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Experimental determination of deformations of the hard faced samples made of steel for operating at elevated temperatures

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Abstract

An experimental procedure for determination of the lateral and longitudinal deformations of the multi-layer hard faced samples made of steel for operating at elevated temperatures is presented in this paper. Two plates, which were hard faced in three passes, were used to determine the level of residual stresses. The cored electrodes UTOP 38 and UTOP 55 were used. Deformations were measured in two phases: before and after the hard facing. The objective of deformations measurements was to establish the correlation between deformations, namely the applied technology (the input energy/heat) and the level of residual stresses, for different plate thicknesses.

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Keywords: Hard facing; Filler metals; Deformations; Residual stresses; Driving energy.

1. Introduction

In this paper is pointed to the complex problems of reparatory hard facing of forging dies, which are in exploitation conditions exposed to impact loading and cyclic heating up to elevated temperatures. Steels 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

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those tools are used alloyed steels, which have relatively poor weldability what impedes regeneration of the damaged tools by the hard facing procedures. This is why any reparation by hard facing is practically a unique job, since it asks for the technology to be adapted to each individual working piece. However, the general procedure could 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. In addition, besides the selected technology of hard facing, results of experimental measurements of deformations, which regularly appear because of the heat input during the welding, are presented in this paper.

Nomenclature

BM – base metal
FM – filler metal
HF – hard facing
I – welding current
T_p – preheating temperature
U – welding voltage
b – width of the hard faced layer
d_e – electrode diameter
h – height of the hard faced layer
q_1 – driving energy
s – plate thickness
v_z – welding/hard facing speed

2. Base metal (BM) properties

Steel 55CrMo 8 (SRPS – Č 5742, DIN - 56NiCrMoV7) was applied as the base metal out of which the thin and thick plates were made, with thickness of 7.4 *mm* and 29 *mm*, respectively. 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 [1-5]. The chemical composition, mechanical properties and microstructure of those steels are presented in Tables 1 and 2, respectively [6].

Since the forging shops mainly use dies in the heat tempered condition Q+T (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.

Table 1. Chemical composition of 58CrMo 8 steel.

C	Si	Mn	P	S	Cr	Ni	Mo	V
0.55	0.3	0.7	0.035	0.035	1.1	1.7	0.5	0.12

Table 2. Mechanical properties and microstructure of 58CrMo 8 steel.

Soft annealing			Tempering			B. M. Microstructure
t, °C	HV_{max}	R_m, *MPa*	t, °C	HRC	R_m, *MPa*	
670-700	250	850	400-700	50-30	1700-1100	M + B (interphase)

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's formula [7] and it was within range from $\underline{T_p}$ = 286°C for $\underline{s}$ = 7.4 *mm* up to $\underline{T_p}$ = 315°C for $\underline{s}$ = 40 *mm*. The adopted preheating temperature was $\underline{T_p}$ ≈ 300°C [1, 5-7].

3. Selection of the hard facing method, technology and the filler metal (FM)

Hard facing of the selected samples was done by application of the cored electrodes. Technological parameters of hard facing were determined according to recommendations from [1, 5, 6-9], while the hard facing was executed with two and three passes. This is done to reduce the mixing-dilution, i.e., to obtain the declared properties, provided by the electrodes supplier [12]. 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 D1200 (with thermocouple NiCr-NiAl and measuring range from –50 ºC 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 [8-10]. Hardness of the hard faced layers, according to conducted tests, was stable until 570ºC (tempering temperature) [1, 7]; according to electrodes' supplier hardness is stable up to 600ºC [12-1]. Prior to application, electrodes were dried for 2 *h* at 350-400ºC. Drying of electrodes 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, respectively [1, 12-1].

Table 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

Table 4. Filler metals properties [12].

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 $b \approx$ 10-12 *mm* and height $h \approx$ 1.5 *mm*, while the layer deposited with electrode of diameter ∅5.00 *mm* had dimensions: width was $b \approx$ 16-18 *mm* and height $h \approx$ 2.1 *mm*.

4. Experimental measurement of deformations on the hard faced samples

Samples taken from the thin and the thick plates were prepared by grinding for experimental measurement of deformations (Fig. 2). The plates' dimensions were 394×192×7.4 *mm* - 4 pieces and 394×192×29 *mm* – 3 pieces.

Deformations were measured in two phases: before the hard facing – after the plates' preparation by grinding and immediately after the hard facing. The objective of those measurements was establishing the correlation between deformations, namely the applied technology (the input energy-heat), and the magnitude of the residual stresses, for different thicknesses. After the plates were prepared by grinding, the raster was applied to their surface – the straight lines in three longitudinal directions (I-I, II-II and III-III) and in three lateral directions (IV-IV, V-V and VI-VI), with total of 111 measurement points in the *x-y* plane (Fig. 2). The contact-measuring device OPTON UMC 850 was used for deformations measurement.

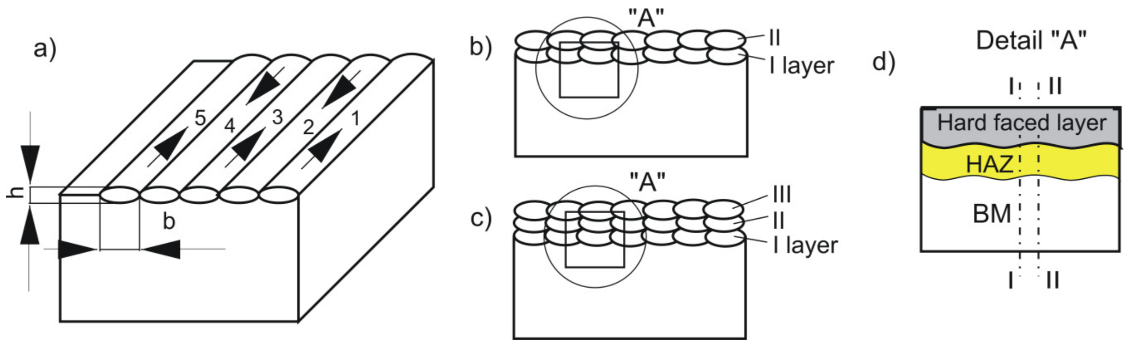

Fig. 1. Order of deposition of the hard faced layers: (a) layer 1; (b) layer 2; (c) layer 3; (d) metallographic slit scheme.

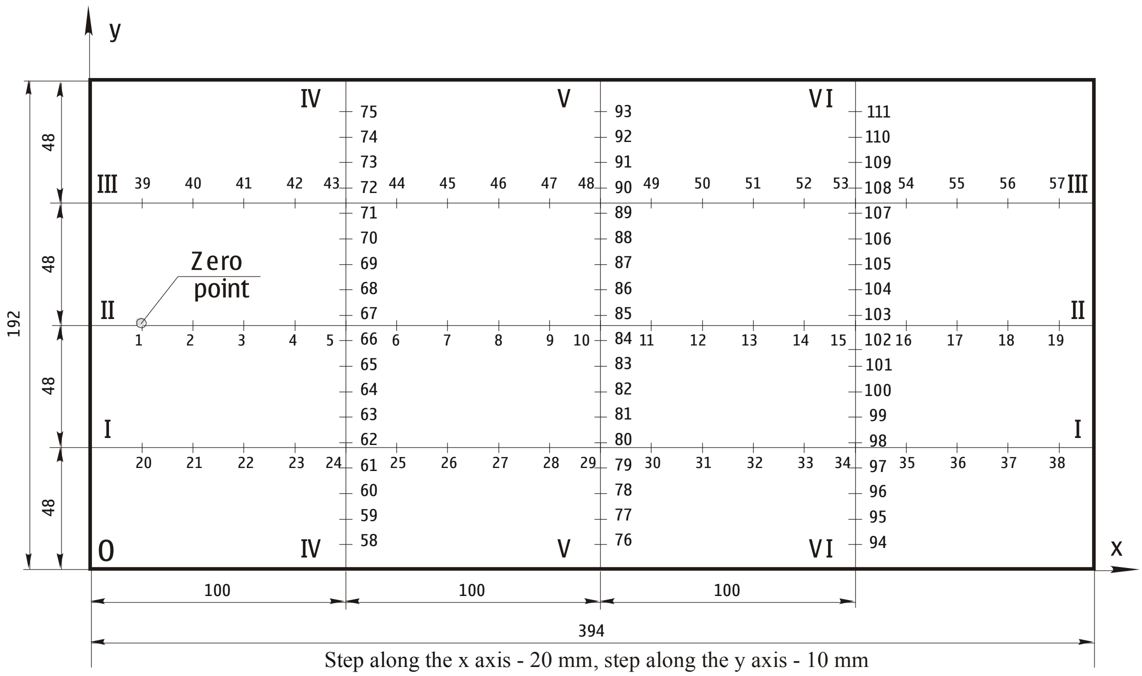

Fig. 2. Schematics of the plates' and their calibration.

5. Results

The longitudinal and lateral deformations were measured within the experimental investigations. Obtained results are presented in the form of diagrams for the corresponding measurements directions (Fig. 2) and plates. The measured longitudinal and lateral deformations for the thick plate (s = 29 *mm*), before and after the hard facing, respectively, are presented in Figures 3 and 4, while in Figures 5 and 6 are presented longitudinal and lateral deformations, respectively, for the thin plate (s = 7.4 *mm*).

In Figures 7 and 8 are presented results of the deformations' measurements for the thin and the thick plate, respectively, in the form of the 3D diagrams with the deformations distribution along the plate's width and length and the corresponding fields.

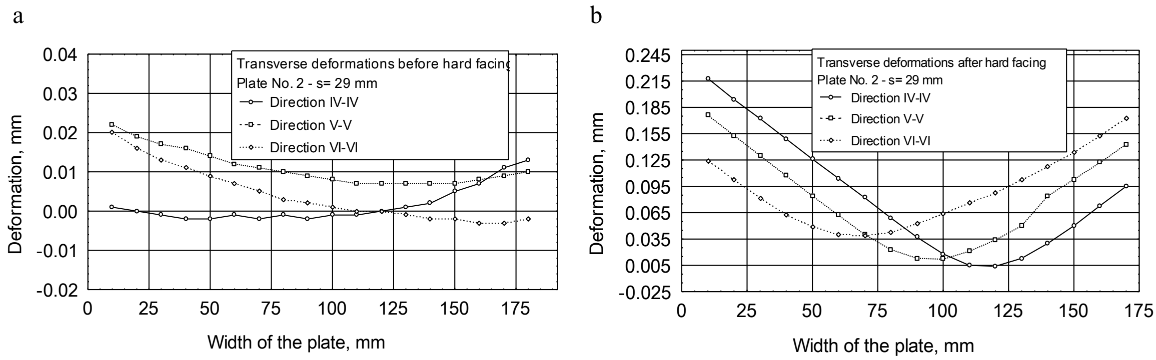

Fig. 3. Lateral deformations of the thick plate #2 (s = 29 *mm*); (a) before; (b) after the hard facing.

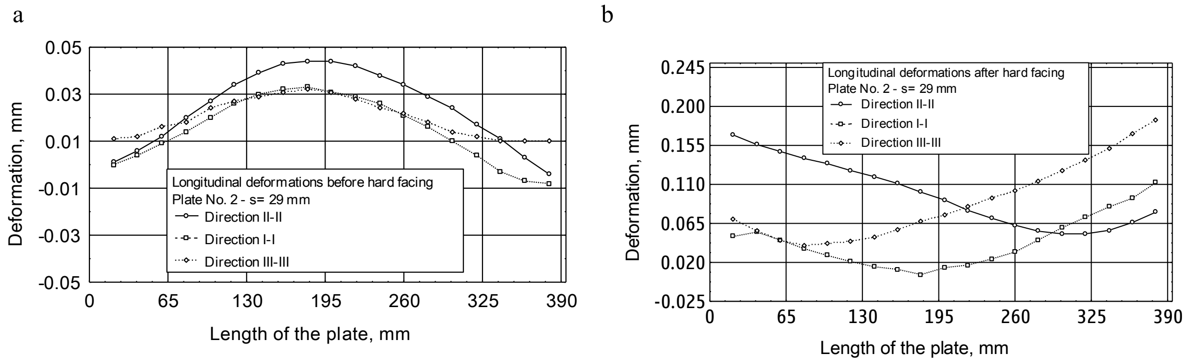

Fig. 4. Longitudinal deformations of the thick plate #2 (s = 29 *mm*); (a) before; (b) after the hard facing.

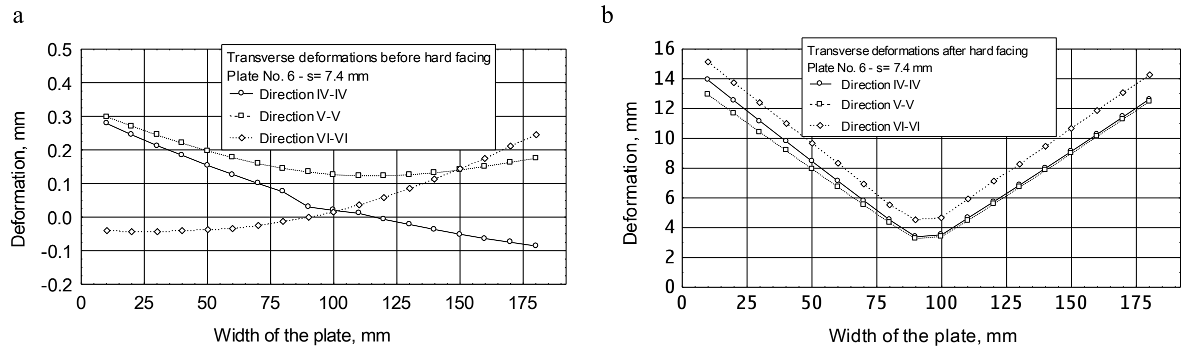

Fig. 5. Lateral deformations of the thin plate #6 (s = 7.4 *mm*); (a) before; (b) after the hard facing.

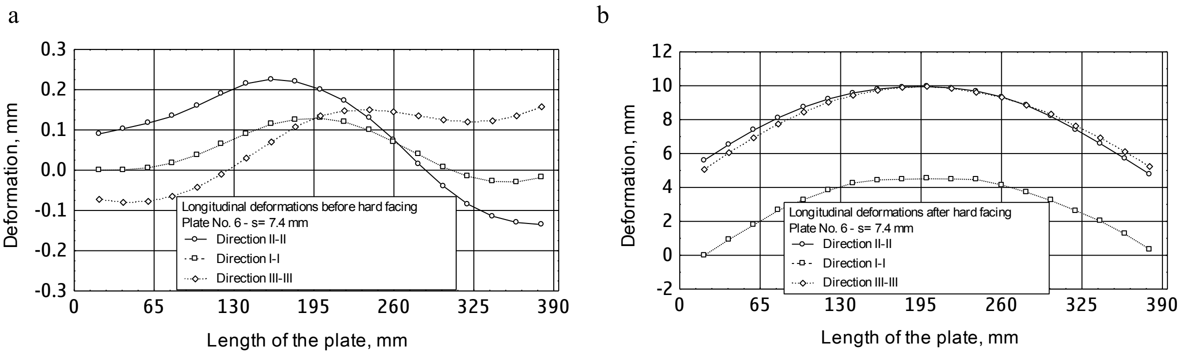

Fig. 6. Longitudinal deformations of the thin plate #6 *s* = 7.4 *mm*); (a) before; (b) after the hard facing.

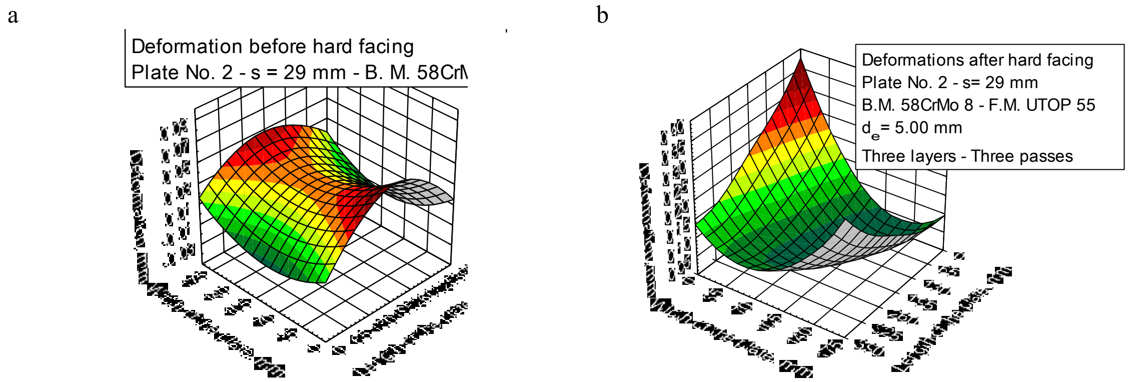

Fig. 7. 3D deformations of the thick plate #2 (*s* = 29 *mm*); (a) before; (b) after the hard facing.

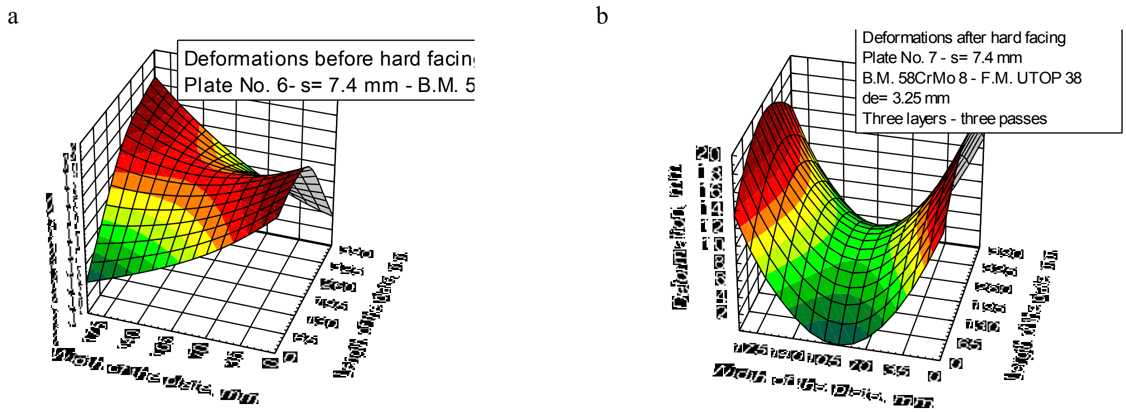

Fig. 8. 3D deformations of the thin plate #6 (*s* = 7.4 *mm*); a – before and b - after the hard facing.

6. Conclusion

The technology of hard facing of the thin and the thick plate is presented in details in this paper. By measurements of deformations, it was established that they are the most prominent in hard facing of the thin plates, when the drastic increase of deformations appear at all the points of the hard faced layer in both the lateral (Fig. 5) and longitudinal direction (Fig. 6). For thick plates, however, the increase of deformations in the lateral directions is negligible (Fig. 3), while the increase in the longitudinal direction (Fig. 4) is more prominent. This is confirmed by the corresponding 3D diagrams (Figs. 7 and 8), what verifies the conclusion that the thin plates (s = 7.4 *mm*) deform more than the thick plates (s = 29 *mm*).

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