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PROBLEMS IN LASER REPAIR WELDING OF POLISHED SURFACES

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This paper presents problems in laser repair welding of the tools for injection moulding of plastics and light metals. Tools for injection moulding of the car headlamps are highly polished in order to get a desirable quality of the injected part. Different light metals, glasses, elastomers, thermoplastics and thermosetting polymers are injected into the die cavity under high pressures resulting in the surface damages of the tool. Laser welding is the only suitable repair welding technique due to the very limited sputtering during deposition of the filler metal. Overlapping of the welds results in inhomogeneous hardness of the remanufactured surface. Results have shown strong correlation between hardness and surface waviness after final polishing of the repair welded surface.

Key words: laser welding, injection moulding, polishing, repair welding, hardness

INTRODUCTION

Injection moulding is a manufacturing process for production of the parts by injecting the molten material under high pressures and velocities into the cavity [1]. Injection moulding is widely used in the mass production of complex automotive parts with high dimensional accuracy [2, 3]. Increasing number of moulded components in the majority of current commercial products has placed the mould sector in a key position in the global manufacturing industry [4]. The high costs of mechanical tooling and time required for the manufacturing of the new tool are two of the most important factors justifying the remanufacturing of a damaged tool [5]. The expected life of the mould should be more than 100 000 cycles [6, 7]. Surface cracks and erosion are most common failures on the dies [8, 9]. Laser beam welding and GTAW are widely used in the remanufacturing of the tools for different purposes due to the energy concentration available for welding [10–15].

Mean R_a value recommended in plastic injection industry is 0,05 µm [3]. It was already published that GTAW can be used as a suitable welding technique if an appropriate filler metal and heat treatment are chosen [15]. Hardness deviation must be reduced in order to obtain similar properties of the weld metal, heat affected zone and base material. Injection moulds are normally manufactured from AISI P20, H11 or H13 tool steels which should be preheated prior to welding due to the high carbon equivalent [16, 17]. Due to highly polished surfaces, the high preheating temperature drastically affects the oxidation of the surface. In order to preserve the surface properties of the tool pulsed laser welding is the only suitable repair welding technique with very limited literature about problems. According to the reviewed literature there is very little information about welding of highly polished injection moulds and hence the data about the surface properties after final polishing operation are very limited.

This paper presents the problem in laser repair welding of the highly polished tools where the hardness deviation strongly affects the waviness of the polished surface and hence the light reflectance of injected part. Study also includes the influence of the laser beam characteristics on the porosity formation. Four different commercially available filler materials in a form of welding wire were used in order to obtain the influence of chemical composition and weld hardness on the properties of the deposited layer. A model for the material flow during the melting of the welding wire and its effect on the weld geometry was established in order to improve the quality of the laser beam welding of polished tools.

EXPERIMENTAL WORK

AISI H13 hot work steel plate with dimension of 100 mm × 80 mm × 10 mm was used as a base material. Prior to welding base material was quenched and double tempered to the hardness of 48 HRC. Four different filler materials with the diameter of 0,5 mm, suitable for the repair welding of the H13 hot work tool steel, were deposited using Nd: YAG laser LASAG SLS 200 CL 60. Deposition areas in dimension of 25 mm × 10 mm × 0,4 mm were machined from the base material according to the Figure 1. Chemical compositions of the materials used in experimental procedure are presented in the Table 1. and welding parameters are listed in the Table 2. Prior to welding all filler materials were cleaned

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using grinding paper and wiped with acetone in order to avoid contamination of the weld with impurities [18]. Three layers of the filler material were deposited on each surface in order to get the chemically pure weld metal. Preheating was not applied due to the possible surface oxidation.

Table 1 **Chemical compositions of the materials / mass. %**

	C	Cr	Mn	Mo	Ni	Si	V	W
Base	0,39	5,15	0,38	1,35	/	1,00	1,00	/
Filler A	0,35	5,00	0,50	2,30	/	0,20	0,60	/
Filler B	0,20	17,0	1,00	1,00	0,50	0,50	/	/
Filler C	0,30	2,30	0,30	/	/	/	0,60	4,30
Filler D	0,10	6,50	0,60	3,30	/	0,40	/	/

Table 2 **Welding parameters**

Pulse peak power / W	2 600
Pulse length / ms	11
Pulse energy / J	12
Focus distance / mm	160
Welding speed / cm·min^{-1}	10
Pulse frequency / Hz	10
Argon flow / l·min^{-1}	6

WELD SURFACE ANALYSIS

Surface of the deposited layers and base plate was grinded using SiC grinding papers with the grits from 80 to 2 500. Surface was also machine polished according to the industrial praxis in order to get the R_a value of 0,03 µm.

3D optical microscope Bruker Contour GT-I was used in order to characterize the properties of the polished weld beads. Zwick Roell ZHU/Z2.5 automated testing machine was used to measure the Vickers hardness under the load of 500 g. Twenty indentations with linear distance of 0,25 mm were measured for each filler material. Figure 2 shows the position of the hardness measurement course and the surface with dimension of 3,5 mm × 2,6 mm which was analysed using 3D optical microscopy.

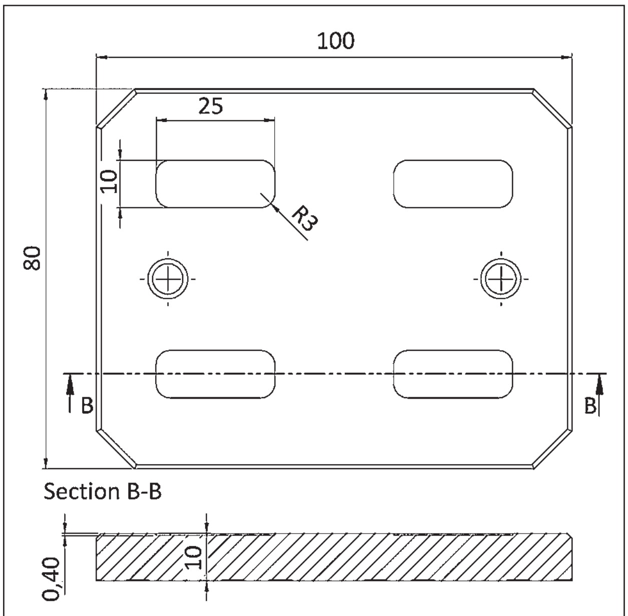

Figure 1 Dimension of the base plate with four areas with the depth of 0,4 mm for the deposition of three layers of the filler material

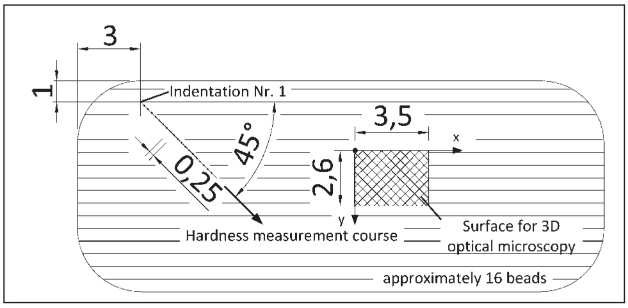

Figure 2 Position of the hardness measurement course and the surface for the 3D optical microscopy

According to the Figure 3 it is clearly seen, that the surface appearance is different for different type of filler material. Profile was measured in Y direction at fixed X position of 1,7 mm. The surface roughness R_a is equal for all tested materials and the value is 0,03 µm. Waviness of the polished surface is an important parameter of highly polished injection moulds, where the light reflectance of the injected parts is crucial. Filler material A shows the lowest waviness the profile. Measured difference between largest peak height and largest valley depth within evaluation length was just 0,17 µm. Filler material C shows the highest deviation of profile waviness and the measured distance was 0,35 µm which is for a factor of two higher compared to filler material A.

Surface hardness after polishing operation is presented in the Figure 4 and the values are numerically listed in the Table 3. According to the observed data it is clearly seen that hardness deviation is the lowest for the filler material A. Hardness deviation is the highest for the filler material C which corresponds well to the highest surface waviness shown on the Figure 3c.

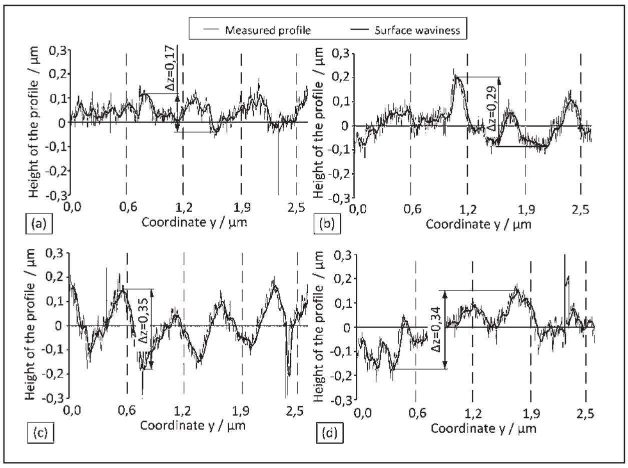

Figure 3 Profiles of the polished surfaces in the coordinate Y according to Figure 2, a) Filler A, b) Filler B, c) Filler C, d) Filler D

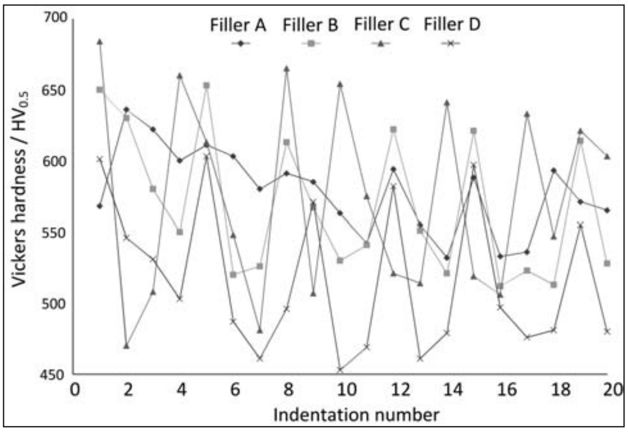

Figure 4 Hardness of the polished surfaces across the hardness measurement course

All tested filler materials have high content of carbon and other alloying elements. Filler material C also includes 4,3 mass.% of tungsten which could be the influencing element for high deviation of hardness and consequently affects the surface waviness. Tungsten is a strong carbide forming element. Due to the high content of carbon inside of the base material and filler rod WC may form during weld pool solidification.

Table 3 **Surface hardness values**

	Hardness properties / $HV_{0.5}$			
	Filler A	Filler B	Filler C	Filler D
max value	636	653	684	603
min value	532	512	470	443
average value	578	568	574	516
standard deviation	30	50	69	52

INFLUENCE OF THE LASER BEAM

Filler material D, with the lowest average hardness, shows almost similar waviness of the profile as the filler material C. One of the influencing factors affecting the waviness of the polished surface could be the parameters and the shape of the laser beam presented in the Figure 5.

Energy distribution, laser beam diameter and the focus position result in a melting sequence of a welding wire and consequently in a shape of the welding pool. If a focus of the laser beam is placed on the top of the welding wire it results in a low dilution with the base material according to the Figure 5a and undercut may appear during solidification. In this case $d_{L1} < d_w$ and energy of the laser beam is concentrated in the focus of the laser beam. According to the Figure 5b sound weld is formed with deep penetration and without undercut due to the circular distribution of the energy and the ratio $d_{L2} \approx 1{,}2\ d_w$. Figure 6 shows the porosity formation. It appears when manual feeding of the welding wire is used during deposition. During welding the focus position may vary resulting in the weld shape as presented in the Figure 5b. During final machining and polishing of the weld surface the undercuts present the areas without filler material and consequently small holes appear on the polished surface.

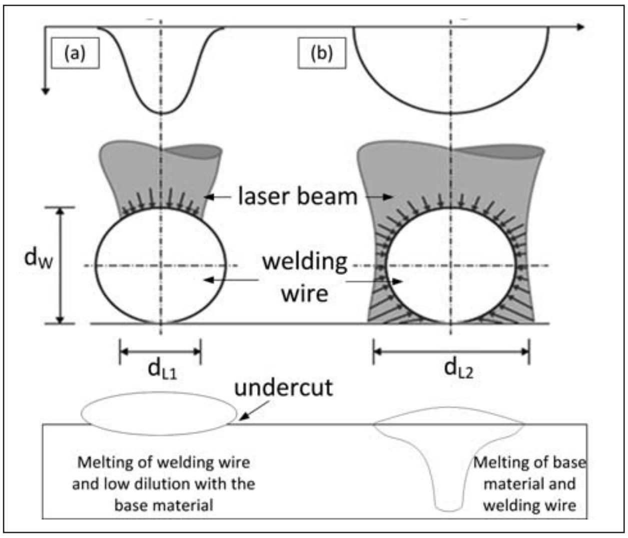

Figure 5 Effect of the laser beam on the melting and the shape of the weld pool, a) small diameter of the laser beam d_{L1} results in undercut of the deposited bead, b) diameter of the laser beam d_{L2} is wider as the diameter of the welding wire d_W resulting in sound weld

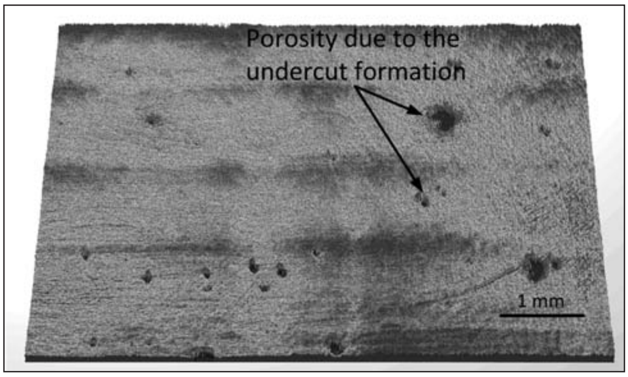

Figure 6 3D optical microscopy of the polished surface showing the porosity due to undercut formation

CONCLUSIONS

In this paper remanufacturing of the polished surfaces of tools for injection moulding by pulsed laser welding is presented. It is shown that different types of filler materials show different appearance of the polished layer. The R_a value of 0,03 μm was observed for all the tested filler materials while the waviness of the profile was the lowest for the filler material A. The waviness of the profile corresponds well with the deviation of the surface hardness which was measured using automated testing machine. A model for the influence of the laser beam characteristics and focus position was also established in this paper. Gauss's energy distribution and inappropriate focus position on the top of the welding wire results in an undercut formation which result in a porosity formation.

In order to get appropriate roughness in correlation with minimum waviness of the polished surface the choice of the filler material is of great importance.

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