Application of progressive technologies in the restoration of functional areas of products

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Abstract: *The paper presents the results of research focused on the restoration of functional areas of products by the application of PTA technology. Hardfacing layers intended for the renovation of the surfaces of aluminum alloy injection molds were evaluated. The base material was medium alloy steel X38CrMoV5-1 (H11). Three types of powder additives were applied to form the functional layers: two types based on iron, designated HSS 23 and HSS 30, and one type based on nickel, designated DEW Nibasit 625-P. The quality of the layers was evaluated using non-destructive and destructive tests. The surface integrity of the layers was assessed by visual and capillary tests. The microstructure of the materials and its hardness were evaluated. The tribological properties of the welds were determined by the pin-on-disc method.*

Keywords*: PLASMA WELDING, PTA TECHNOLOGY, MOLDS REPAIR, WEAR PROPERTIES*

1. Introduction

To reduce CO_2 emissions and to implement electric mobility, it is necessary to use low weight technology on the effective weights of the vehicle and its components [1]. Injection molding and die casting are very high economic key technologies for the production of a complex of thin-walled components from plastics or light metals in large quantities [2]. Molds for tools have a significant impact on the economic efficiency of process production. About 5 - 15% of production costs can be allocated to the production of components.

Injection molds used in the automotive industry are often subjected to cyclic thermomechanical loading and are therefore subject to local damage and wear [3,5]. Mold repair is an economical alternative to the production of a new mold, especially for large and complex molds [6,8]. The repair process is usually a very demanding process performed manually by a qualified worker. Traditional repair methods such as tungsten inert gas (TIG), thermal spraying, high speed oxygen fuel (HVOF) or gas arc welding (GMAW) have inherent problems that can lead to thermal damage and deformation of the finished component [5]. Matrices and molds often have complex 3-D shapes and require very precise shaped deposition that must not generate any harmful residual stresses. Highly accurate and focused heat transfer is required during the mold repair process. Therefore, in order to maintain the properties of the base material, it is necessary to minimize contamination of the cladding with the base material and vice versa [9]. In this respect, a promising technique is laser deposition technology, such as laser cladding, characterized by local heating and rapid synthesis of materials. This is because the laser beam creates a relatively narrow zone of dilution and heat (HAZ). The quality and integrity of the resulting repaired component with the new layer is affected by a number of physical phenomena, such as melt morphology, microstructure development and residual stress formation [10,13].

X38CrMoV5 (H11) is a martensitic steel with a hardness in the range of 40–56 HRC depending on the heat treatment parameters. Satisfactory hardness is usually maintained up to a temperature of 600 °C. High mechanical strength and good resistance to thermal shocks are provided by the presence of vanadium, molybdenum and chromium [14]. The excellent properties of martensitic steels for high-temperature applications results from their complex microstructure obtained by special heat treatment. Carefully controlled austenitization, hardening and tempering. The mechanical properties of these martensitic steels are firmly linked to the complex microstructure. After heat treatment, which is usually performed in order to achieve very good hardness and tensile strength with sufficient ductility (> 12 J). Decreased dislocation density and coalescence of secondary carbides help to reduce the ultimate stress during tempering and fatigue [15].

The high-temperature flow stress of martensitic steels is related both to the extremely high dislocation density. These two factors are introduced during the martensitic transformation and to the alloy carbides that precipitate at tempering [16,18]. These microstructural properties offer several ways to improve the high temperature mechanical properties by adjusting the heat treatment conditions. However, the dislocation density is fixed by hardening conditions. They strongly depend on the tool geometry, and a slight modification of the hardening conditions can lead to a catastrophic result. In addition, the mechanical properties show that the volume fraction of small precipitates (VC, Fe3Mo3C) directly affects the mechanical resistance at high temperatures, but has an adverse effect on the impact energy [19].

However, repairing molds with vanadium carbide metallurgical steel powders can potentially solve the existing problems of excessive damage / wear after repair. This is because vanadium carbide steels have an excellent combination of toughness, hardness and wear resistance [20].

2. Materials and Methods

Medium alloy tool steel marked X38CrMoV5-1 (W. Nr. 1.2343; HRC 50) was used as the base material to produce test hardfacing layers. It is characterized by high heat strength and resistance to tempering, as well as very good toughness and plastic properties at both normal and elevated temperatures. Furthermore, the steel shows very good resistance to thermal fatigue cracking and low sensitivity to sudden thermal shocks. It is well malleable when hot and well machinable in the soft annealed condition. The chemical composition of the base tool steel and its mechanical properties are presented in Table 1.

Table 1: *Chemical composition of the base material X38CrMoV5-1 (wt. %).*

C	Mn	Si	Cr	Mo	V	P	S	Fe
0.37	0.45	1.0	5.3	1.3	0.4	0.017	0.011	Bal.

As additive, the powder made of HSS 23 and HSS 30 was used, which are high-alloy high-speed steels produced using progressive methods of powder metallurgy. Both materials have high purity, low content of nonmetallic inclusions, high hardness, high compressive strength, toughness, machinability, and high resistance to abrasive wear. Both materials are used to make cold working materials, such as cutting tools for cutting harder materials. In addition, HSS 30 is also used in the production of cutting tools. The DEW Nibasit 625-P additive in powder form is used for high-quality hardfaces and hardfacing joints of materials with a high content of Mo, Ni, and Cr. Refractory and heat-resistant steels used for hardfacing are steels resistant to scale, operating at low temperatures, with heterogeneous joints, with low alloy content, and made of difficult-to-weld materials. The chemical composition of the powder filler materials used is presented in Table 2.

Table 2: *Chemical composition of the powder filler materials HSS 23, HSS 30, and DEW Nibasit 625-P (in wt %), Fe Ball.*

HSS 23									
C	**Cr**	**Mo**	**W**	**V**	**Co**	**Si**	**Mn**	**Fe**	**Ni**
1.28	4.2	5.0	6.4	3.1	-	-	-	Bal.	-
HSS 30									
C	**Cr**	**Mo**	**W**	**V**	**Co**	**Si**	**Mn**	**Fe**	**Ni**
1.28	4.2	5.0	6.4	3.1	8.5	-	-	Bal.	-
DEW Nibasit 625-P									
C	**Cr**	**Mo**	**W**	**V**	**Co**	**Si**	**Mn**	**Fe**	**Ni**
0.025	22	9	-	-	0.01	0.4	0.7	0.5	Bal.

For hardfacing, Vanadis HSS 23, Vanadis HSS 30, and DEW Nibasit 625-P powders were used on the base material X38CrMoV5-1, and a plasma hardfacing machine (Fig. 2 and Fig. 3) PPC 250 R6 (KSK s.r.o., Česká Třebová, Czech Republic). This automatic hardfacing machine is designed for the hardfacing of rotating and nonrotating parts using the PTA method. Components can be hardfaced on the forehead or around their perimeter. The machine enables pulse hardfacing with a current of 50–250 A and a frequency of 0–200 Hz.

Fig. 1 *The plasma hardfacing machine PPC 250 R6 with plasma transferred arc (PTA) technology.*

We applied additional material to the base material in two hardfacing layers using the hardfacing machine. Before proceeding with the hardfacing process itself, the surface of the base material was prepared properly. Then we preheated the base material to 250 °C and started the hardfacing process with the hardfacing parameters for individual layers shown in Table 4. Heat treatment was performed as follows: quenching from 1230 °C/2 min, followed by triple tempering at 550 °C/1 h.

Table 3: *Hardfacing parameters for the first and the second layer.*

First Layer	
Pulsating direct current:	110/45 A, with a frequency of 44.4 Hz
Trajectory:	swing step 3.9 mm (step speed 2.1 mm·s^{-1}) swing length 80 mm (speed 3.1 mm·s^{-1})
Serving:	26.4 g·min^{-1}
Second Layer	
Pulsating direct current:	140/45 A, with a frequency of 44.4 Hz
Trajectory:	swing step 5 mm (step speed 4.5 mm·s^{-1}) swing length 80 mm (speed 3.3 mm·s^{-1})
Serving:	27.8 g·min^{-1}

Weld-on layers were evaluated under dry friction adhesive wear conditions. (Adhesive wear according to EN 1071-13: Determination of wear by ball-on-disc method ISO 20808). High temperature tribometer by. CSM Instruments, model 4.4.V, the friction coefficients of the evaluated weldments were determined by the ball-on-disc method.

Test conditions: temperature 23 °C, ball - counterpart Si3N4 with a diameter of 3 mm, radius of the circle 2.5 m, linear velocity of the ball 0.1 m.s-1 on the track 500 m; normal load 20 N.

3. Results

The results of the hardface metallographic analysis are presented in Fig. 2, Fig. 3, Fig. 4. For the hardfacing layers HSS 23 and HSS 30, cracks are visible in the hardface, separating the hardface from the base material. The DEW Nibasit 625-P hardfacing layer is free of microscopically visible defects.

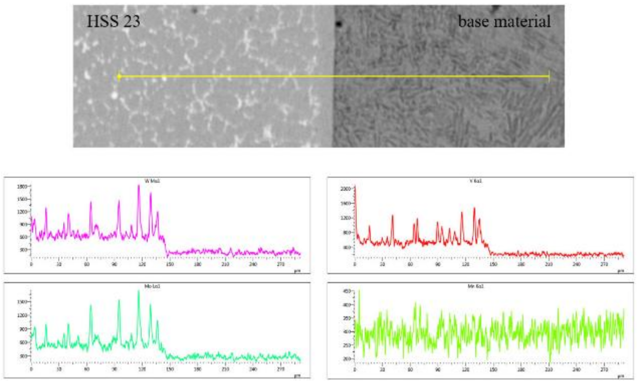

Fig. 2 *Energy-dispersive X-ray spectroscopy (EDX) line analysis of the transition region between hardface HSS 23 and base material.*

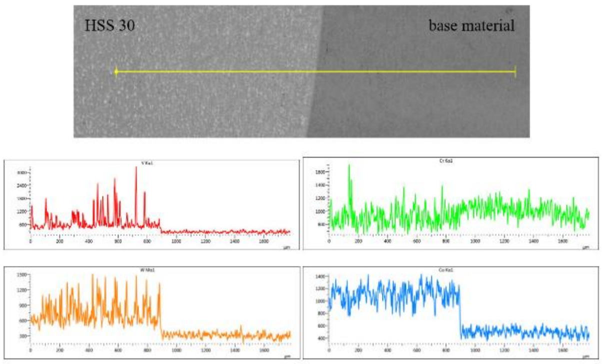

Fig. 3 *EDX line analysis of the transition region between hardface HSS 30 and base material.*

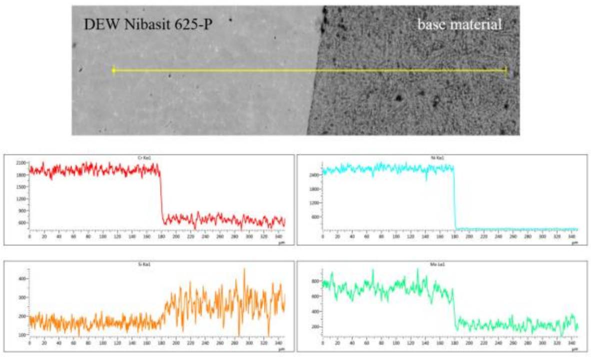

Fig. 4 *EDX line analysis of the transition region between hardface DEW Nibasit 625-P and base material.*

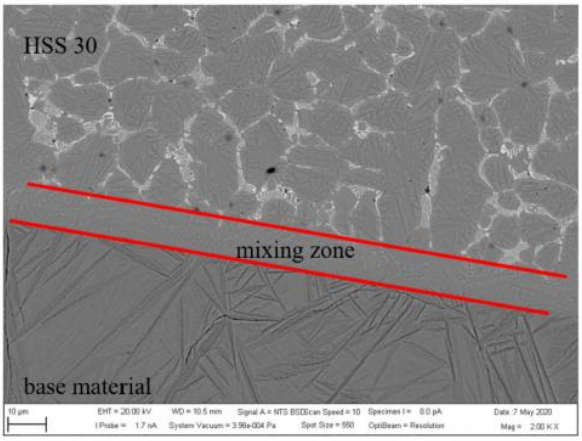

Fig. 5 *HSS 30 welding layer on the base material, visible martensitic structure with missing eutectic phase in the mixing zone.*

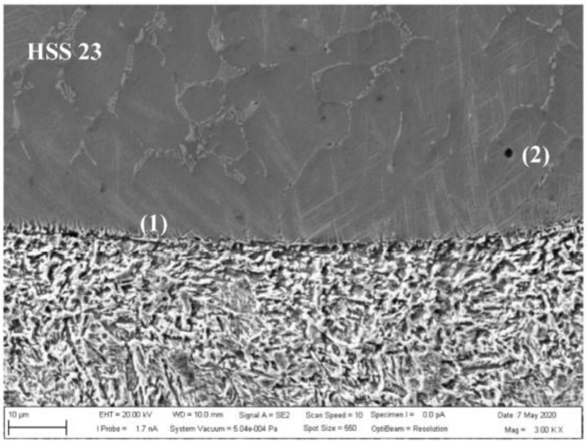

Fig. 6 *Weld-on layer HSS 23 with base material.*

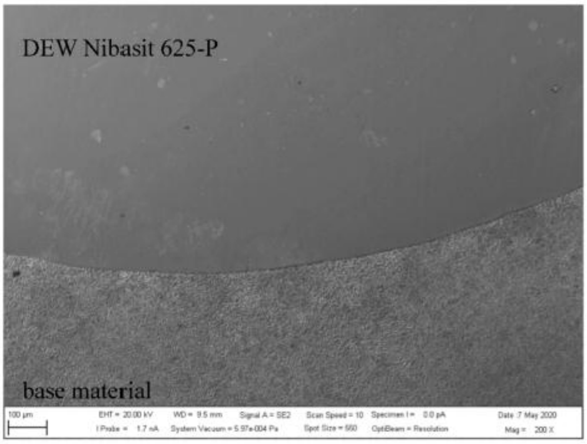

Fig. 7 *Mixing zone - DEW Nibasit 625-P weld metal and base material.*

The hardness of HSS 23 and HSS 30 hardfacing layers ranged from 650 to 850 HV 0.5. The materially different hardfacing layer DEW Nibasit 625-P reached the base material hardness level, i.e., 210–250 HV 0.5, Fig. 8.

The tribological and wear properties of the investigated materials are given in Table 4. The lowest value of the coefficient of friction at an ambient temperature of 20 ± 2 °C was achieved by DEW Nibasit 625-P. The cover hardfacing layers made using the additive HSS 23 showed the highest average friction coefficient. The measured values for respective test samples correspond to the chemical composition of the evaluated covering layer surfaces of the assessed samples and to the base material of the casting die. Carbon content and content of the carbide-forming additives Cr, Mo, W, and V have a primary impact on friction coefficients.

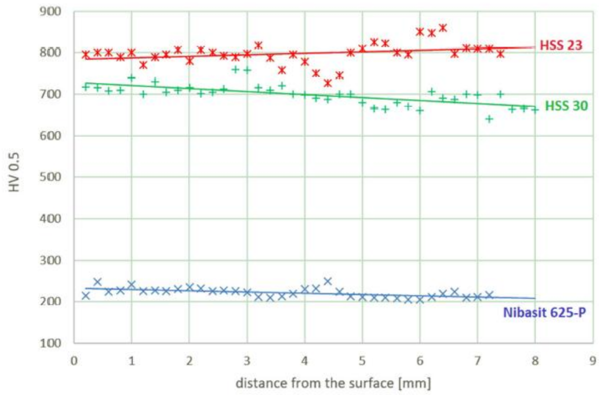

Fig. 8 *Hardness comparison of individual hardfaces.*

Table 4: *Tribological and wear properties of the investigated materials.*

Experimental Materials	Sliding Speed (mm.s^{-1})	Normal Load (N)	Distance (m)	Coefficient of Friction	Wear Rate $\times 10^{-6}$ (mm^3/m·N)
Base material	50	20	50	0.55 ± 0.09	33.96 ± 1.2
HSS 30	50	20	50	0.53 ± 0.04	7.6 ± 0.4
HSS 23	50	20	50	0.56 ± 0.12	14.49 ± 0.6
DEW Nibasit 625-P	50	20	50	0.35 ± 0.09	21.39 ± 0.8

4. Conclusions

The paper presents the results of research on the quality of functional layers made from the powder filler materials HSS 23, HSS 30, and DEW Nibasit 625-P by plasma transferred arc (PTA) hardfacing technology. Layers were made using the plasma hardfacing machine PPC 250 R6 on X38CrMoV5-1 base material. This type of medium alloy steel is used in the production of die-casting molds for aluminum parts for automotive production. The hardfacing was made in two layers. The quality of the hardfacing layers was evaluated using nondestructive and destructive tests. Surface integrity as well as the occurrence of surface defects were evaluated using visual testing (VT) according to the standard EN ISO 17637 and penetration testing (PT) according to the standard EN ISO 23277. Surface defects were not detected on the hardfacing layers. As part of the destructive testing, metallographic sections were made for observation by light microscopy and electron microscopy, as well as for the evaluation of the chemical composition of the surface spectra of selected parts of the samples. The occurrence of inner defects in the hardfacing layers was recorded on the cross sections. The defects were classified as rare pores. EN 12517-1 classifies this type of defect as permissible in this quantity. After metallographic analysis, the hardness in the lines passing through the hardface metal into the base material was evaluated on the sections. The maximum values of the hardness in the interval 720 HV 0.5–850 HV 0.5 were measured in the covering layers of the HSS 23 hardface metal, which is in accordance with their chemical composition and the observed martensitic structure.

The lowest hardness values were measured for DEW Nibasit 625-P samples (210 HV 0.5–250 HV 0.5). As part of the experiments, the tribological properties of the newly formed hardfacing layers were analyzed. The lowest friction coefficient was shown by surfaces with the DEW Nibasit 625-P layer and the highest values of the friction coefficient were measured on surfaces with the HSS 23 hardfacing layer. Based on the experiments performed, it can be stated that the selected energy beam (PTA) technology for the renovation of the functional surfaces of casting molds is suitable. As an additional material for the restoration of exposed mold areas, all investigated additional materials can be used, but due to its low friction coefficient, it is possible to recommend the nickel-based additive DEW Nibasit 625-P.

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5. References

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