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ABSTRAKT / ABSTRACT

Experimentálne merania reziduálnych napätí vo zvaroch ocelí pre prácu za vysokých teplôt

Experimental measurements of residual stresses in welding of steels operating at high temperatures

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Abstrakt:
Článok sa zameriava na proces experimentálnych meraní reziduálnych napätí počas sústruženia čelných plôch oceľových súčastí určených na výrobu kovacích zápustiek. Tieto ocele sú určené k použitiu za vysokých teplôt. Majú extrémny sklon k samozakaleniu a majú nízku tepelnú vodivosť a sklon k nerovnomernému ohrevu. Kvôli týmto vplyvom sa objavujú prídavné napätia, ktoré, ak prekročia medzu klzu základného materiálu, môžu viesť k vzniku deformácií a prasklín. Existuje množstvo metód na zníženie týchto reziduálnych napätí. Relaxácia je aplikovaná, aby sa znížil stupeň prídavných napätí a došlo k žiaducej zmene martenzitickej štruktúry do štruktúry vhodnejšej, zabezpečujúc tak zároveň dobré mechanické vlastnosti povrchovo spracovaných vrstiev. Výsledky prezentovaných výskumov môžu byť zvyčajne aplikované v praxi, rovnako pre výber optimálnych opravárenských technológií, ako aj pre určenie typu a režimu tepelného spracovania.

Abstract:
In the paper is described a procedure for experimental measurements of residual stresses during the reparatory hard facing of models made of steel aimed for manufacturing the forging dies. Those steels are aimed for operating at elevated temperatures. They are extremely prone to self-hardening and especially sensitive to localized heat input. Because of those influences appear residual stresses, which, if superseded the yield stress of the base metal, can lead to appearance of deformations and cracks. Numerous methods exist for reducing the residual stresses. Relaxation is used in order to reduce their level and to transfer the martensitic structure into the more favorable ones, while preserving the good mechanical properties of the hard faced layers. Results of presented investigations can be usefully applied in practice, both for selecting the optimal reparation technology and for defining the type and regime of the heat treatment.

1. Introduction

In this paper, we point out the complex problematics of reparatory hard facing of forging dies, which are in exploitation conditions exposed to impact loading and cyclic heating up to elevated temperatures. Steel aimed for manufacturing of those tools thus have to sustain high impact loads, while preserving good mechanical properties at elevated temperatures and they have to be resistant to wear and thermal fatigue. From all the mentioned reasons, for those tools are used alloyed steels, what impedes regeneration of the damaged tools by the hard facing procedures. This is why every reparation by hard facing is almost a unique job, since it asks for the technology adapted to each individual working piece. However, the general procedure can be established, which must be obeyed if one expects to successfully repair the forging dies and similar tools. Prior to being able to select the optimal reparation technology, one must conduct numerous model investigations, what is partially presented in this paper.

2. Residual stresses due to reparatory hard facing

Considering that the reparatory hard facing is realized by the localized heating and cooling that creates uneven temperature field. Thus, the shrinking and extension are restrained, what causes the *thermal stresses*, which are proportional to the temperature difference in individual hard faced layer zones. Besides the thermal stresses, the *structural stresses* can also arise in certain zones of the hard faced layer because of the austenite transformation into phases with different specific volumes. Martensite possesses the largest specific volume, so when it is surrounded by other phases it cannot expand freely. The structural stresses appear during the reparation of the forging dies made of steel for operation at elevated temperatures, since the phase transformations unfold in the elasto-plastic or elastic range (undercooled austenite), what prevents the free expansion of the just formed Martensite, so it remains compressed.

Thermal and structural stresses are called the *own stresses* since they come due to the hard facing process. The own (or self) stresses are always accompanied by the corresponding strains, both during the hard facing process and after it is finished. During the process itself, the stresses vary both in intensity and in sign so they are called the *transient stresses*, while the stresses that remain permanently in the material, after the hard facing and cooling are called the *residual own stresses*. Both stresses impose negative influence on the properties of the welded joint; the transient stresses can lead to appearance of cracks, especially the hot cracks, while the residual stresses can cause change of dimensions and shape, stress concentration, redistribution of the stress state, cracks and brittle fracture [1-4].

3. Materials for operating at elevated temperatures

The subject are the tools that operate at elevated temperatures of about 600ºC, which are subjected to high static pressures or even impact loads. Steels alloyed with Cr, V and Mo, with increased content of carbon (0.3 – 0.6% C) provide the good hardenability, needed for larger cross-sections of tools, as well as higher hardness at elevated temperatures [1, 3, 4, 12].
In this research we investigated the possibility for reparatory hard facing of the two typical steels for forging dies Č5742 (JUS) - 56NiCrMoV7 (DIN) – aimed for forging dies of all kinds and Č4751 (JUS) - X38CrMoV51 (DIN) – primarily aimed for casting

dies of the non-ferrous metals. Those two steels are the most frequently used in forging shops for manufacturing the forged pieces for passenger cars and trucks. The chemical composition, mechanical properties and microstructure of those steels are presented in Tables 1 and 2 [12].

Tab. 1 *Chemical composition and comparable marks of steels Č5742 and Č4751*

No.	Mark by JUS	Chemical composition, %									Mark by DIN
		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	56NiCrMoV7
2.	Č4751	0.40	1.0	0.4	0.025	0.025	5.0	-	1.3	0.4	X38CrMoV5

Tab. 2 *Mechanical properties and microstructure of steels Č5742 and Č4751*

No.	Mark by JUS	Soft annealing			Tempering			B.M. Microstructure
		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	M + B (interphase)
2.	Č4751	800-830	250	850	550-700	50-30	1700-1100	M + B (interpahse)

Since the mentioned forging shops mainly use the forging dies in heat tempered condition (quenching and high tempering), all the samples-models were subjected to that heat treatment, in order to simulate the exploitation conditions as close as possible. Hardness was measured on selected samples after the heat treatment, and it ranged from 40 to 42 HRC for steel Č5742 and 41 to 49 HRC for steel Č4751. Samples were not subjected to the softening annealing (though HV was > 350), since the machining was mainly done by grinding.

Samples of various thickness (s = 7.4 – 40 *mm*) were hard faced for experimental purposes to steels prone to self-hardening (C > 0.35%); thus it was necessary to apply preheating. The preheating temperature was determined according to Seferian formula [5] and it was within range from T_p = 286°C for s = 7.4 *mm* up to T_p = 315°C for s = 40 *mm*. The adopted preheating temperature was $T_p \approx$ 300°C [1-2, 6-8].

4. Selection of the hard facing method, technology and filler metal

Hard facing of the selected samples was done by application of the cored electrodes. Technological parameters of hard facing were determined according to [1-2, 6-8], while hard facing was executed with two and three passes, for reducing the mixing-dilution, i.e., to obtain the declared properties, provided by the electrodes supplier. The deposition speed was measured in each pass, while the preheating temperature, namely the interpass temperature, was checked prior to deposition of each new pass, i.e., layer. The measuring device was Tastotherm D1299 (with thermocouple NiCr-NiAl with measuring range from –50 to +1200ºC).

The filer metals were highly alloyed basic electrodes UTOP 38 (E3-UM-40T ∅3.25 *mm* - DIN 8555) and UTOP 55 (E6-UM-60T ∅5.00 *mm* - DIN 8555). They are used for hard facing of tools like: steel molds, dies and thorns for pressing, etc. Hard faced layers are tough and resistant to wear and impact. Hardness of the hard faced layers, according to conducted tests, was stable until the tempering temperature $T_{temp} \approx 570°C$ [1-2, 6-9]; according to electrodes' supplier hardness is stable up to 600ºC [13-SŽ Fiprom].

Prior to application, electrodes were dried according to the following regime: heating within the furnace up to temperature of 350-400ºC, holding at the drying temperature for 2 *h* and then cooling in the furnace for 1 *h*, with the temperature not falling below 150ºC. Thus heated electrodes were applied for hard facing of the preheated samples, what caused reduction of the diffused hydrogen and prevented hydrogen induced cracks.

In Tables 3 and 4 are presented parameters of hard facing (the hard facing current is for about 10% smaller than for welding), as well as the properties of the filler metals [1-2, 13-SŽ Fiprom].

Tab. 3 *Parameters of hard facing by the MAG method*

No.	Electrode mark		Core diameter d_e, *mm*	Hard facing current I, *A*	Voltage U, *V*	Hard facing speed v_z, *mm/s*	Driving energy q_l, *J/mm*
	SŽ Fiprom	DIN 8555					
1.	UTOP 38	E3-UM-40T	3.25	115	26	≈ 2.8	854.3
2.	UTOP 55	E6-UM-60T	5.00	190	29	≈ 2.5	1763.2

Tab. 4 *Filler metals properties [13]*

No.	Electrode mark		Chemical composition %					Current type	Hard faced layer hardness, HRC
	SŽ Fiprom	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

Order of depositing the hard faced layers is shown in Figure 1a. Prior to each new pass, the slug was removed by the steel brush. Other layers were deposited according to this scheme (the second – Figure 1b), the third – Figure 1c), etc.). The layer hard faced with electrode of diameter ∅3.25 *mm* had dimensions: width was b ≈ 10-12 *mm* and height h ≈ 1.5 *mm*, while the layer deposited with electrode of diameter ∅5.00 *mm* had dimensions: width was b ≈ 16-18 *mm* and height h ≈ 2.1 *mm*.

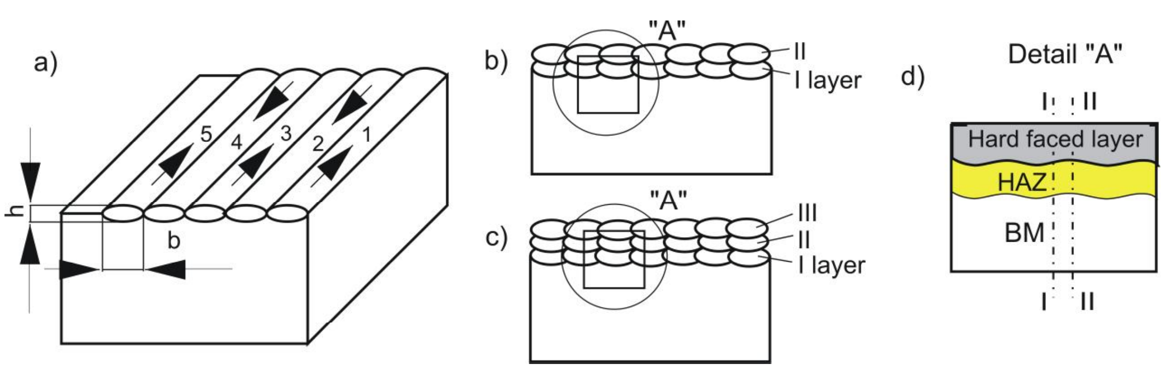


Fig. 1 *Order of deposition of the hard faced layers: a) layer 1; b) layer 2; c) layer 3; d) metallographic slit scheme.*

5. Hard facing of models – thin and thick plates

Samples (models) in shape of thin and thick plates were used for determination of the level of residual stresses and for measuring strains. The selected plates (4 plates of dimensions 394×192×7.4 *mm* and 3 plates of dimensions 394×192×29 *mm*) were thermally tempered (quenching plus high tempering) and machined by fine grinding in order to make the experimental conditions as close as possible to the real – exploitation ones. The base metal of models/plates was steel Č5742, which was the used the most for forging dies manufacturing.

The plates were hard faced according to the described technology, by depositing three caterpillars hard faced layers in one, two and three passes (Figure 2). In Table 5 are presented the hard facing parameters, with depositing speed measured for each pass. The preheating temperature, as well as the interpass temperature were controlled by the digital device Tastotherm, namely with thermo-chalks. The thin plates were hard faced with electrode UTOP 38 with diameter Ø3.25 *mm* and UTOP 38 with diameter Ø2.5 *mm* (for the calibrating sample – plate 6* in Table 5) and the thick plates were hard faced with electrode UTOP 58 with diameter Ø5.0 *mm* [1-2].

Tab. 5. *Hard facing parameters* [1]

Plate mark	Thickness s, *mm*	Number of layers	Electrode diameter d_e, *mm*	Hard facing current I, *A*	Voltage U, *V*	Hard facing speed v_z, *mm/s*	Driving energy q_l, *J/mm*
1	29	2	5.00	190	29	≈ 2.3	1916.5
2	29	3	5.00	190	29	≈ 2.3	1916.5
3	29	1	5.00	190	29	≈ 2.4	1836.7
4	7.4	1	3.25	115	26	≈ 2.6	920.0
5	7.4	2	3.25	115	26	≈ 1.7	1407.0
6	7.4	3	3.25	115	26	≈ 2.5	956.8
6*	7.4	1	2.5	80	23	≈ 2.3	640.0

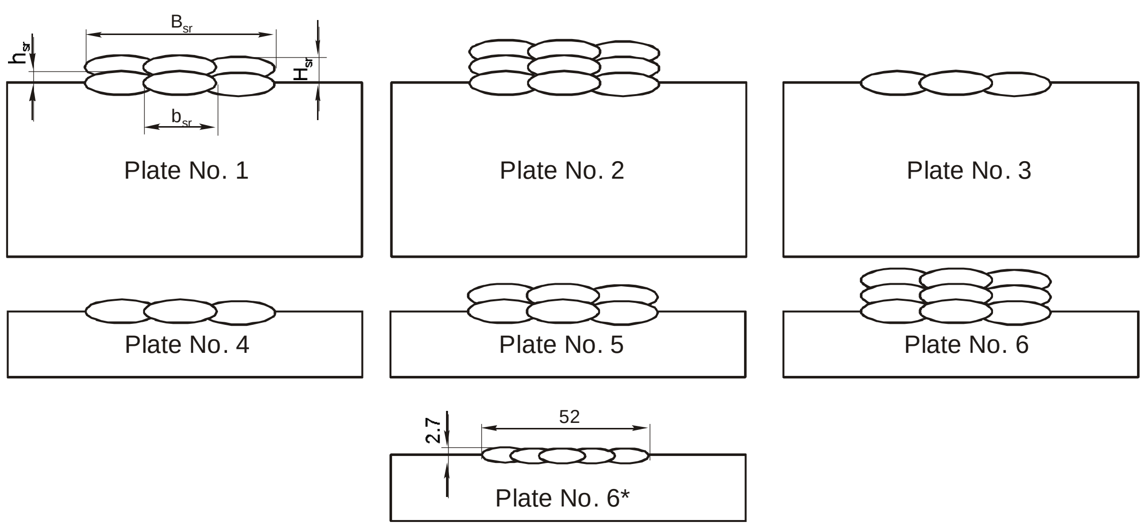


Fig. 2 *Schematic of hard facing of plates* [1]

After the hard facing and the follow-up measurements, the plates were tempered (Figure 3), primarily to cause the level of residual stresses and strains. This type of heat treatment was adopted based on recommendations from the steel manufacturer [12], production experience and our own earlier investigations in order to eliminated the risk of appearance of the tempering brittleness [1, 6-8].

Geometrical characteristics of the caterpillar (average values) (b_{av} and h_{av}) and total height (H_{av}) and width (B_{av}) are given in reference [1]. During depositing of caterpillars the partial re-melting of them was performed ($\approx$ 1/3 b_{av}) [1].

6. Experimental measurement of residual stresses

6.1 Measurements scheme for residual stresses

Stresses and strains were measured after the hard facing and tempering. The purpose of those measurements was to establish the level of stresses in terms of the hard facing regime, thickness of the hard faced plates, number of passes/layers and technology of additional heat treatment. After the plates were prepared by grinding, the three grids (raster) were applied to them in three longitudinal and lateral directions according to Figure 3. Besides the residual internal stresses, the deformations were thoroughly measured after the final preparation of plates, after the hard facing of layers, as well as after the heat treatment by tempering [1].

6.2 Magnetic method for residual stresses measurements

Magnetic method belongs into a group of relatively new methods for measuring the residual stresses. The principle of operation of this method is based on dependence of the magnetic permeability of the ferro-magnetic materials on the stress state, which enables recording of the instantaneous stress state, only. Advantages of this method are the fast and efficient operation, low costs and possibilities of measurements in the field, etc., while its deficiency is a somewhat lesser accuracy in comparison to other experimental methods, as well as possibility of measuring the residual stresses only in the ferro-magnetic materials. In practical conditions, when residual stresses are measured in the very responsible structures, this method is amended with some other standard method [1]. In this case, we used the SMMT-1 device to measure the residual stresses. The device has the battery power source and it is easily portable due to its small mass, what is convenient for fields' measurements.

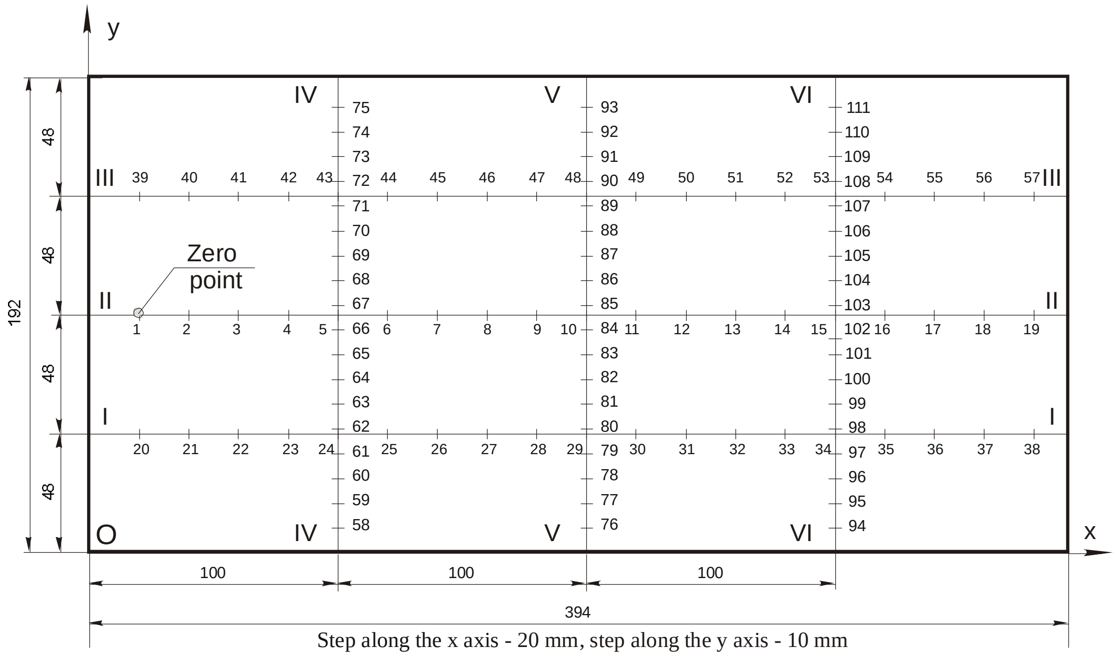


Fig. 3 *Schematics of the plates' calibration*

Fig. 4 *Residual stresses measuring device*

Prior to commencing the measurements, it was necessary to calibrate "zero" on the device's scale. Here were possible two cases: in the first case, the zero is red-off based on calibration and the probe is sufficiently far away from the material (the probe is in the air); in the second case, the probe is leaning onto the calibrating sample. The probe position and point of contact must correspond to the calibrating position. According to references [11-12] the possibility for the measurements error is lesser in the first case. Then the measurements were performed. No special preparation of the measurements surfaces is required, except that they have to be flat. The probe position, at which the maximum stress was red-off corresponds to the maximum principal stress σ_1, awhile the stress σ_2 was determined by turning the probe for 90°, where it is also possible to determine approximately the angle of principal stresses [10-11].

6.3. Device calibration before measurements

As it was already mentioned, by this method one measures the magnetic permeability, while the correlation of the magnetic characteristic and the stress is reached by the calibration curve, which must be done for each material type. For determination of the calibration curve ne needs the standard tensile specimen, which is loaded in tension up to the force that corresponds to 0.8 R_{eh}. Test is done by gradual increasing of load with registering the load values and the corresponding magnetic characteristics expressed in digits (*dig*). Based on thus obtained values, the load is recalculated into stress with relation to the specimen's cross section area; then the calibration diagram is drawn, Figure 5.

From Figure 5 one can notice that the calibration curve does not pass through the origin of the coordinate system. The reason for that was that the device was calibrated by the method "zero in the air". By fitting according to the law of the linear regression, one obtains the calibration equation, based on which then one can recalculate obtained values of magnetic characteristics.

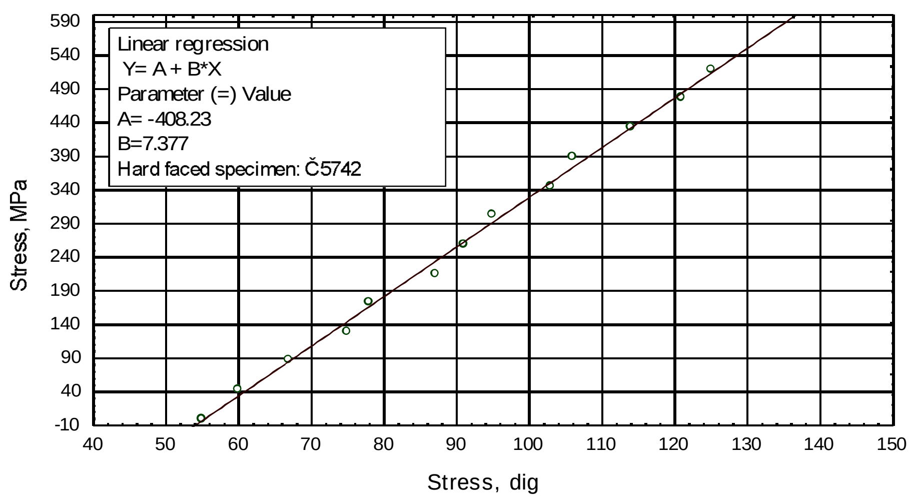


Fig. 5 *Calibration curve for steel Č5742*

6.4. Preparation of the calibrating sample

Before the residual stresses were measured by the magnetic method and before the device calibration, one of the tin plates (6*) was hard faced by a single layer (according to adopted technology) with electrode UTOP 38 - Ø 2.5 *mm*. Then, a sample for calibration (Figure 6) was mechanically cut out from it and machined by grinding.

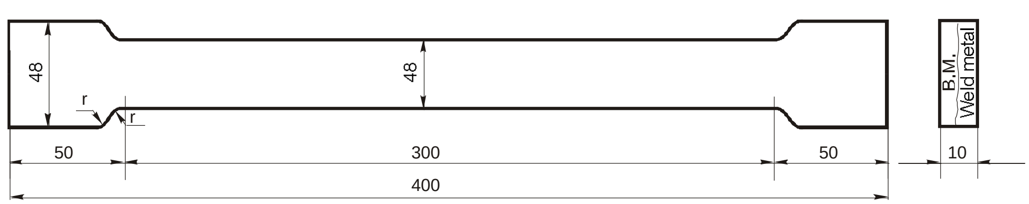


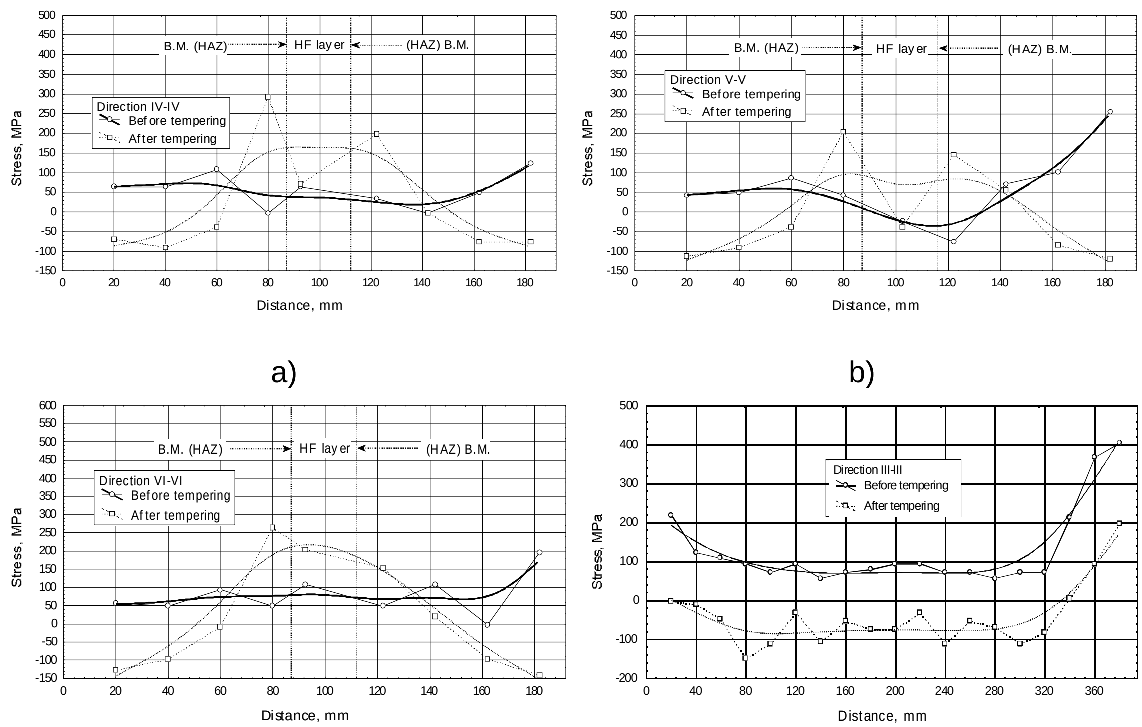
Fig. 6 *Appearance of the calibrating sample*

The calibrating sample was aimed for establishing the dependence σ (*dig*) – σ (*MPa*) (Figure 5), based on which the stresses were recalculated after measurements by the magnetic method.

Before the commencing the measurements, the roughness tips on the hard faced layers were flatten by grinding (only for the thick plates 1, 2 and 3) and all the plates were demagnetized on the special device. Then the stresses were measured in the characteristic directions (cf. Figure 3). Namely, in the mentioned plates, the longitudinal stresses were measured in the III-III direction and the lateral stresses in directions IV-IV, V-V and VI-VI. For plates 1, 2 and 3 stresses within the hard faced layers were measured as well, while for the thin plates that was not possible, due to prominent deformations (especially angular) and also due to smaller total width of the hard faced layers.

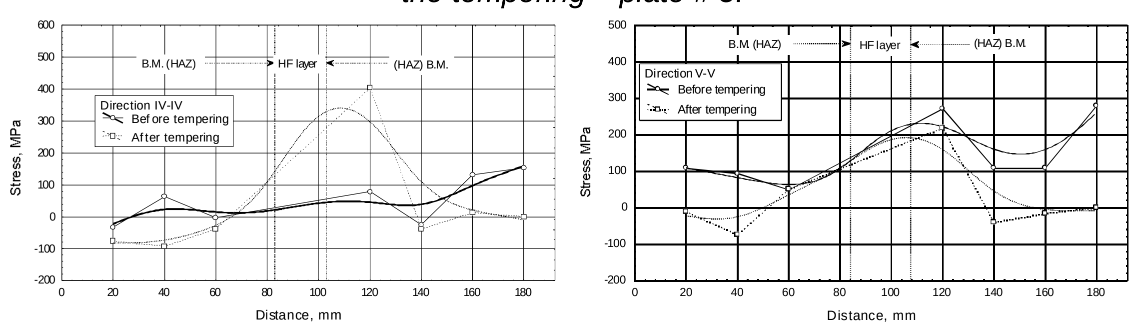
6.5 Results of residual stresses measurements

In Figures 7 and 8 are presented results of measurements of residual stresses in the cited directions, only for plates 3 and 4.

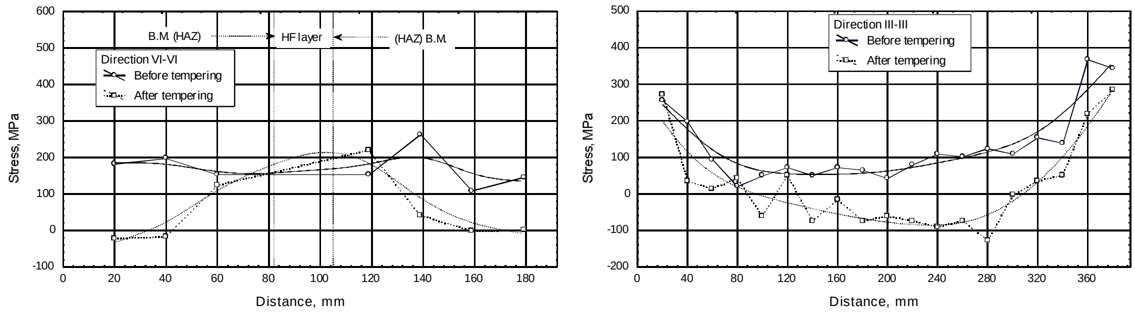


a) b) c) d)

Fig. 7 *Distribution of the lateral (a, b, c) and longitudinal stresses (d) before and after the tempering – plate # 3.*



a) b)



c) d)

Fig. 8. *Distribution of the lateral (a, b, c) and longitudinal stresses (d) before and after the tempering – plate # 4.*

7. Conclusions

Conducted experimental measurements of residual stresses in hard faced model plates led to the following conclusions:

- Distribution of residual lateral stresses corresponds to data found in literature;
- Measured residual stresses in thick plates are significantly higher than those in thin plates;
- It was established that the heat input causes increase of the residual stresses;
- Necessity of application of tempering after the hard facing was stressed out in order to reduce the residual stresses, reduce hardness and realize favorable micro structure in individual zones of the hard faced layers;
- It was established that in hard facing the thick plates and when depositing is done in several passes, more favorable is high tempering, while in hard facing of the thin plates and depositing the single hard faced layer, more favorable is medium or low tempering;
- By applying the selected technology of hard facing, measured values of residual stresses are significantly lower than the yields stress of the base metal, what eliminates the possibility of appearance of cracks.

All the enumerated conclusions can be usefully applied in hard facing of the real forging dies. This proves that the model investigations, done in this way, can define the optimal hard facing technology, which would enable reducing of the residual stresses and eliminating the possibility of cracks appearance in reparatory hard facing of forging dies.

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References

[1] Lazić, V.: Optimization of the hard facing process from the aspect of the tribological characteristics of the hard faced layers and the residual stresses, Doctoral dissertation, Faculty (of Mechanical Engineering in Kragujevac, 2001. (in Serbian)

[2] Lazić, V., Jovanović, M., Adamović, D., Ratković, N.: Selection of the optimum technology of the forging dies reparation from the aspect of tribological characteristics, Tribologia - teoria i praktika, 28(2), 2005, pp. 11-31.

[3] Beljski, E. I.: Persistence of forging dies, "Science and technics" Publishing, Minsk, 1975. (in Belarus)

[4] Pasierb, R.: Welding of chromium-molybdenum steels for operating at elevated temperatures, WNT, Warszawa, 1982.

[5] Jovanović, M., Adamović, D., Lazić, V.: Technology of Welding – The Handbook, Independent authors publishing, Kragujevac, 2012.

[6] Lazić, V., Jovanović, M., Ristović, J., Nedeljković, B., Josifović, D., Adamović, D.: Influence of heat treatment after hard facing on working characteristics of the hard faced forging dies, Welding and welded structures, 46(1-2), 2001, pp. 5-11. (In Serbian)

[7] Lazić, V., Sedmak, A., Aleksandrović, S., Milosavljević, D., Čukić, R., Grabulov, V.: Reparation of damaged mallet for hammer forging by hard facing and weld cladding, Technical Gazette 16(4), 2009, pp. 107-113.

[8] M. Mutavdžić, V. Lazić, D. Milosavljević, S. Aleksandrović, R. Nikolić, R. Čukić, G. Bogdanović: Determination of the optimal tempering temperature in hard facing of the forging dies, Materials Engineering, 19 2012, pp. 95-103.

[9] Lazić, V., Sedmak, A., Krstić, B., Nikolić, R., Aleksandrović, S., Čukić, R: Determination of the cooling rate and its influence on the hard-faced forming dies properties, Materials Engineering, 16(3a), 2009, pp. 124-131.

[10] Tatarkin, G., Ilić, V., Filipović, N., Zrilić, M.: Determination and characterization of cracks in welded joints during exploitation, Welding and welded structures, 46(1), 1997, pp. 13-29. (In Serbian)

[11] Zrilić, M., Rakin, M., Milović-Matić, Lj., Putić, S.: Determination of residual stresses on rotation furnace for clinker production, Welding and welded structures, 46(3), 1997, pp. 219-223. (In Serbian)

[12] 1. Standards and catalogues of the base metal: Steel mill "Ravne", Slovenia,
2. Thyssen Marathon Edelstahl: Verkaufsgesellschaft M.B.H., Vosendorf,
3. Atlas zur Wärmebehandlung der stähle, Verlag stahleisen M.B.H Düsseldorf.

[13] 1. Catalogues of the filler metals: Steel mill "Jesenice-Fiprom",
2. Bohler-Kapfenberg, Messer Griesheim-Frakfurt am Main,
3. Esab-Göteborg,
4. Lincoln Electric-USA.