ANALYSIS OF TECHNOLOGY IN VARIOUS INDUSTRIES

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Chapter 12

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APPLICATION OF HARD-FACING IN REPARATION OF DAMAGED FORGING DIES

Abstract: In this paper is considered reparatory hard-facing of forging dies used for obtaining forged pieces in automobile industry. Prior to reparatory hard-facing of the real forging dies, the necessary experimental hard-facings on models were performed, in order to establish the optimal reparation technology. All the tests were done on steels that are used for production of the real forging dies. In this way, the tests' output results are related to selected procedure and technology. The forging dies are in exploitation conditions subjected to heating up to very high temperatures, variable impact-compressive and shear loads. Steels, aimed for manufacturing of those tools, should withstand extreme impact loads, while maintaining mechanical properties at high temperatures, they should be resistant to wear and thermal fatigue. This is why the alloyed steels are being used for this purpose, though they have worsened weldability, since alloying increases proneness to hardening. Thus, any reparatory hard-facing of the damaged parts requires the specially prescribed technology adjusted to the particular forging die. Besides the optimal hard-facing technology one also needs to define the adequate heat treatments, the preceding, the current and the additional one. The established optimal technology, after the verification, was applied to real forging dies, whose working life was further monitored in exploitation conditions.

Key words: Hard-facing, forging dies, automobile industry, hardness, microstructure

12.1. Introduction

In this paper is considered the problematics of reparatory hard-facing of the forging dies, which are in exploitation conditions subjected to

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heating up to extremely high temperatures. Steels aimed for production of such tools ought to sustain high impact loads, to maintain the good mechanical properties, to be resistant to wear and thermal fatigue. Due to all these reasons, the alloyed steels are used, which possess the worsen weldability, since alloying increases proneness of those steels to self-hardening. This is why any reparation by the hard-facing procedure requires specially prescribed technology, adjusted for the particular working piece. Besides the optimal hard-facing technology, it is also necessary to define the corresponding heat treatment – prior, current and the final one. Resulting welds obtained after the hard-facing and the final heat treatment were tested by the destructive methods in order to establish the hardness distribution in the cross section, microstructure of the hard-faced layer, heat affected zone and the base metal.

12.2. Basic causes of the forging dies damages

The forging dies are in exploitation exposed to numerous cyclic loadings, thus after certain time the engraving sustain damages, so the tool has to be either replaced or repaired. Statistical investigations of the damaged tools have shown that the main causes for working pieces being withdrawn from exploitation could be the following: changes of dimensions and shape of engraving due to friction and wear, cracks all over the tool due to thermal fatigue and micro cracks caused by the stress concentrators (ABACHI S. et al. 2010, CHOI C. et a. 2012, EBARA R. and Kubota K. 2008, LAVTAR L. et al. 2005, SUMMERVILE E. et al. 1995).

Wear caused by action of the impact-compressive loads is characterized by appearance of deformation and friction, as well as cracks at certain depth below the working surfaces. The fatigue cracks can appear as well, also at certain depth below the surface.

Wear that appeared at elevated temperatures is the consequence of oxidation, creation of scaling at high temperatures, degradation of mechanical properties at the surface layers, what together with action of thermal fatigue leads to increase of self-stresses and eventually to surface destruction. Rapid wear of tool surfaces that operate at elevated temperatures is the most frequently in the form of characteristic cracks and even husking caused by thermal fatigue. Factors that lead to thermal fatigue are: thermo-physical material properties (heat conductivity, specific heat and the thermal expansion coefficient), the piece geometry (size, shape, surface type) and material properties (mechanical, chemical, structural).

Besides the thermal stresses caused by the temperature gradient, structural stresses appear, as well, which depend on steel's chemical composition, kinetical transformation of austenite, namely the cooling speed. Initial cracks can appear on the material's surface due to influence of cyclical changes of the thermal stresses.

Through analysis of changes of the tool steels' physical properties changes it was established that the material destruction occurs in three phases: first the strength is dropping, then the dislocation pileup occurs and finally the crack appears. In the first phase the increased temperature causes tempering, what causes drop of the steel's strength and hardness, as well as increase of the carbides shear and their coagulation. In the second phase phenomenon of plastic deformation arises, what causes material hardening. In the third phase, the decisive influence has the carbides coagulation and pileup of crystal lattice defects, what creates the initial cracks at points of already existing pores and micro cracks. If the possibility exists for action of dislocation mechanisms for creating the fatigue cracks, then in numerous cases initiators of such cracks are surface notches, material flaws of technological origin (rolled-in oxide, micro cracks at interphase boundaries between hard phases and plastic substrate, nonmetallic inclusions, brittle phases).

Investigations of forging dies implied that the lowest resistance to thermal fatigue, in temperature range 200 – 760 °C, possess materials with higher content of tungsten: replacing of this alloying element with molybdenum improves steel resistance to cracks. Chromium has the same effect, though the degree of resistance improvement depends on tungsten content. Alloying with nickel is usually not useful, with regards to resistance to thermal fatigue. This resistance is also decreasing with increase of carbon ($C > 0.3$ %). Manganese mainly improves resistance to thermal fatigue (EBARA R. and KUBOTA K. 2008, ITO Y. and BESSYO K. 1972, JOVANOVIĆ M. et al. 2011).

In the considered case we analyzed forging dies for manufacturing parts in the automobile and truck industry. During the extensive monitoring of those tools in exploitation conditions, it was noticed that failures (tool withdrawal from exploitation) could be caused by the following reasons:

- increase of dimensions of the forged pieces due to die wearing,
- deformation of the thin-walled portions of the die (ribs, thorns),
- appearance of the barely visible cracks on some portions of the die and
- local fractures.

The numerated damages can be repaired mainly by application of hard-facing by the MAG procedure, followed by grinding, rarely by milling – depending on the filler metal applied. In order to define the optimal hard-facing technology for forging dies we conducted numerous tests on models whose sizes were determined by application of the similarity theory, namely the dimensionless analysis.

Change of hardness and structure in layers of the applied hard-faced welds, namely in the heat affected zone (HAZ) below the weld, was adopted as the quality criterion of the executed hard-facings.

Hard-facing of tools that operate at elevated temperatures should repair them by recovering losses that resulted due to friction or husking. Manufacturing of new tools made of construction carbon steels, with the working surface hard-faced by the tool steel, constitutes an exception. In the case for tools that operate at lower temperatures, the reparatory hard-facing was also frequently applied, as well as manufacturing of the alternative tools with hard-faced blades.

12.3. Materials for tools manufacturing and their properties

Steels for work at elevated temperatures are operating at temperatures higher than 300 °C. The considered parts are small, eventually medium and large dies for hot forming, pressing tools, tools for extrusion of nonferrous metals, tools for hot trimming, dies for casting under pressure of aluminum and its alloys, zinc and magnesium.

For manufacturing of forging dies, most frequently applied steels are: 55NiCrMoV6 (for dies, pressing molds, dies holders), 56NiCrMoV7 (for dies and their inserts of extremely loaded pressing tools, press dies and extruders), X40CrMoV51 (for dies and their inserts for forging machines, casting molds, presses' thorns) and X32CrMoV33 (for dies' inserts for tools for screws manufacturing, for forging machines).

In the considered case all the experiments were conducted on forging dies made of two steels: Č5742 (DIN 17350 - 56NiCrMoV7) and Č4751 (DIN 17350 - X38CrMoV51). Chemical composition and mechanical properties of those steels are given in tables 12.1 and 12.2 (Catalogues and Prospects 2013, LAZIĆ V. 2001).

Table 12.1. Chemical composition of applied steels

No.	Mark (JUS)	Chemical composition, %								
		C	Si	Mn	P	S	Cr	Ni	Mo	V
1.	Č5742	0.55	0.3	0.7	0.035	0.035	1.1	1.7	0.5	0.12
2.	Č4751	0.40	1.0	0.4	0.025	0.025	5.0	-	1.3	0.4

Table 4.2. Mechanical properties and microstructure of applied steels

No.	Mark (JUS)	Soft annealing			Tempering		
		t, °C	HV_{max}	R_m, MPa	t, °C	HRC	R_m, MPa
1.	Č5742	670-700	250	850	400-700	50-30	1700-1100
2.	Č4751	800-830	250	850	550-700	50-30	1700-1100

Since the operating conditions of forging dies are such that they work in thermally tempered conditions (quenching and high tempering), all the samples were treated in that way, so they could be as close as possible to real operating conditions. The measured hardness on selected samples (post heat treatment) was 40-42 HRS for Č5742 and 41-49 HRC for Č5741. The soft annealing was not performed (though HV > 350) since mechanical processing was mainly done by grinding. Because the hard-faced samples of thicker cross sections *(*s = 40-45 *mm*) were hard-faced as well, made of steels prone to self-hardening, it was necessary to preheat the samples; the preheating temperature was calculated according to Seferian's formula (LAZIĆ V. 2001), and it was $T_p \approx 300°C$.

12.4. Welding procedure and parameters selection

Technological parameters of hard-facing were determined according to (EBARA R. and Kubota K. 2008, LAVTAR L. et al. 2005), what implied layers deposition in two and three passes, in order to reduce the degree of mixing (the so-called dilution), i.e., to obtain the declared weld properties prescribed by the electrodes manufacturers. The hard-facing speed of each pass was measured, and prior to depositing the next layer the preheating (namely the interpass0 temperature was checked as well. Measuring device was Tastotherm D120 (with NiCr-NiAl thermocouple and measurements range of -50 to 1200 °C).

As the filler metal we used the high alloyed rutile electrodes UTOP 38 (DIN 8555 E3-UM-40T ∅3.25 *mm*) and UTOP 55 (DIN 8555 E6-UM-60T ∅5.00 *mm*). Those filler metals are aimed for hard-facing of tools, for cold and hot forming of steels and other metals, like steel molds, dies and pressing thorns. Hard-faced layers possess high toughness, resistance to wear and impacts. Their hardness is stable up to temperature of 600 °C (JOVANOVIĆ M. et al. 2011).

Rutile electrodes were, prior to hard-facing, dried according to the following regime: heating together with the furnace up to 350-400 °C, maintaining for 2 h at the drying temperature and cooling in the furnace for 1 h, when the temperature did not fall below 150 °C. Electrodes, thus heated, were used for hard-facing of the preheated samples, what resulted in decreasing of the difunded hydrogen and eliminating possibility of cold cracks appearance.

In Tables 12.3 and 12.4 are presented hard-facing parameters and the filler metal properties, respectively; the hard-facing current is about 10 % lower than for welding.

The hard-faced layer deposition order is shown in Figure 12.1.a. prior to depositing the next layer, the slag was removed from previous one by the steel brush. The same scheme was applied for depositing of other layers (Figures12.1.b and 12.1.c). The with of the pass deposited by the electrode with ∅ 3.25 *mm* was b ≈ 10-12 *mm, the height was* h ≈ 1.5 *mm*; and by the electrode with ∅ 5.00 *mm* parameters were b ≈ 10-12 *mm* and h ≈ 2.1 *mm*. The sample for estimates of microstructure and hardness measurement was the metallographic ground piece, Figure 12.1.d (LAZIĆ V. 2001, LAZIĆ V. et al. 2011).

Table 12.3. Hard facing parameters for the MAG procedure

No.	Electrode mark		Core diameter, *mm*	Welding current, *A*	Voltage, *V*	Welding speed, *cm/s*	Driving energy, *J/cm*
	Železarna Jesenice	DIN 8555					
1.	UTOP 38	E3-UM-40T	3.25	115	26	≈ 0.28	8543
2.	UTOP 55	E6-UM-60T	5.00	190	29	≈ 0.25	17632

Table 4.4. Filler metal properties

No.	Electrode mark		Chemical composition, %					Current type	Hardness, HRC
	Železarna Jesenice	DIN 8555	C	Cr	Mo	V	W		
1.	UTOP 38	E3-UM-40T	0.13	5.0	4.0	0.20	+	= (+)	36-42
2.	UTOP 55	E6-UM-60T	0.50	5.0	5.0	0.60	+	= (+)	55-60

12.5. Estimate of weldability based on CCT diagrams

It is of decisive importance to relate the useful input-output properties of the hard-faced layer with applied technology, as well as to establish the newly

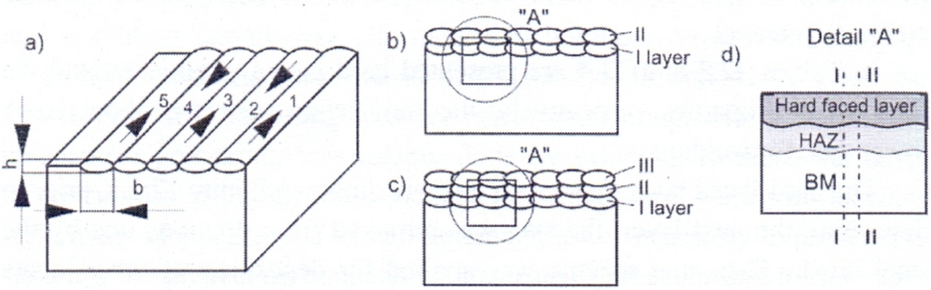

Fig. 12.1. Layers deposition order: a – 1, b – 2, c – 3, d – metallographic ground sample.

created structure and hardness in the heat affected zone (HAZ) after hard-facing and cooling. In that sense, it is useful to know the corresponding continuous cooling transformation (CCT) diagram. Though those diagrams are drawn based on numerous test of steel from the same batch, they can also be applied for estimate of weldability of steels with similar chemical composition. To be able to apply those diagrams, it is necessary to know the cooling time within temperature range 800 to 500 °C ($t_{8/5}$) for points beneath the hard-faced layer. This time can be calculated by application of corresponding analytical expressions (JOVANOVIĆ M. et al. 2011, Lavtar L. et al. 2005, LAZIĆ V. et al. 2010, LAZIĆ V. et al. 2013), or experimentally – by recording the temperature cycle curve at certain point beneath the hard-faced layer. By entering the calculated cooling time $t_{8/5}$ into the corresponding CCT diagram, for steel Č5742, the newly created structure can be estimated and the hardness could be red off the diagram, Figure 12.2.

This steel is very self-hardening (C > 0.35) and it is very sensitive to heat input. Besides the high carbon content, this steel also has high content of alloying elements (Cr, Mo, V) which cause separation of perlite and bainite transformation, extend the area of austenite stability and lower (move downwards) the initial temperature of martensitic transformation. All these cause the worsen weldability.

Chemical composition, %	C	Si	Mn	P	S	Cr	Mo	Ni	V	W
	0.52	0.29	0.70	0.01	0.01	1.09	0.43	1.72	0.74	-

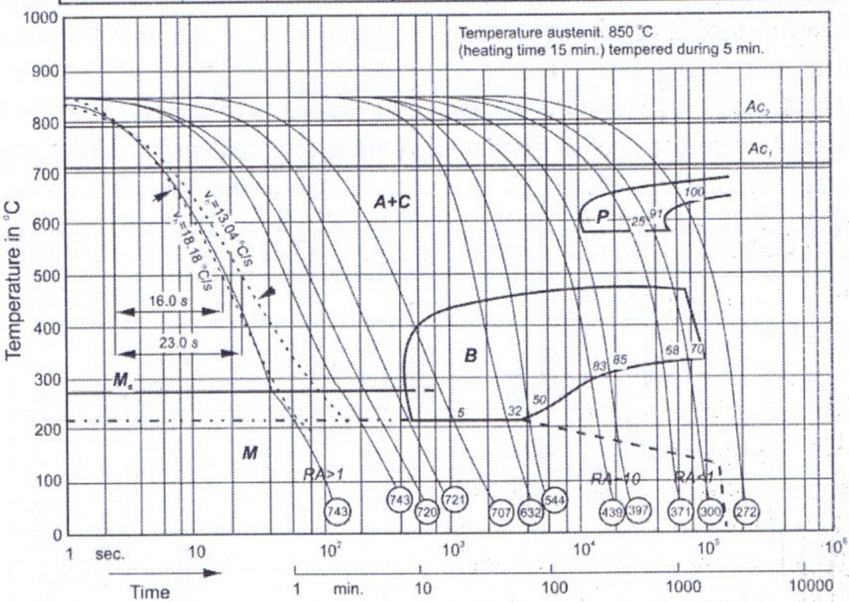

Fig. 12.2. CCT diagram for Č5742 steel.

12.5.1. Determination of temperature cycles in hard-facing of Č5742 steel

In order to determine the cooling speed as precisely as possible, i.e., the cooling time $t_{8/5}$, in hard-facing of steel for forging dies, the special plates-models were prepared according to Figure 3. Plates were tempered and the corresponding holes for measuring the temperature cycles were ground on them.

According to official methods for estimates of weldability (JOVANOVIĆ M. et.al. 2011), LAZIĆ V. et al. 2005, LAZIĆ V. et al. 2011, MUTAVDŽIĆ M. et al 2008, MUTAVDŽIĆ M. et al 2012) this steel must be preheated, the suitable hard-facing technology and additional heat treatment have to be applied, in order to decrease the level of residual stresses in the welded piece. By recording the temperature cycle during the hard-facing, it is possible to read off the cooling time $t_{8/5}$. Besides experimentally, it was also determined theoretically, by using the Dziubinski - Klimpel formula (DZIUBINSKI J. and KLIMPEL A. 1985). The Ito - Bessyo formula (ITO Y. and BESSYO K. 1972) and the Rikalin's expressions (RIKALIN N. N. 1951). Calculated values together with experimentally obtained values are presented in Tables 12.5 and 12.6 (LAZIĆ V. 2001, LAZIĆ V. et al. 2010, LAZIĆ V. et al. 2013).

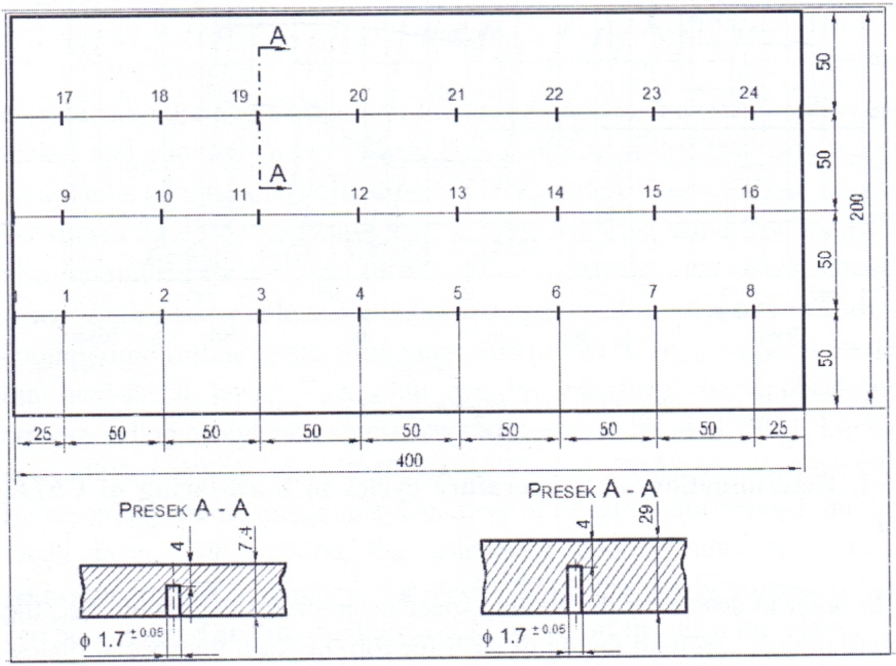

Fig. 12.3. Appearance of plates prepared for measuring the temperature cycles.

By entering experimentally obtained cooling times (shaded fields in Tables 5 and 6) into the CCT diagram for the given steel the newly created structure is estimated and the HAZ hardness. From diagram in Figure 12.2 one can notice that the limiting $t_{8/5} = t_{100}$ is within range 500 to 1500 *s*. Limiting time $t_{8/5} = t_{100}$ approximately 500 *s*, with preheating (T_p = 300 °C), could be achieved with q_l = 60 *kJ/cm* for s = 7.4 *mm*, namely with q_l = 150 *kJ/cm* for s = 29 *mm*. These energy values can not be obtained by the MAG procedure, what implies that regardless of the hard-facing input parameters

Table 12.5. Comparative values of the cooling time $t_{8/5}$ (s = 7.4 mm, I = 115 A, U = 25 V, q_{eff} = 2300 V).

Speed v_z, *cm/s*	**Driving energy** q_l, *J/cm*	**Preheating temperature** T_0/T_p, °C	**Cooling time** $t_{8/5}$, *s*				**Point / Layer**
			$(t_{8/5})^J$	$(t_{8/5})^{Sgr}$	$(t_{8/5})^{exp}$	$(t_{8/5})^c$	
0.238	9663	20	8.62	24.00	14.50	16.5-20	1/1
0.220	10560	20	9.85	29.0	17.00	20-21	24/1
0.186	12192	20	13.34	43.63	16.00	24-26	21/1
0.241	9543	70	10.14	31.17	16.50	20.5-23.5	21/2
0.172	13372	273	44.20	273.9	28.00	88-90	17/1
0.169	13609	280	47.35	304.50	34.00	94-98	10/1
0.136	16911	185	39.00	206	23.50	70-76	9/1
0.208	11058	180	20.1	84.9	27.00	42-50	18/1
0.175	13142	240	35.50	194.2	30.50	71-78	18/2
0.190	12105	178	22.80	100.3	23.00	48-54	11/1
0.183	12568	178	24.05	107.3	19.00	48.5-57	19/1
0.215	10698	169	18.19	73.4	19.50	36-43	3/1
0.150	15333	180	32.90	163.2	24.50	59-68	2/1
0.158	14557	290	55.80	386.7	31.00	104-113	2/2

Table 12.6. Comparative values of the cooling time $t_{8/5}$ (s = 29 mm, I = 190 A, U = 28 V, q_{eff} = 4256 V).

Speed v_z, *cm/s*	**Driving energy** q_l, *J/cm*	**Preheating temperature** T_0/T_p, °C	**Cooling time** $t_{8/5}$, *s*				**Point / Layer**
			$(t_{8/5})^J$	$(t_{8/5})^{Sgr}$	$(t_{8/5})^{exp}$	$(t_{8/5})^c$	
0.148	28757	20	11.20	14.10	16.0	10.8-12.5	1/1
0.130	32738	355	76.17	287.50	78.0	70.5-74.5	16/1
0.161	26436	231	24.36	47.30	25.0	24-27	14/1
0.152	28049	218	24.80	47.80	22.0	23.2-25.5	7/1
0.142	29870	231	29.30	60.40	24.0	27-29.6	7/2
0.258	16500	204	10.43	14.89	12.0	13.5-14.5	6/1
0.257	16912	204	10.83	15.52	12.0	13.6-14.7	6/2
0.167	25414	178	17.60	28.80	16.0	18-20	13/1
0.185	23000	235	20.20	37.10	20.5	21-23.5	21/1
0.163	26136	271	30.12	66.80	23.0	30-32	19/2

(q_l and T_p) one always obtains martensitic-carbide structure of the HAZ, with hardness between 721 and 743 HV (Figure 12.2). Due to that, it is necessary to perform the subsequent tempering, primarily to lower the residual stresses and to decrease HAZ hardness and increase plasticity in individual hard-faced layer's zones.

12.6. Investigation of hardness and microstructure

To measure hardness and investigate newly created structures in individual hard-faced layer's zones, the metallographic samples were prepared by grinding, obtained in various hard-facing conditions. The thickness was varied (s = 7.4 *mm* and 29 *mm*), as well as the type of filer metal and its diameter, namely the technology and parameters of the hard-facing procedure. Samples were cooled in fireclay powder, and prior to metallographic tests, samples were heated together with the furnace at annealing temperature T_a = 340 °C and then slowly cooled to reduce the residual stresses level.

For this experiment the similar plates were used as those applied for obtaining the temperature cycles. Similar welding regimes were selected as well, given in Table 12.2. The hardness distribution diagrams are presented in Figures 12.4 and 12.5. In both cases, samples were preheated to T_p = 300 °C, and after the hard-facing tempered at T_{tem} = 340 °C (LAZIĆ V. 2001). From comparison of experimentally obtained results to those from the CCT diagrams the high correlation was noticed between the input and output characteristics, certain deviations stem from unavoidable differences between experimental and CCT diagrams obtaining conditions.

Based on experimental results it was established that the calculated cooling time, within the critical temperature interval, can be the most accurately determined by the Ito - Bessyo formula (ITO Y. and BESSYO K. 1972). With that, the objective of this work was achieved, namely it was shown that the cooling speed can be accurately predicted without the expensive experimental procedures. The sufficiently accurately determined cooling speed enables reading off the structure and hardness from the CCT

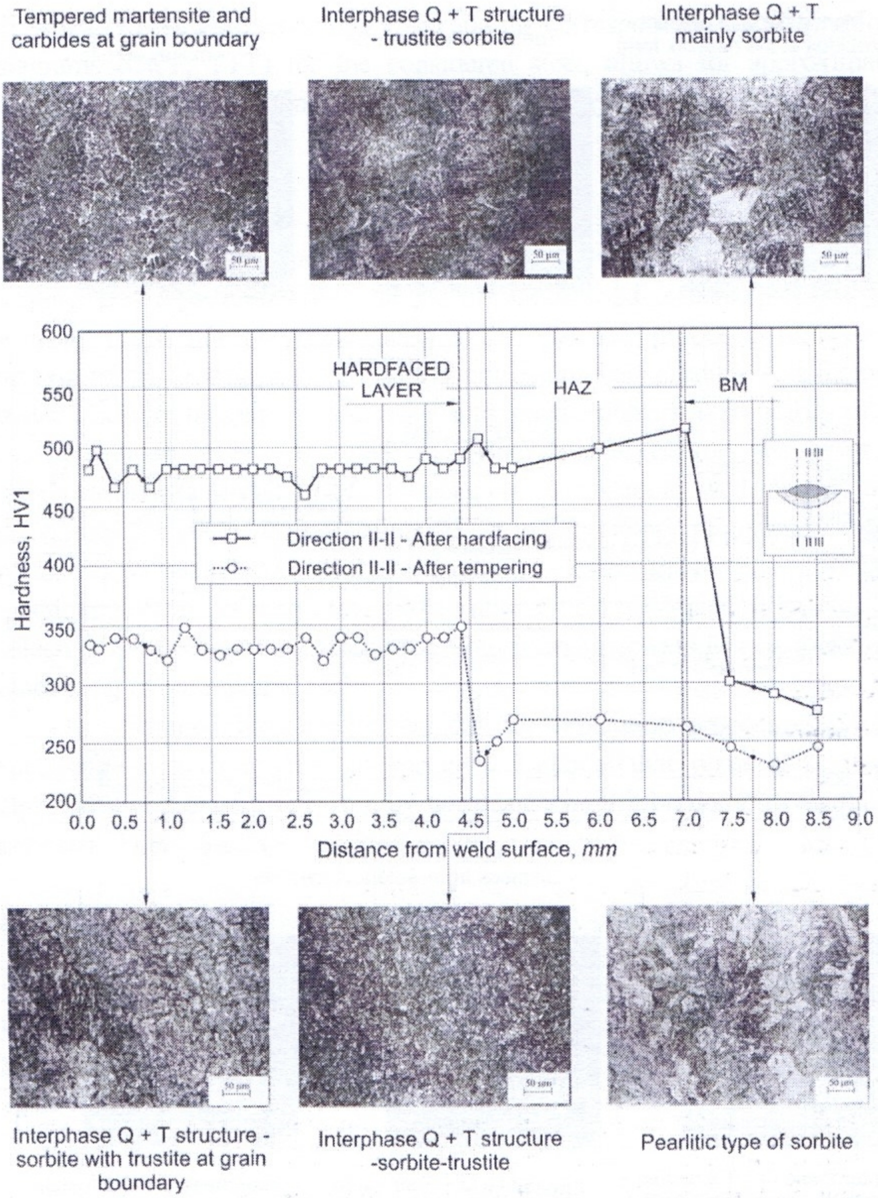

Fig. 12.4. Hardness distribution and microstructure of the hard-faced layer zones (BM (Base Metal) Č5742 – FM (Filler Metal) UTOP 38 – s = 7.4 mm).

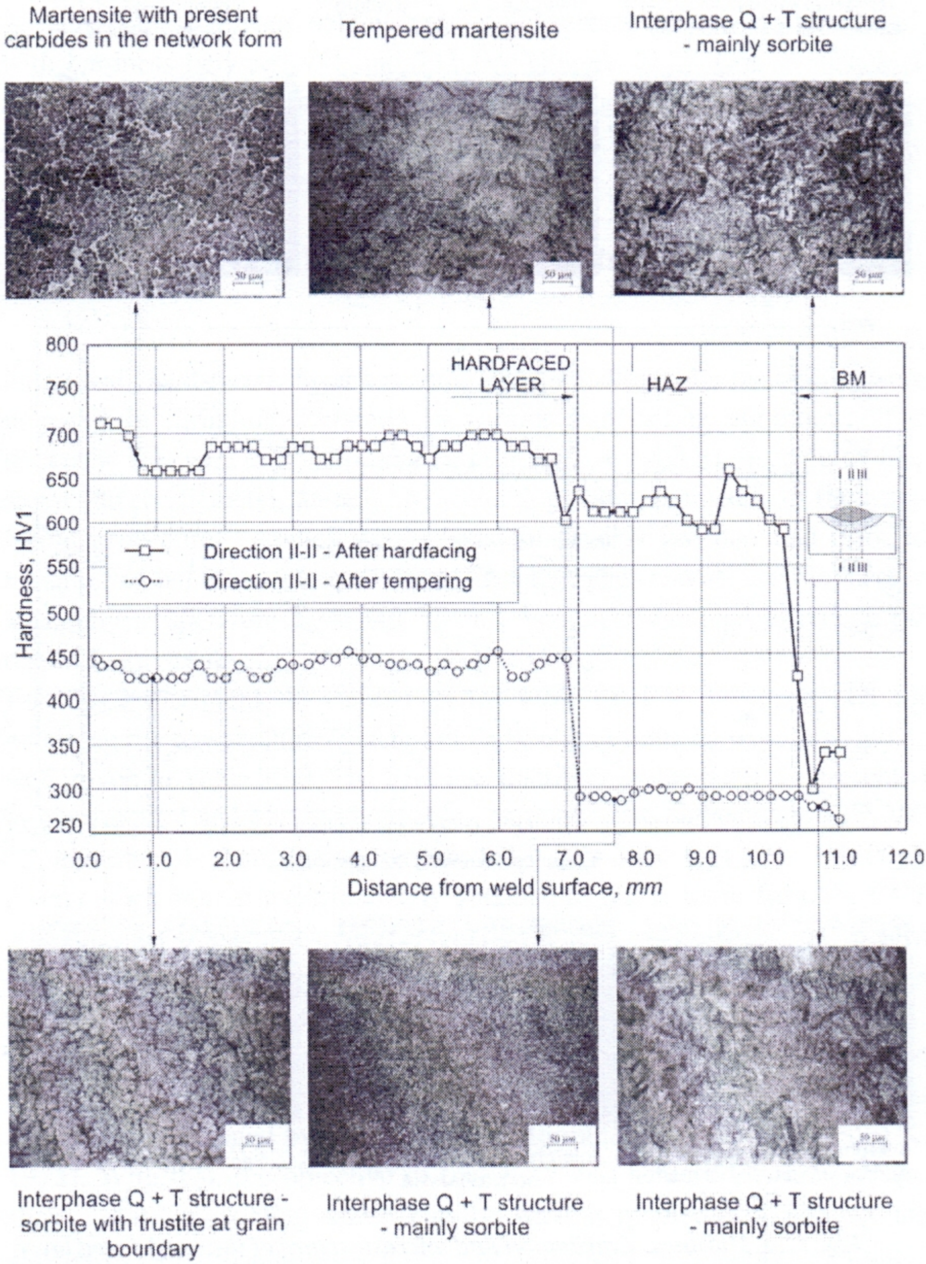

Fig. 12.5. Hardness distribution and microstructure of the hard-faced layer zones (BM Č5742 - FM UTOP 55 – s = 29 mm).

diagrams. Knowing the cooling speed and the corresponding transformation diagrams (CCT, TTT) for the considered steel, allows for approximate determination of the optimal hard-facing technology.

12.7. Conclusion

In this paper we demonstrated validity of detailed investigation of the forging dies reparation problematics. Presented models investigations (as well as those not presented here) show that the proposed reparation procedure on models and in the real conditions can produce satisfactory results. Besides the requirements regarding good mechanical properties of the hard-faced layer, wear resistance and thermal fatigue, the optimal toughness and favorable micro structure are requested, as well, namely the possibility for adequate machining. Those contradictory requirements can be met by proper selection of the reparation procedure and the adequate filer metal, application of preheating and additional heat treatment, as well as by selecting the optimal hard-facing technology and as cheap as possible final machining of the repaired tool.

All mentioned point to the fact that the reparation procedure can be successfully executed only in specialized plants, that possess adequate equipment and expert staff, and by no means could it be done in, for those purposes, improvised workshops.

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