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DETERMINATION OF OPTIMUM TEMEPERING TEMPERATURE IN HARD FACING OF THE FORGING DIES FOR WORKING AT ELEVATED TEMPERATURES

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Abstract: *In this paper is presented only a part of the complex procedure that must be conducted in order to successfully regenerate damaged forging dies by hard facing. After identification of the type and cause of the dies damage, we have selected the procedure and parameters of hard facing, that were further corrected by test hard facing on models. In that way, we were able to relate the output results with the repairing technology. This made possible selection of optimum hard facing technology for the adopted procedure and the filler material, as well as for the chosen regime of thermal treatment.*

Key words: *forging tools, hard facing, tempering brittleness, toughness.*

1. INTRODUCTION

The forging dies are in exploitation subjected to numerous cyclic loads, thus, after certain operating time, the impression damages occur, and the tool has to be replaced or repaired [1, 2]. Statistical investigations of the damaged dies have shown that main causes of their removing from exploitation could be: change of dimensions and form of impressions due to friction and wear, cracks all over the die due to thermal fatigue, and micro cracks caused by action of the stress concentrators [3, 4, 5, 6].

Besides the thermal stresses, caused by temperature gradient, also appear the structural stresses, which depend on chemical composition of steel, kinetics of austenite transformation, and of the cooling speed. Due to influence of cyclic variation of thermal stresses, the initial cracks can also appear on the material surface.

In the present case, we analyzed the forging dies aimed for manufacturing parts in car and trucks making industry. During the excessive monitoring of dies in exploitation, it was noticed that failures could be due to following reasons: increase of the forged pieces dimensions due to worn die, deformation of the thin-walled portions of the die, appearance of cracks at certain parts of the die, and local fractures.

The aforementioned damages are remedied primarily by application of the manual metal arc welding (MMA) procedure, and machining is mainly done by grinding, depending on the application of the filler material. In order to select the optimum technology of forging dies hard facing, numerous test were conducted at the model whose sizes were determined according to the similarity theory principle, namely the non-dimensional analysis.

For the quality criterion of the performed hard facing was adopted the change of hardness and structure in the zones of the hard faced layer, namely in the heat affected zone and beneath it, as well as the resistance of the deposited layers to wear.

Hard facing of dies aimed for operation at elevated temperatures as an objective has generally their repairing by compensating losses caused by friction or crumbling.

2. MATERIALS FOR FORGING DIES MANUFACTURING AND THEIR CHARACTERISTICS

Refractory steels are used for temperatures above 300°C. Here we speak of small, medium and large dies, for hot forming, tools for pressing and extrusion of non-ferrous metals at elevated temperatures, tools for hot trimming, dies for pressurized casting of pure Al, Zn and Mg.

In the considered case, all experiments were conducted on forging dies made of steel Č5742 (DIN 17350 56NiCrMoV7) and Č4751 (DIN 17350 X38CrMoV51). Chemical composition, mechanical characteristics and microstructure of these steels are given in Tables 1 and 2 [1, 2].

Table 1. Chemical composition and comparative marks of steels Č5742 and Č4751

No.	Mark by YUS	Chemical composition, %									Relation to other standards	
		C	Si	Mn	P	S	Cr	Ni	Mo	V	DIN	UNI
1.	Č5742	0.55	0.3	0.7	0.035	0.035	1.1	1.7	0.5	0.12	56NiCrMoV7	U52NiCrMo6KU
2.	Č4751	0.40	1.0	0.4	0.025	0.025	5.0	-	1.3	0.4	X38CrMoV51	UX35CrMo05KU

Table 2. Mechanical characteristics and microstructure of steels Č5742 and Č4751

No.	Mark by YUS	Soft annealing			Tempering temperatura			Preheating temperature, T_p, °C	Microstructure B.M.
		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	≈ 300	M + B (Interpass)
2.	Č4751	800-830	250	850	550-700	50-30	1700-1100	≈ 300	M + B (Interpass)

Since blacksmith workshops use forging dies in thermally tempered state (quenching and high tempering), we subjected all the samples to that treatment, to come as close as possible to real exploitation conditions. On selected samples (models) we measured hardness after thermal treatment and it was 40-42 HRC for Č5742 and 41-49 HRC for Č4751. The softening annealing was not performed (though HV>350) since mainly grinding was used for machining.

Since the samples of thicker cross sections were also hard faced (s = 40-45 mm), made of steels prone to self-hardening (C>0.35%), the preheating was necessary. The preheating temperature was determined according to Seferian formula [7], obtaining $T_p \approx 300$°C.

3. SELECTION OF PROCEDURE, TECHNOLOGY AND FILLER MATERIAL

Hard facing of chosen samples was performed in Laboratory of Zastava cars, by application of cored electrodes. Technological parameters of hard facing were determined according to [1, 7, 8, 9, 10], and hard facing was performed in two and three passes to decrease the degree of mixing (dilution), i.e., to obtained declared characteristics supplied by the manufacturer of electrodes. We measured the velocity of hard facing during each pass, and we also, prior to applying another layer, checked the preheating temperature, i.e., the interpass temperature. The digital-measuring device Tastotherm D1200 was used for measurements, which is supplied with a thermocouple NiCr-NiAl with a measuring range from - 50°C to 1200°C.

Ass a filler material there were applied highly alloyed basic electrodes UTOP 38 (DIN 8555 - E3-UM-40T, ∅3.25 *mm*) and UTOP 55 (DIN 8555 - E6-UM-60T, ∅5.00 *mm*). The filler materials were aimed for hard facing of dies

that are used for forming of steels and other metals both in hot and cold state, like ingot mold, steel molds, dies and pressing mandrels. Hard faced layers are tough, resistant to wear and impact. The hard faced layers hardness is constant up to temperature of 600°C [1].

This basic electrodes were dried prior to application according to the following regime: heating up together with the furnace up to temperature of 350-400°C, keeping for 2 hours at the drying temperature, and cooling in the furnace for 1 hour, while the temperature did not fall below 150°C. Thus heated electrodes were used for hard facing of the preheated samples, with decreasing the level of diffusive hydrogen and eliminating the possibility appearance of hydrogen induced cracks.

In Tables 3 and 4 are presented the hard facing parameters (hard facing current was for about 10% lower than at welding), as well as properties of the filler material [1].

Table 3. Parameters of the MMA hard facing

No.	Electrode mark		Core diameter, *mm*	Hard facing current, *A*	Voltage, *V*	Hard facing velocity, *cm/s*	Heat input energy, *J/cm*
	Iron plant - SŽ 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. Filler material properties

No.	Electrode mark		Chemical composition, %					Type of current	Hard face layer hardness, HRC	Application
	Iron plant "Fiprom"	DIN 8555	C	Cr	Mo	V	W			
1.	UTOP 38	E3-UM-40T	0.13	5.0	4.0	0.20	+	= (+)	36-42	Hard facing of dies for operation at elevated and normal temperatures
2.	UTOP 55	E6-UM-60T	0.50	5.0	5.0	0.60	+	= (+)	55-60	- II -

Order of hard faced layers deposition is given in Figure 1.a, where prior to each pass, the layer of slag was removed with a steel brush. The following layers were also applied according to this scheme (the second - Figure 1.b and the third - Figure 1.c).

The width of a pass hard faced with the ∅3.5 *mm* electrode was b ≈ 10-12 *mm*, the height of the faced layer was h ≈ 1.5 *mm*, and with the ∅5.00 *mm* electrode measures were b ≈ 16-18 *mm* and h ≈ 2.1 *mm* [1].

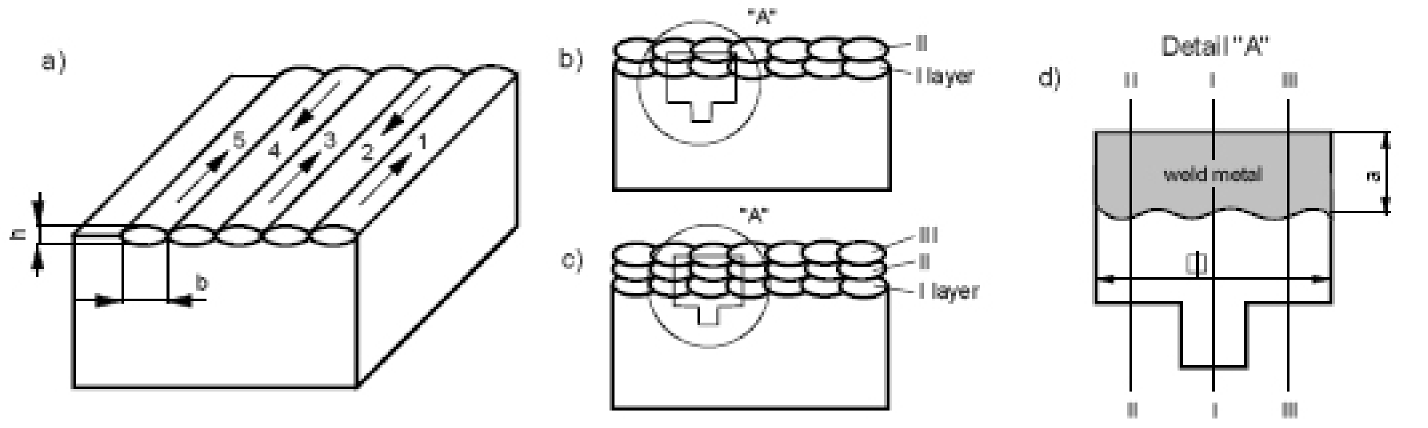

Figure 1. Order of hard faced layers deposition: a - 1st layer, b - 2nd layer, c - 3rd layer, d - pin appearance

4. PHENOMENON OF TEMPERING BRITTLENESS

4.1 Theoretical considerations

During hard facing of hardening prone steels aimed for forging dies, in the vicinity of the hard faced layer, appear brittle unfavorable structures, the residual stresses increase occur, which frequently surpass the yield strength. From all these reasons, it is necessary to perform tempering, after the forging dies hard facing, in order to decrease the level of residual stresses, and to transfer martensite structures into the upper bainite (feathery) structures, with preservation of good mechanical properties. Frequently, in real manufacturing conditions, arises a problem of selecting the optimum annealing temperatures, which in fact represents the compromise between the presented requirements.

It was noticed that, in some steels that were alloyed with Mn or Cr, i.e., Cr-Mn or Cr-Ni, during annealing can appear a damaging phenomenon of the so called "tempering brittleness". Tempering should be avoided from temperatures in zones in which is recorded the increased hardness, so it is recommended that tempering starts even from higher temperatures. In cases when tempering is performed from higher temperatures, the rapid cooling is recommended through the critical temperatures region, i.e., undercooling, what prevents diffusion as an essential factor for appearance of tempering brittleness [1, 11].

On the other hand, for some classes of steels, the decrease of toughness is possible to notice also by metallographic methods [1, 11], while for reduction of hazard that this phenomenon occurs it is strongly recommended to alloy these steels by molybdenum (up to 0.6%), by tungsten (up to 1.5%), as well as by niobium. During tempering, these elements exhibit positive effects, since they are slowing segregation. On the contrary, carbon and phosphorus contribute to appearance of the tempering brittleness. The assumption is that the negative effect of phosphorous initiates already at small amounts (≈ 0.005% P) [1, 11]. Influence of phosphorus is related to its expressed tendency to segregation. Also, about very important influence of phosphorus on this phenomenon, displays the fact that carbides, extracted from steel in brittle condition, are richer with phosphorus than carbides extracted from steels that posses normal toughness. The mentioned phenomenon of toughness decrease is reversible, which means that it will reappear after later heating over 520°C, and slow cooling.

Sensitivity of material to tempering brittleness can be established by testing the steel for impact toughness, in the wide temperature range, as well as by determination of the steel transition temperature from ductile to brittle fracture. Tendency of different steels to appearance of tempering brittleness depends mainly on their chemical composition, manufacturing procedure and processing.

In the present case, we have investigated influence of the tempering temperature of hard faced tools on hardness distribution across the hard faced layer cross section. To do that, we varied tempering temperatures from 370 to 670°C, taking 30°C as the temperature interval. Time of keeping the sample at certain temperature was two hours, with slow cooling down to room temperature. In Figure 2 are presented hard faced layer and base metal hardness variation as a function of the tempering temperature. It can be noticed that at temperature ≈ 520°C an increase of hardness occurs, what points to possibility of tempering brittleness that was caused by martensite decomposition, and residual austenite in the structure. Function of hardness variation of the hard faced layer, obtained by experiments, is in agreement with data from literature for the base metal [12, 13], since the chemical composition of the filler material, approximately corresponds to base metal.

4.2 Presentation of obtained results

In order to investigate the cooling speed influence to the tempering brittleness, we heated new samples up to 520°C, then heated through for two hours, and in one case cooled slowly together with the furnace, and in the other in the quiet air. The HV1 hardness was measured on those samples in the I-I direction (Figure 1d), starting from different distances from the hard faced layer surface. In Figure 2a,b are given diagrams as representation of the hardness variation.

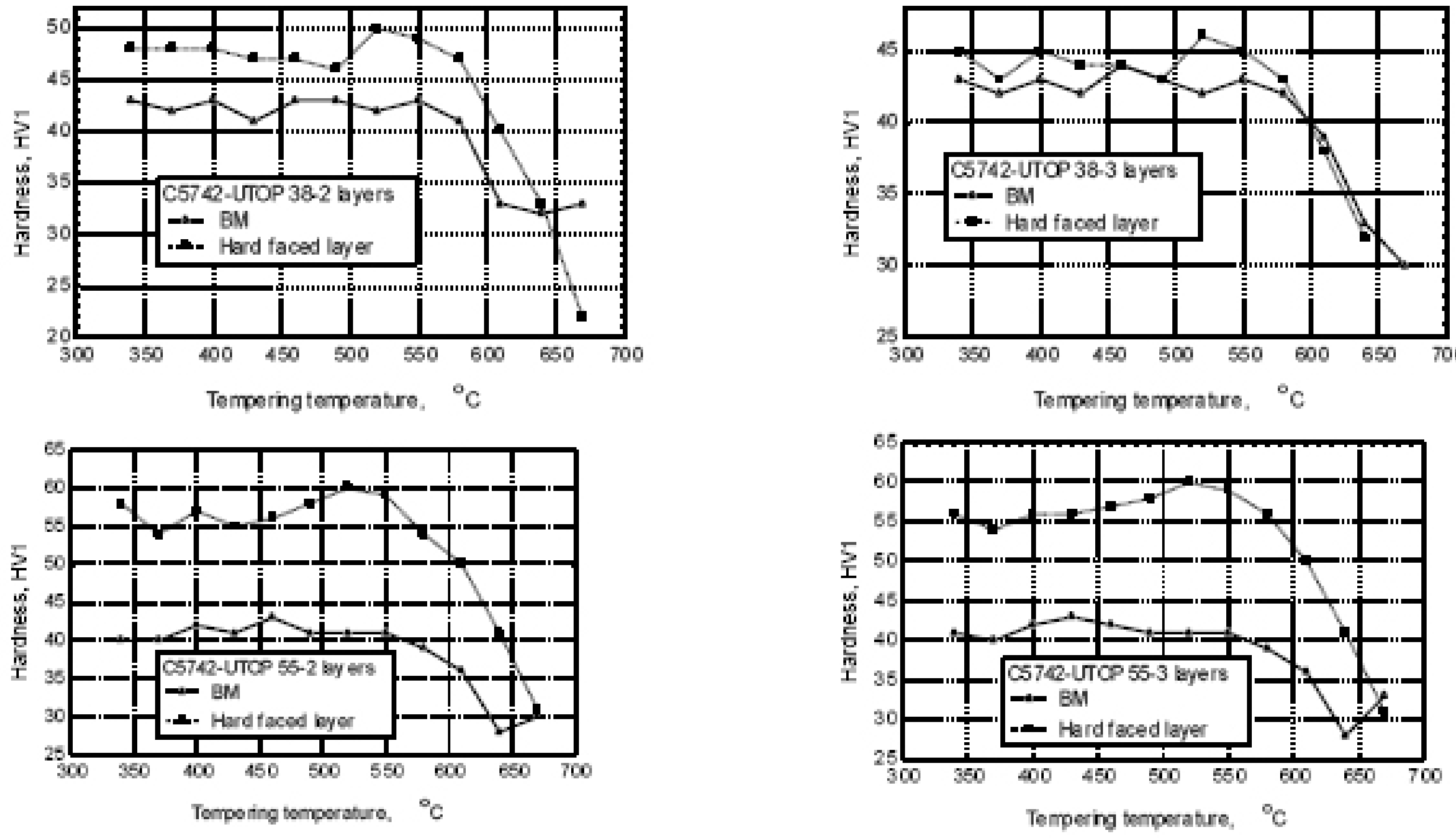

Figure 2. Hardness variation as a function of tempering temperature

5. CONCLUSION

In the paper we have shown that successful hard facing of forging dies is possible only after detailed investigation on models. Besides the corresponding technology of hard facing, it is also necessary to determine experimentally the thermal treatment regime which will ensure that the reparation procedure, proposed here, produce satisfactory results also in exploitation conditions. Besides requirements that are related to mechanical properties of the hard faced layer, the resistance to wear and thermal fatigue, also needed is proper toughness and favorable microstructure, as well as good machinability. These contradictory requirements can be fulfilled only by appropriate selection of the reparation procedure and corresponding filler metal, then by selection of optimum hard facing technology, including also as cheap as possible final machining of the repaired part.
All these point out the fact that the reparation tasks can be successfully performed only in specialized plants, which have at their disposal, the adequate equipment and corresponding expert staff, and in no case can that be done in improvised workshops.

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