Selection of the optimal hard-facing technology for reparation of the machine parts made of hot work tool steel

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Abstract

The selection procedure for welding/hard-facing of thermo-resistant steels, with emphasis on the reparatory hard-facing of the forging dies, is presented in the paper. The forging dies for hot forging are being exploited in the extreme conditions of the compressive-impact loading and high temperatures, which locally can reach even 600 ºC. This is the reason why, after certain number of cycles, damages of the forging dies can arise, regardless of the cause that can be either wear, thermal fatigue or appearance of surface cracks. Reparatory hard-facing of these steels is a very complex procedure, which consists of careful selection of the welding process type, the filler metal, welding parameters, as well as adequately prescribed heat treatment regime. Besides that, in the paper are presented results of hardness measurements in various zones of the hard-faced samples, as well as the metallographic investigations performed on the optical and scanning microscopes. For the prescribed technology one can say that it is adequate if the brittle phases or the zones of high hardness do not appear in the material after the welding, since they could cause stress concentration and places of eventual fracture.

Keywords: *hot-work tool steel, forging tools, welding, microstructure, hardness.*

1. Introduction

Prescribing the optimal technology for reparatory welding of parts made of hot-working steels belongs into a group of the most complicated challenges for the welding engineers. The tool steels for hot-working have the broad application in industry, especially for manufacturing the parts in the forging industry, like the forging dies, matrices, inserts, etc. Those parts are during the exploitation exposed both to high compressive and impact loads and intensive wear [1-4], which in time cause their damages. The most frequent cause of the tool failure are wear (in about 50 % of cases) and thermo-mechanical fatigue (in about 30 % of cases) [5]. Once the tool is damaged, there are two possibilities: to buy the new one or to repair the damaged one. Purchasing/making the new tool is the simplest and easiest way out, but it carries the higher costs and/or time for its manufacturing. On the other hand, reparation of machine parts, if properly executed, has been shown as a very reliable alternative in numerous cases [6-7], with simultaneous realization of significant savings both money and timewise [8].

The selected reparation technology, presented in this paper, refers to hard-facing of damaged surfaces of the forging dies, executed on two examples of thermo-resistant steels. It was first tested on model plates (samples) welding and then applied for reparation of the actual tools and it was proven as very reliable.

2. Base materials, filler materials and welding technology

Tools that were repaired by the proposed technology are made of the two thermos-resistant steels, namely the low-alloyed steel 55NiCrMoV6 and the high-alloyed steel X37CrMoV5-1 (by DIN 17350). Chemical composition and mechanical properties of those steels are presented in tables 1 and 2, respectively [7].

Table 1 Chemical composition of used steels

Steel/composition (%)	55NiCrMoV7	X37CrMoV5-1
C	0.55	0.40
Si	0.3	1.0
Mn	0.7	0.4
P	0.035	0.025
S	0.035	0.025
Cr	1.1	5.0
Ni	1.7	-

Mo	0.5	1.3
V	0.12	0.4

Table 2 Mechanical properties of applied steels

Steel/properties		56NiCrMoV7	X38CrMoV51
Soft annealing	t, °C	670-700	800-830
	HV_{max}	250	250
	R_m, MPa	850	850
Tempering	t, °C	400-700	550-700
	HV_{max}	50-30	50-30
	R_m, MPa	1700-1100	1700-1100

Taking into account that those steels are conditionally weldable it is necessary to apply the preheating, the additional heating and post-welding heat treatment. The preheating temperature was calculated Seferian's formula [9] and it was 300 ± 10 °C. After adopting the preheating temperature, the welding procedure and parameters were adopted, as well. The MMAW procedure with the rutile electrode was selected, while the welding parameters were determined based on the recommendations and previous experience of researchers [7, 8], Table 3.

Table 3 Hard facing parameters for the MMAW procedure

MMAW properties	Electrode mark	
	Steel plant "Jesenice"/DIN 8555	
	UTOP 38/ E3-UM-40T	UTOP 55/ E6-UM-60T
Core diameter, *mm*	3.25	5.00
Welding current, *A*	115	190
Voltage, *V*	26	29
Welding speed, *mm/s*	≈ 2.8	≈ 2.5
Input heat, *J/mm*	854.3	1763.2

Two high-alloyed rutile electrodes UTOP 38 and UTOP 55 (Table 4) were used as the filler metals (FM). Such FMs are used exactly for the type of base metals as used in this research, namely for hard-facing of tools made of hot-work tool steels. After the hard-facing executed with these electrodes, the layers should possess high hardness, impact toughness and wear resistance. Their hardness is stable up to temperature of 600 °C (similar to resistance of this tool steels [7]). Prior to hard-facing the electrodes were dried in furnace at 400 °C for 2 hours. Drying of electrodes is needed since it aids in the diffused hydrogen decrease and minimizes the possibility of appearance of the cold cracks.

The layers were deposited in two or three passes due to necessity to reduce the degree of dilution - to obtain the declared weld properties prescribed by the electrodes manufacturers. The hard-faced layer deposition order is shown in Figure 1. Prior to depositing the next layer, the slag was removed from the previous one by the steel brush.

The width of the passes deposited by the electrode of diameter ∅ 3.25 mm was b ≈ 10-12 *mm*, the height was about h ≈ 1.5 mm. For the electrode with diameter ∅ 5.00 mm the deposited pass width was b ≈ 10-12 mm and the height h ≈ 2.1 mm. The samples for estimates of microstructure and hardness measurement were the metallographic ground slits (Fig. 1.d).

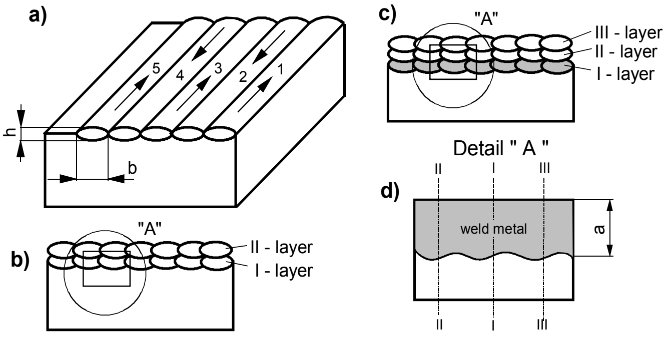


Figure 1 Order of layers deposition: a – layer 1, b – layer 2, c – layer 3, d – metallographic ground slit [7]

3. Experimental investigations

Experimental investigations of welded samples included testing of hardness and microstructure of all the zones of the hard-faced layers. It is considered that with such investigations on can, in reliable manner, determine the quality of the deposited layers and properties of the joint, for future use of real pieces in exploitation. Besides that, some authors were determining, by special tests the shear characteristics in the hard facing zones in order to determine the most critical zone of the weldment [10]. Hard facing was done on the plates (models) 15 *mm* thick, from which were later cut out the samples for investigating the microstructure and metallography. It goes without saying that the real forging tools are of the greater thicknesses, however if the good results are obtained on model weldments, the technology can be successfully "transferred" to the real part, if the instructions are followed carefully to the letter. The following four combinations of samples were prepared for tests:

1. X37CrMoV51 + UTOP 38,
2. X37CrMoV51 + UTOP 55,
3. 55NiCrMoV7 + UTOP 38,
4. 55NiCrMoV7 + UTOP 55.

The metallographic samples were prepared by grinding from hard-faced plates. Samples were cooled in fireclay powder, and prior to metallographic tests, they were heated together with the furnace to the tempering temperature T_a = 400 °C and then slowly cooled to reduce the residual stresses level and to stabilize weld metal. Etching was done with the 4 % vilele solution.

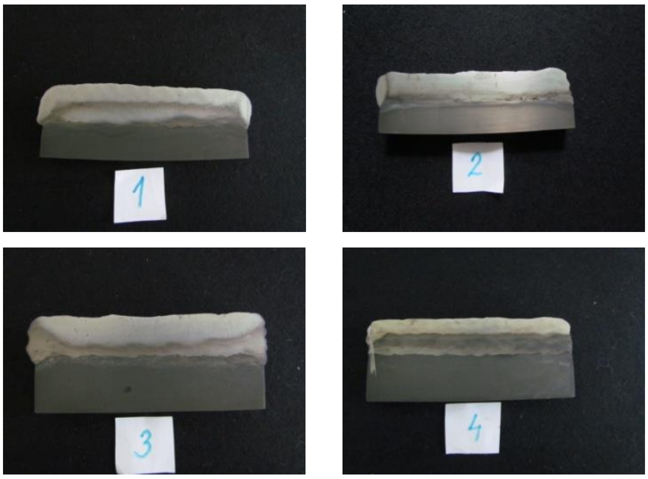
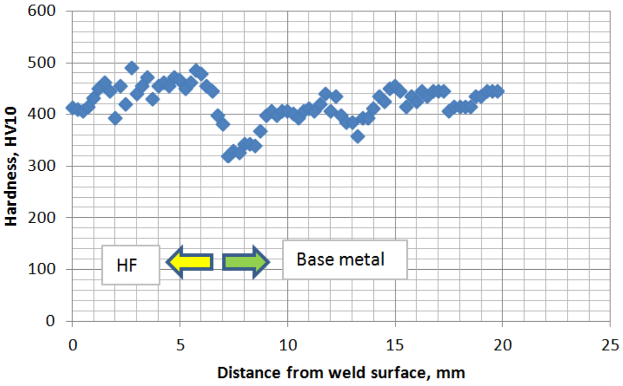


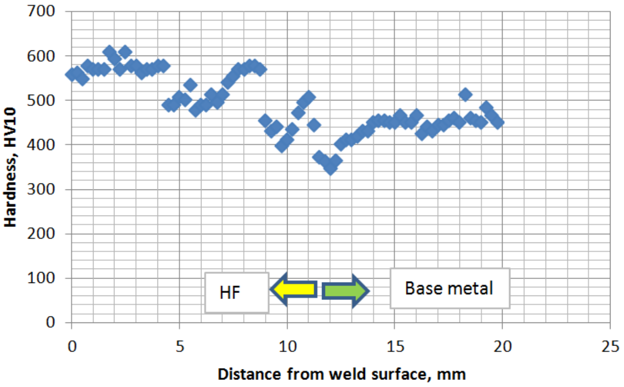
Figure 2 Macrographs of the samples

Hardness was measured on the presented samples by the Vickers HV10 method according to appropriate standard [12], in three perpendicular directions (see Fig. 1d). Obtained results are presented as diagrams of the hardness distribution in Fig. 3 for all the four samples.

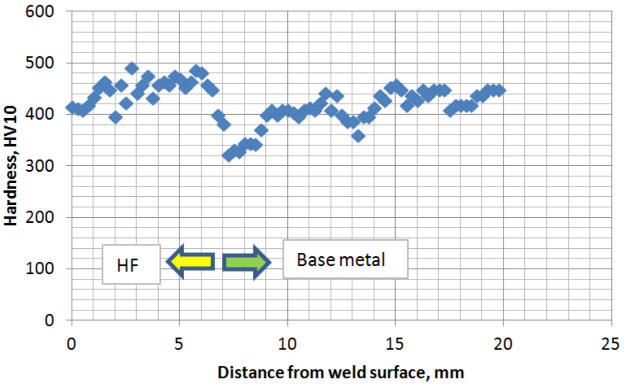
Analysis of obtained results shows that hardness is relatively constant in individual hard faced layer's zones and in the base metal. Generally speaking, it was intended that the surface of samples (tools) should be somewhat harder, so the wear resistance should be as high as possible. For samples hard faced by the UTOP 38 electrode, where number 38 denotes expected minimal hardness of the hard faced layer in HRC (equivalent to 370 to 375 HV), it is evident that the hardness is higher, about 450 HV, samples 1 and 3, Fig. 3. That increase of hardness can be explained by absence of relaxation at higher temperatures, however, it is considered that this will not lead to creation of the critical spots for appearance of cracks, what should be confirmed by additional investigations. In addition, certain drop of hardness in the heat affected zone of the base metal can be noticed, which could be explained by the relaxation effect, which the deposition of the first layer has on the base metal (substrate). The critical recrystallization temperature is exceeded by the heat entered in that zone, thus the softening and creation of the more stable phases occur. On the other hand, that zone could become critical with respect to the structural integrity in the sense that a crack could appear and propagate, what will be the subject of certain further investigations.



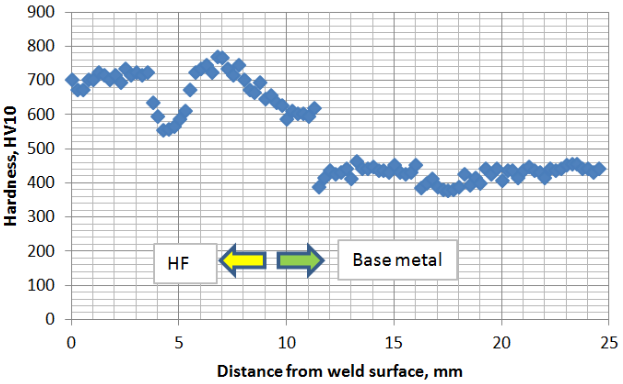
a) U1



b) U2

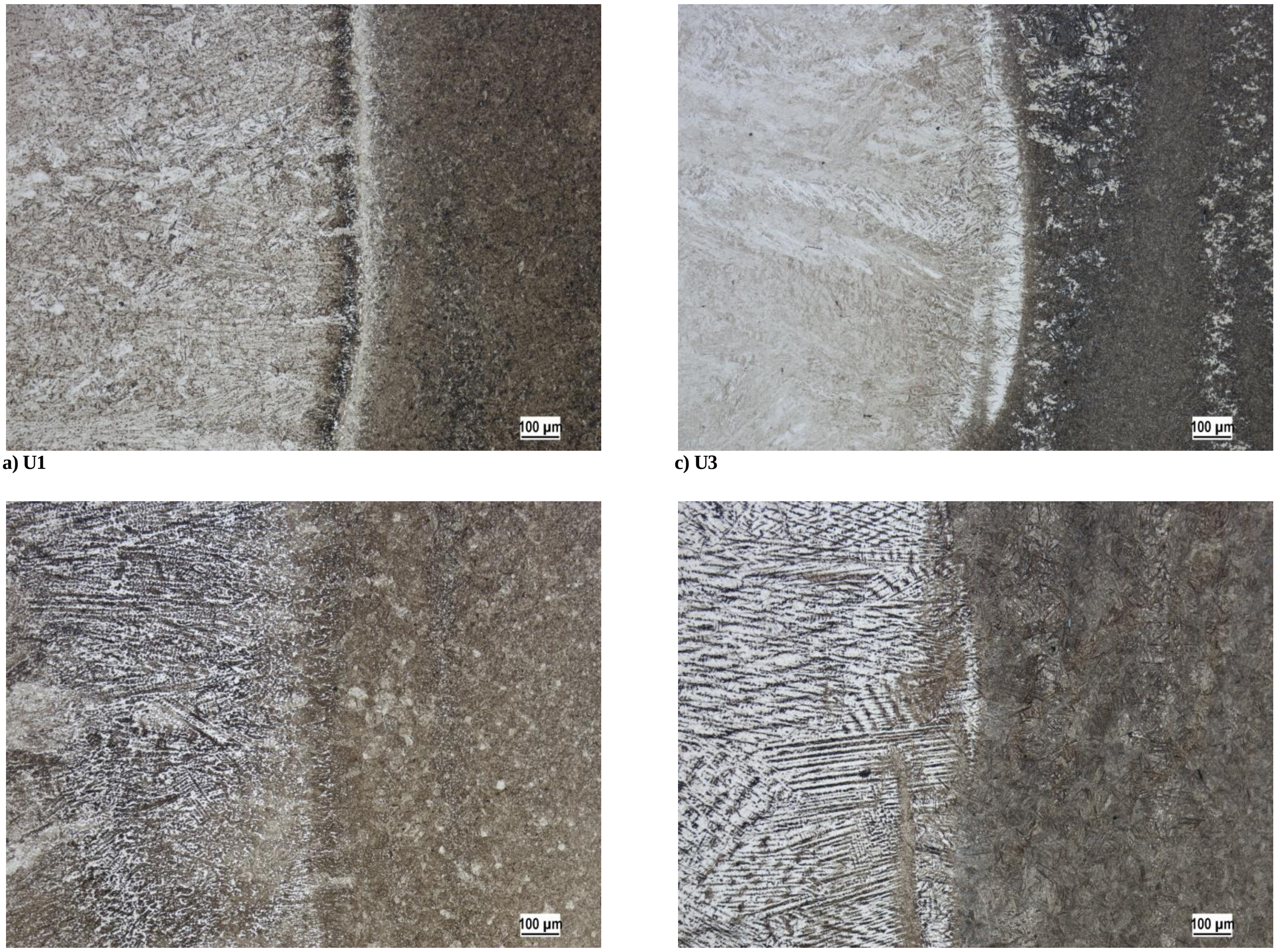


c) U3



d) U4

Figure 3 Hardness measurement results



a) U1

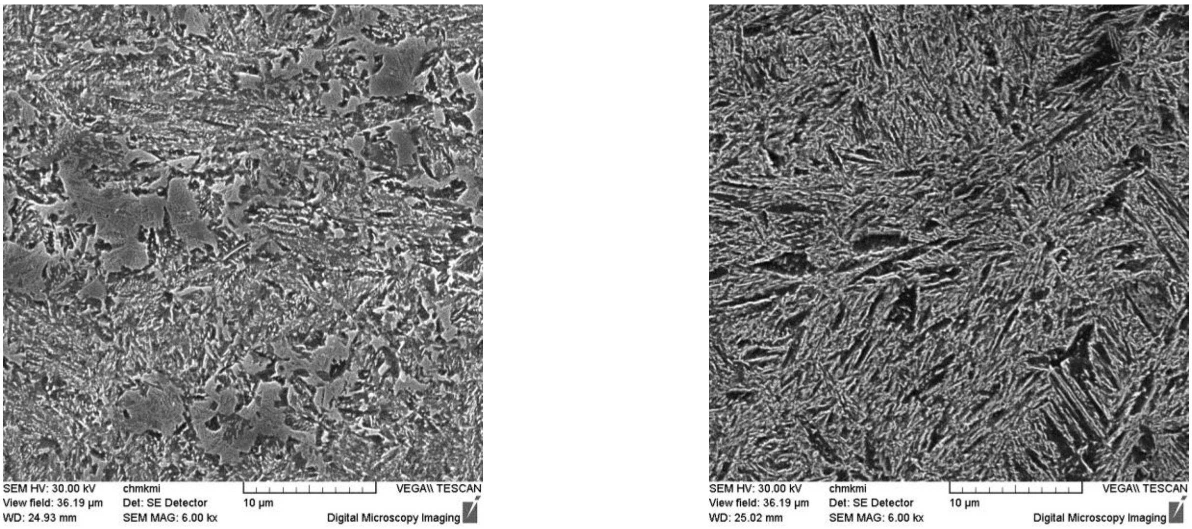
c) U3

b) U2

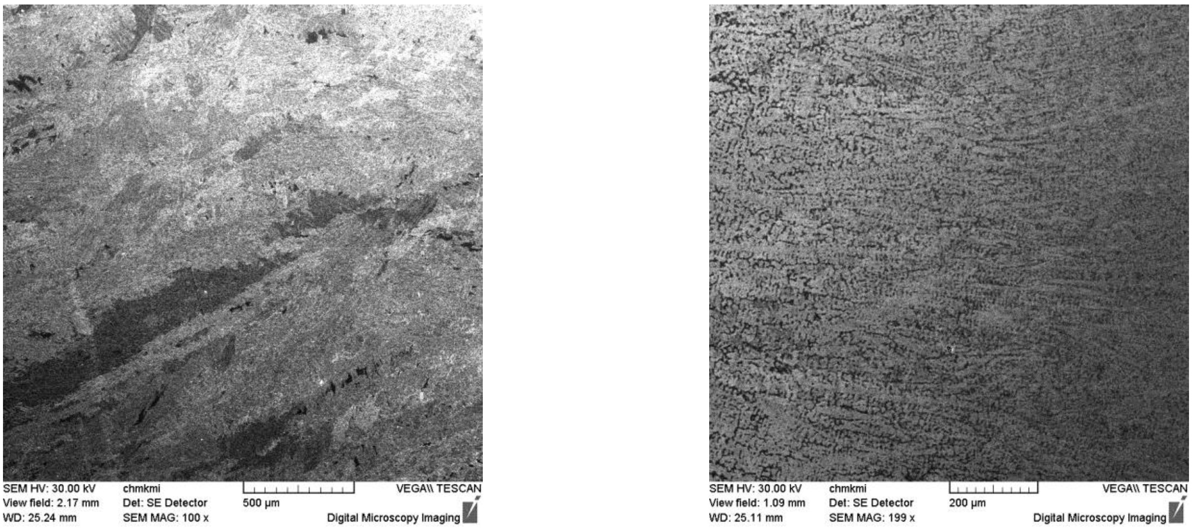
d) U4

Figure 4 Metallographic recording from the optical microscope

After the hardness measurements, the microstructure was red-off of the same samples, by the optical and scanning electron microscopes. In all the figures are presented the zones between the hard faced layer and the base metal. The recordings show that joining of the hard faced layer to the substrate was good, that there are no visible flaws or cracks and that the transition along the joining line is in a way gradual (Fig. 4b). The biggest mixing of the base and filler metals occurs in the first hard faced layer, so one can expect creation of various compounds and structures. In addition, the HAZ is created in the base metal. Form analysis of recordings one can say that the fine-grained structure of the HAZ is noticed, with carbide inclusions, while on the hard faced layer side the dendritic structures can be clearly noticed. That was expected, taking into account that the structures obtained by welding could be considered as the casting ones, since they are created by forming of the metal bath and its solidification. The joining line is homogeneous on all the samples, without visible zones of extracted hard carbides, impurities etc. For hard faced parts of the forging dies type, the good joining between the hard faced layer and the substrate is of the key importance, since due to high dynamic loads during



BM - X38CrMoV51 BM - 55NiCrMoV7



FM - UTOP 38 FM - UTOP 55

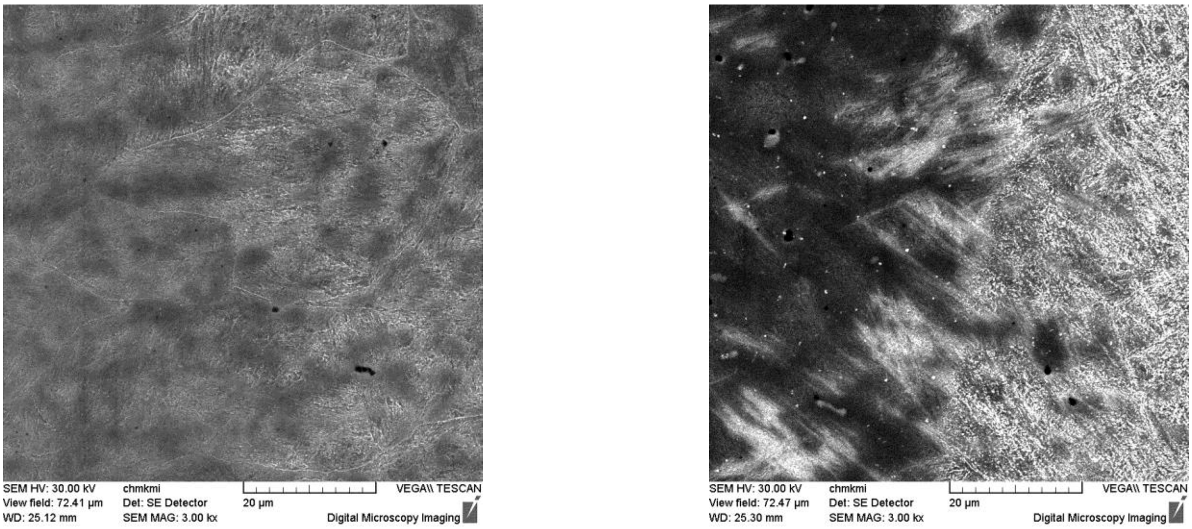


Figure 5 SEM micrographs of characteristic zones

the forging cracks or delamination can occur in those zones. In some future works, authors of this research will present results of the toughness testing in the mentioned zones, as well as the tendency of those zones for appearance and propagation of cracks; all these being done for the purpose of verification of the prescribed technology and evaluation of the hard faced structures integrity.

Analysis of the SEM figures has confirmed that the microstructure of the base metal was needle-like structure, tempered martensite structure with the share of bainite and small carbides. The small carbides can be noticed and they are evenly distributed within the substrate. The filler metal micro structure is primarily inhomogeneous dendritic austenite structure with carbides in the metal substrate for UTOP 38 and inhomogeneous dendritic austenite structure for UTOP 55. What concerns the heat affected zone, its microstructure is similar to that of the base metal, namely needle-like martensite with share of bainite and small carbides. It can be considered that the structure is favorable, since during the hard facing it was exposed repeatedly to heat several times (when each hard faced layer was deposited), thus the heat treatment effect of the HAZ was achieved after the first hard faced layer was deposited.

4. Conclusion

Since this hard facing technology was to be applied to forging dies reparation, it was necessary to perform the detailed investigation in order to verify that the selected procedure is adequate. Besides the requirements regarding good mechanical properties of the hard-faced layer, its wear resistance and thermal fatigue, other requirements include the optimal toughness and favorable micro structure, as well as the possibility for adequate machining. Those requirements are quite contradictory, thus they could be met only by proper selection of the reparation procedure, the adequate filer metal, heat treatment (preheating, additional heating and the post hard-facing treatment), all those leading to defining the optimal hard-facing technology. That also assumed that final machining of the repaired tool should be as cheap as possible.

The prescribed technology was first teste on the model plates hard facing, which were subjected to hardness measurements and analysis of microstructure. They have revealed that the appearance of unfavorable purely martensitic structure was avoided; the microstructure was estimated as the tempered martensite and interphase tempering structures. The two important achievements were that the hardness of the hard-faced layer was higher than that of the base metal (about 500 HV for the UTOP 38 electrode and about 700 HV for the UTOP 55 electrode) and that the hardness in the heat affected zone (the most critical zone of the hard-faced layer) was reduced by tempering, which prior to heat treatment was equal to hardness of the base metal.

The whole process presented here, namely the selection and definition, i.e. establishing of the optimal reparation procedure of hot-work tool steel machine parts, is very complex and the conclusion is that it could be successfully executed only in very specialized plants. The procedure requires adequate equipment and expert staff to define and execute it and it could not be done in an ad hoc improvised workshops and conditions.

The defined technology was applied, with satisfactory results, for reparation of forging dies in the real conditions.

Acknowledgement

This research was partially financially supported by the Ministry of Education, Science and Technological Development of Republic of Serbia through grant TR35024 and by European regional development fund and Slovak state budget by the project "Research Centre of the University of Žilina". The authors are also thankful to the Laboratory for Materials Engineering, University of Žilina, Slovakia for providing resources for the part of experimental investigations.

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