RC 44*

	Chemical composition in (% wt.)						
C	Mn	Si	Cr	Mo	W	V	Fe
0.35	0.6	0.7	5.3	1.5	0.3	0.8	Bal.

Cladded sample C.

Used cladings parameters for the samples are in Tab. 5. Clads were made on a Fronius MagicWave 4000 Job. W + 2% ThO_2 was used. Diameter of electrode 2.4 mm. Electrode Tip angle 30 º. Arc length 2 mm. Post welding gas flow time 10sec.

***Table 5:** Used cladding parameters*

Cladding parameters				
Method	Sample	Cladding current [A]	Cladding voltage [V]	Current type / polarity
141	**A**	95	13,4	DC -
141	B	95	13,4	DC -
141	C	95	13,4	DC -

3. Results and discussion

Within experiments, the quality of the clad layers was evaluated by a visual test in accordance with EN ISO 17637, where the surfaces of the clads were evaluated under illumination of 500 lux. Presence of surface defects such as e.g. cracks, surface cavities, spatter, etc.is monitored. Presence of surface defects was not detected on the evaluated weldment surfaces. Light microscope was used on transverse metallographic sections. The microstructure of the welded clads and base material were highlighted by etching in the following etching agents: 120 mL CH_3COOH, 20 mL HCl, 3 g picric acid, 144 mL CH_3OH). Microstructures were observed using OLYMPUS GX71 light optical microscope (OLYMPUS Europa Holding GmbH, Hamburg, Germany). Basic material (Fig. 4) has a structure formed by fine-grained line sorbitol. The weld metal microstructures are documented in Fig. 5 to Fig. 7.

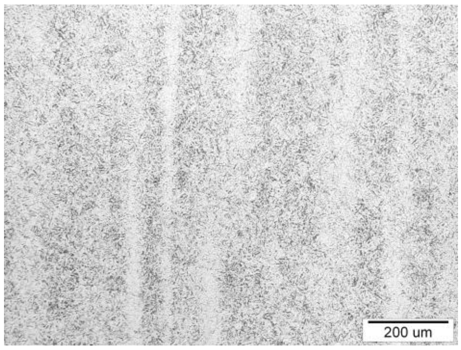

***Fig. 4**. Structure of base material Dievar*

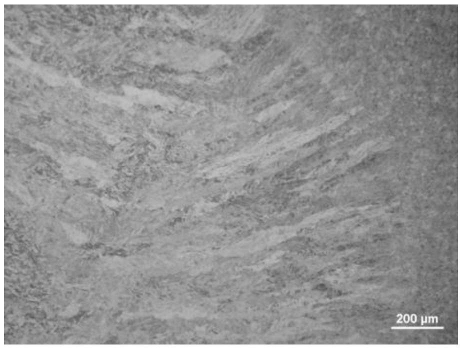

***Fig. 5**. Structure of clad layers sample A*

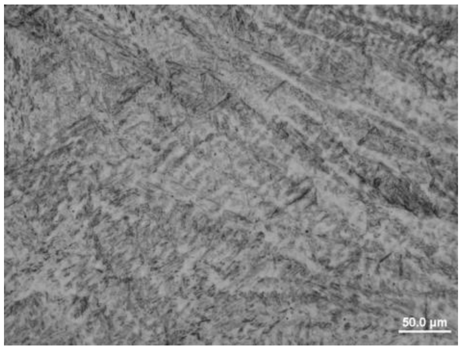

***Fig. 6**. Structure of clad layers sample B*

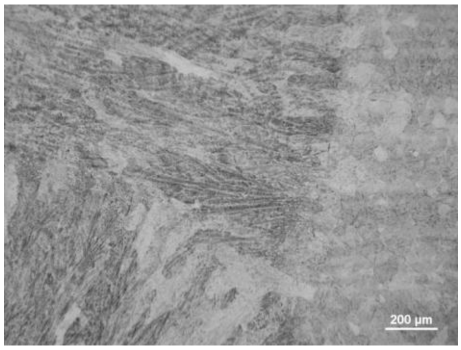

***Fig. 7**. Structure of clad layers sample C*

Clad metal has a characteristic dendritic structure with oriented grains with a well-readable solidification direction. Mixing of the clad metal with the base material was minimal and the area of mixing of the metal did not exceed 400µm. The HAZ was also narrow, which indicates suitably selected clading parameters, as well as the good skill of the welder, given that it was not a mechanized feed during clading, but manual clading. No internal defects were noted on the transverse sections. The presence of massive carbide inclusions was not observed on the structures. The structures of the clading layers are formed by tempered martensite - sorbitol. Which is in accordance with the chemical composition of the realized clads. As part of the evaluation of the clad metal properties, hardness values were determined on transverse metallographic sections, which is documented in the graphs in Fig. 8 to 10.

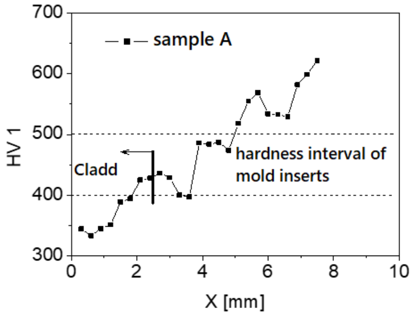

Fig. 8. *Hardness of cladd sample A*

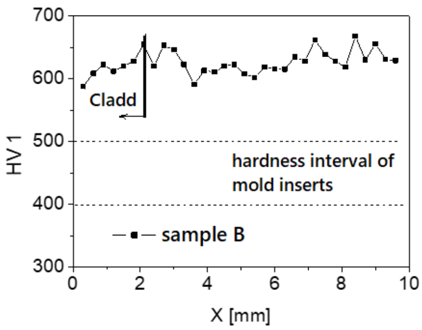

Fig. 9. *Hardness of cladd sample B*

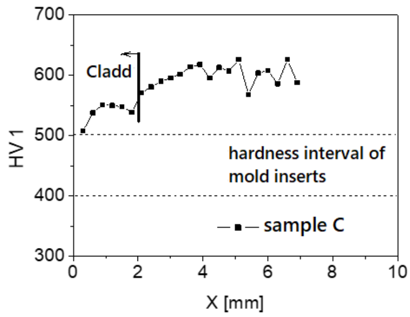

Fig. 10. *Hardness of cladd sample C*

For sample A, the thickness of cladding was max. 2.3 mm. The hardness values of the clading layer were in the range of 330-430HV1. The maximum hardness value 430HV1 corresponds to the recommended values for injection mold inserts. However, up to a clad thickness of 2 mm for sample A (Fig. 8), the hardness is insufficient and therefore it is not possible to recommend the given type of additional material for the renovation of injection mold inserts. The influence of significant heterogeneity of mechanical properties of the clading layer compared to the sub-clading layers will be the goal of further research. In the case of additional materials used in the production of samples B and C, it is possible to observe a significant increase over the measured hardness compared to samples A already in the surface layer of the clad metal, where the measured values exceed the recommended values for injection mold inserts (400-500HV) (Fig. 9. Fig. 10) The finished clads of samples A and B had a height of approx. 2.0mm. The highest hardness values were recorded in the clad layers of samples B. As the injection mold is loaded with a combined load, the service life of which is limited by several factors, it can be high resp. above-limit hardness (above 430HV) a factor degrading the resulting complex values of resistance to all tribodegradation factors. From the point of view of increased susceptibility to crack initiation resp. formation of surface and subsurface defects. Of the additional materials used, the surface hardness values closest to the required values show clad on sample C. The measured hardness values are in accordance with the chemical composition of the additional materials used. The lowest hardness values were shown by the clad metal made with the additive material W / MSG 3-GZ-45-T - DIN 8555. lower hardness values were probably due to the absence of carbide-forming elements W and V. Chemical composition of the filler materials for the production of samples B and C was similar, corresponding to only a small difference in the measured hardness values of the weld layers.

4. Conclusions

Paper presents a part of the experiments carried out in evaluating the quality of the clad layers of the functional surfaces of the injection molds. These are components exposed in demanding tribodegradation conditions and their service life is significantly limited. Possibilities of surface renewal by clading resp. clading and coating (PVD, CVD) are a suitable solution for the restoration of these functional surfaces of molds and cores. To a large extent, they provide significant economic savings for companies. The processes of clading and local repair of damaged parts of molds are dominated by arc methods, namely GMAW and GTAW welding(clading). Due to the chemical composition of materials for the production of injection molds, the aim is to minimize the heat introduced into the clads. This can be extinguished by using the pulse welding mode, resp. application of the CMT (Cold Metal Transfer) method. In addition to the presented arc welding methods, energy beam welding methods are being used in an increasing volume, especially laser welding. The laser beam makes it possible to minimize the amount of heat introduced during welding, which significantly minimizes negative metallurgical changes in the sub-weld areas of medium and high-grade steel grades.

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