Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 111 (2015) 49 – 56
Procedia Engineering
www.elsevier.com/locate/procedia

XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP) (TFoCE 2015)

# Influence of tempering on the deformation level of the multi-layer hard faced samples

Dušan Arsić[a], Vukić Lazić[a], Ružica Nikolić[a,b*], Srbislav Aleksandrović[a], Milan Djordjević[a], Branislav Hadzima[b], Josef Vičan[c]

[a]*Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, Kragujevac 34000, Serbia*
[b]*Research Centre, University of Žilina, Univerzitna 8215/1, Žilina 010 26, Slovak Republic*
[c]*Faculty of Civil Engineering, University of Žilina, Univerzitna 8215/1, Žilina 010 26, Slovak Republic*

**Abstract**

Results of determination of the longitudinal, lateral and angular deformations in hard faced samples are presented in this paper, as well as the influence of the additional heat treatment on the level of residual deformations. Investigation assumed multi-layer hard facing of the two plates (thicknesses 7.4 and 29 mm) made of steel 55CrMo8. Deformations were measured before the hard facing – after the plates' preparation by grinding, immediately after hard facing and after tempering. The objective was to determine if and how much the additional heat treatment (tempering) influences the level of residual deformations in the hard faced joints.


Peer-review under responsibility of organizing committee of the XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP)

*Keywords:* Hard facing; Tempering; Hard faced plates; Deformations.

## 1. Introduction

Reparatory hard facing of forging dies is related to solving numerous tasks including proper selection of filler metals (FM), optimal technology of welding, what also includes decision, which, if any, preheating is necessary. The post hard facing heat treatment is also very important problem, since it influences the level of eventual residual

* Corresponding author. Tel.:+391-64-230-3559
*E-mail address:* ruzicarnikolic@yahoo.com


Peer-review under responsibility of organizing committee of the XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP)
doi:10.1016/j.proeng.2015.07.034

deformations within the hard faced (HF) layers and the heat-affected zone (HAZ). The forging dies are parts that operate in harsh conditions since they are exposed to impact loading and cyclic heating up to elevated temperatures. This is the reason why for their manufacturing the mostly applied are the high quality steels that can sustain high impact loads and at the same time preserve very favorable mechanical properties, as well as wear resistance, at elevated temperatures. Taking into account that those steels are very expensive, reparation (and/or finalizing manufacturing) of tools made of them could be done by hard facing. In that way, both money and time could be saved and the eventual downtime for tools reparation is shortened [1]. Prescribing the optimal hard facing technology is a tedious job, accompanied by numerous model investigations, what was the subject of analysis in some previous articles [2-10]. In some of those publications [7-9] is described the detailed procedure of selecting the filler metal and the optimal reparation technology from the aspect of tribological characteristics of the hard faced layers. The hard facing technology of models is presented in this paper. The deformations, which appeared due to the heat input during the hard facing, were recorded. The objective of this work was to show what is the influence of the heat input on the hard faced layers and to present the level of deformation that can result due to input of the certain amount of heat.

**Nomenclature**

BM – base metal
FM – filler metal
HF – hard facing
HAZ – heat affected zone
$I$ – welding current
Q – quenching
$T$ – (high) tempering
$T_p$ – preheating temperature
$T_{temp}$ – tempering temperature
$U$ – welding voltage
$b$ – width of the hard faced layer
$d_e$ – electrode diameter
$h$ – height of the hard faced layer
$q_l$ – driving energy
$v_z$ – welding/hard facing speed

## 2. Properties of the base metal (BM)

Steel 55CrMo8 (SRPS – Č 5742, DIN – 56NiCrMoV7) was used as the base metal for hard facing. The plates of two different thicknesses were made of this steel – the thin plate of thickness 7.4 *mm* and the thick plate of thickness 29 *mm*. This steel is used for producing the parts and tools that operate at high temperatures (above 600°C) in dynamic loading conditions – like the forging dies. 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 [2, 3]. The chemical composition, mechanical properties and microstructure of those steels are presented in Table 1 [4, 14].

Table 1. Chemical composition, mechanical properties and microstructure of 58CrMo8 steel.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Steel mark 58CrMo 8 | **Chemical composition, %** | | | | | | | | |
| | 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 |
| | **Mechanical properties and microstructure** | | | | | | | | |
| | 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) | | |

Since the forging dies are mainly used in the heat tempered Q + T condition, all the samples were subjected to the same heat treatment. In that way, the exploitation conditions were simulated as close as possible. Hardness was measured on selected samples after the heat treatment, and it ranged from 40 to 42 HRC.

Samples of various thickness ($s$ = 7.4 – 40 *mm*) were hard faced to steels prone to self-hardening (C > 0.35 %). That required application of preheating. The preheating temperature was determined according to Seferian formula [3] 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 [9]. (Note: In this paper are presented results for the two plates only, with thicknesses of $s$ = 7.4 *mm* and $s$ = 29 *mm*.)

## 3. Selecting the hard facing method, technology and the 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 [2-6], while hard facing was executed with two and three passes, for reducing the mixing-dilution, i.e., to obtain the properties declared by the electrodes supplier, but also taking into account large influence of deposition sequence on welding residual stresses and deformation level [13]. The deposition speed was measured in each pass, while the preheating temperature was checked prior to deposition of each new layer. The measuring was done on the Tastotherm D1200 device (measurement range: –50 to +1200ºC).

The 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) were used as the filler metals. They were selected because they are usually applied for hard facing of tools like: steel molds, dies and thorns for pressing. Hard faced layers obtained by their application are tough and resistant to wear and impact [9]. Hardness of the hard faced layers, according to conducted tests, was stable until the tempering temperature of 570ºC [8-9]. The electrodes' supplier stated that hardness should be stable up to 600ºC [15-1]. Electrodes were dried for 2 h at 350-400ºC, before being used for hard facing. This is done because drying of electrodes should cause reduction of the diffused hydrogen and prevent appearance of hydrogen-induced cracks.

Table 2. Parameters of hard facing by the MAG method and filler material properties.

| Hard facing parameters | | | | | | | |
|---|---|---|---|---|---|---|---|
| No. | Electrode mark SŽ Fiprom | Electrode mark DIN 8555 | 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 |
| 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 |

| Filler materials properties | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Electrode mark SŽ Fiprom | Electrode mark DIN 8555 | Chemical composition % C | Cr | Mo | V | W | Current type | Hard faced layer hardness, HRC |
| 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 [5]. Prior to each new pass, the slug was removed by the steel brush. Other layers were deposited according to this scheme.

Table 3. Dimensions of the hard faced layers.

| No. | Electrode mark SŽ Fiprom | Electrode mark DIN 8555 | Core diameter $d_e$, *mm* | Width b, *mm* | Height h, *mm* |
|---|---|---|---|---|---|
| 1 | UTOP 38 | E3-UM-40T | 3.25 | 10-12 | 1.5 |
| 2 | UTOP 55 | E6-UM-60T | 5.00 | 16-18 | 2.1 |

In Table 2 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 [8, 15-1], while the dimensions of the hard faced layers are presented in Table 3.

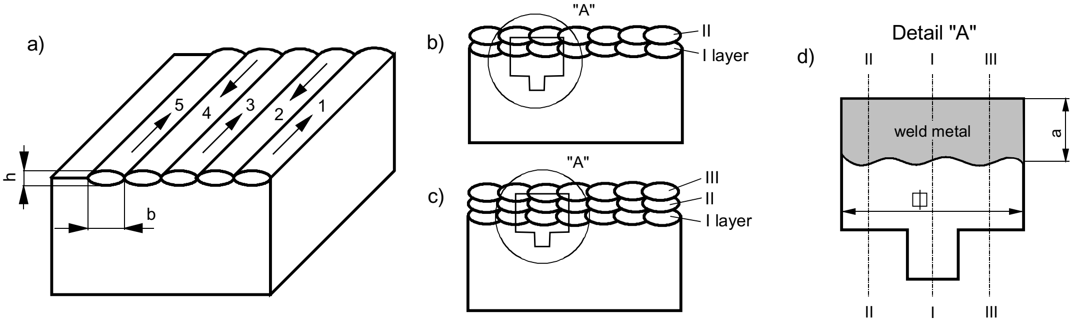


Fig. 1. Order of deposition of the hard faced layers: (a) layer 1; (b) layer 2; (c) layer 3; (d) metallographic slit scheme.

## 4. Experimental measurements of deformations on samples

Samples for experimental recording of deformations were used from both the thin and the thick plates. The plates' sizes were 394×192×7.4 *mm* - 3 pieces and 394×192×29 *mm* - 3 pieces). They were heat tempered and then ground, Table 4. After the hard facing plates were tempered for the purpose of reducing the residual stresses and strains. The tempering temperature was $T_{temp}$ = 520°C [9]. This heat treatment procedure was adopted based both on own previous investigations [10] and on steel manufacturers' recommendations [14].

….Table 4. Hard facing parameters.

| Plate number | 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 |

Deformations were measured in three phases: before the hard facing (after the plates were prepared by grinding), immediately after the hard facing and after tempering. The objective of those measurements was to establish the correlation between deformations (i.e. the applied hard facing technology – the heat input) and the values of the residual stresses, for different plates' thicknesses. The grids were applied to the plates after grinding in three longitudinal and three lateral directions, with 111 measurement points in the *x-y* plane, Figure 2. The OPTON UMC 850 contact coordinate device was used for measurement of deformations.

## 5. Results and discussion

The measurements results – the maximal and minimal deformations, as well as the angular deformations of plates are presented in table 5 and in diagrams in Figs. 3 to 6. In Figs. 3 and 4 are presented the lateral and longitudinal deformation of the thick plate (29 *mm*) and in Figs 5 and 6 are presented the lateral and longitudinal deformation of the thin plate (7.4 *mm*). In Figures 7 and 8 are presented results of deformations' measurements in the form of the 3D diagrams for the thick and the thin plate, respectively.

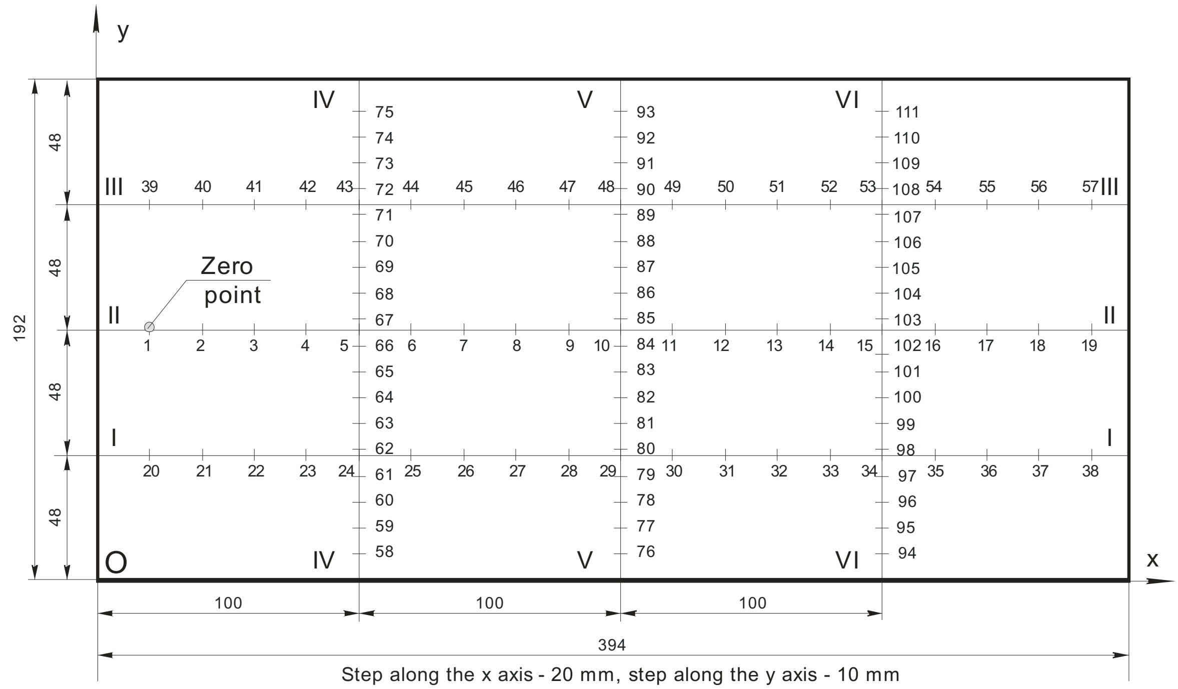


Fig. 2. Schematics of the plates' calibration.

Table 5. Characteristic deformations of the considered plates.

| Measured variables | | | | Plate No. s = 29 *mm* 1 | 2 | 3 | s = 7.4 *mm* 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|
| Deformation [*mm*] | After hard facing | | Max | 0.069 | 0.135 | 0.060 | 3.607 | 5.671 | 7.375 |
| | | | Min | -0.038 | -0.074 | -0.038 | -2.675 | -5.236 | -7.668 |
| | After tempering | | Max | 0.098 | 0.137 | 0.032 | 3.835 | 5.764 | 7.312 |
| | | | Min | -0.157 | -0.208 | -0.025 | -2.976 | -5.441 | -7.245 |
| Angles of transverse deformations [', º] | After hard facing | IV-IV | $\alpha_1$ | 3.1-3.25' | 3.5-7.7' | 2.1-2.1' | 4.1-3.94º | 5.5-6.1º | 6.5-7.4º |
| | | V-V | $\alpha_2$ | 3.2-4.1' | 6.2-6.9' | 0.4-0.7' | 3.7-4.03º | 5.2-6.1º | 6.9-7.5º |
| | | VI-VI | $\alpha_1$ | 3.1-3.8' | 5.9-3.1' | 1.5-1.9' | 3.6-3.7º | 4.7-5.7º | 6.5-6.8º |
| | After tempering | IV-IV | $\alpha_2$ | 0.48-1.6' | 1.6-5.9' | 2.0-1.95' | 3.8-4.2º | 6.0-5.8º | 6.5-7.4º |
| | | V-V | $\alpha_1$ | 1.02-2.3' | 3.7-5.3' | 1.9-2.1' | 3.7-4.3º | 5.6-5.8º | 7.0-7.5º |
| | | VI-VI | $\alpha_2$ | 1.15-2.25' | 3.6-1.8' | 1.95-2.1' | 3.4-4.0º | 5.0-5.4º | 6.6-6.9º |

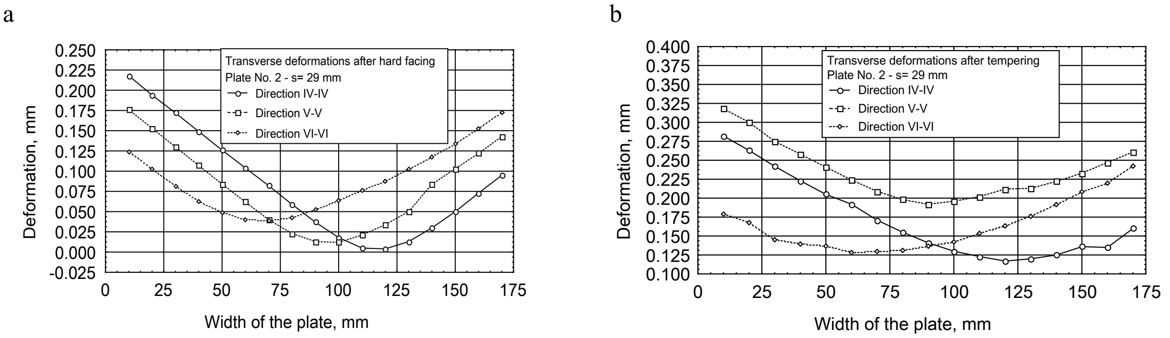


Fig. 3. Transverse deformation of plate no 2 – 29 *mm*; (a) after hard facing; (b) after tempering.

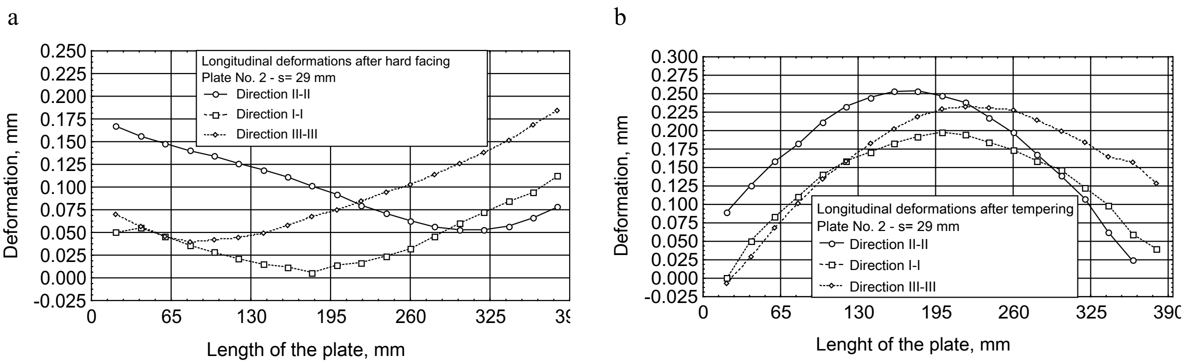


Fig. 4. Longitudinal deformation of plate no 2 – 29 *mm*; (a) after hard facing; (b) after tempering.

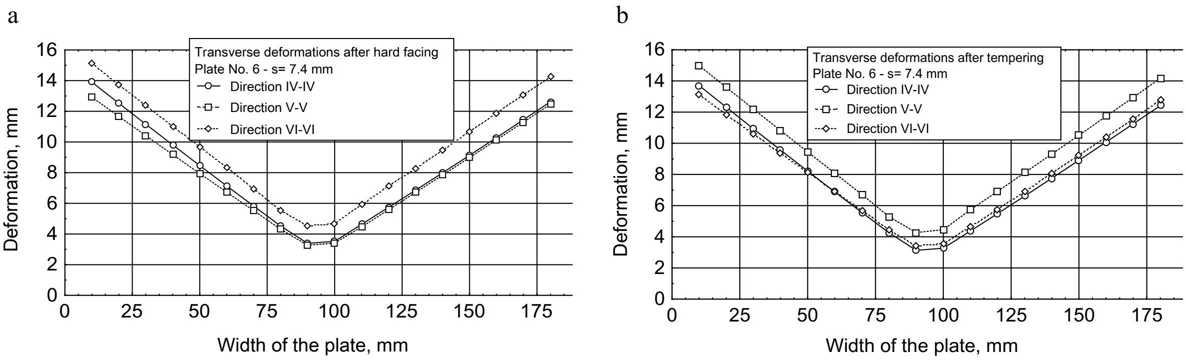


Fig. 5. Transverse deformation of plate no 6 – 7.4 *mm*; (a) after hard facing; (b) after tempering.

a b

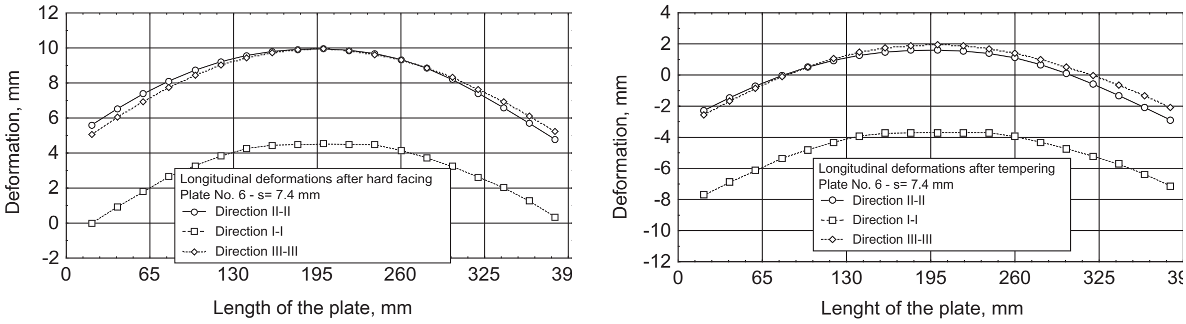


Fig. 6. Longitudinal deformation of plate no 6 – 7.4 *mm*; (a) after hard facing; (b) after tempering.

a b

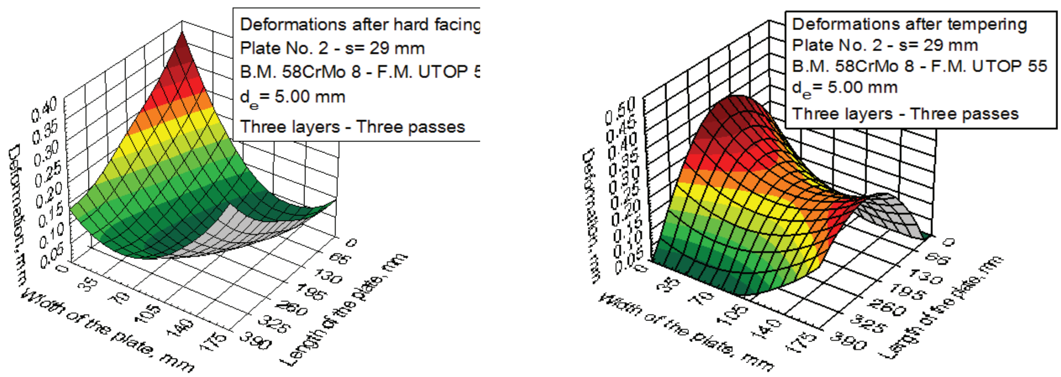


Fig. 7. 3D deformation of plate no 2 – 29 *mm*; (a) after hard facing; (b) after tempering.

a b

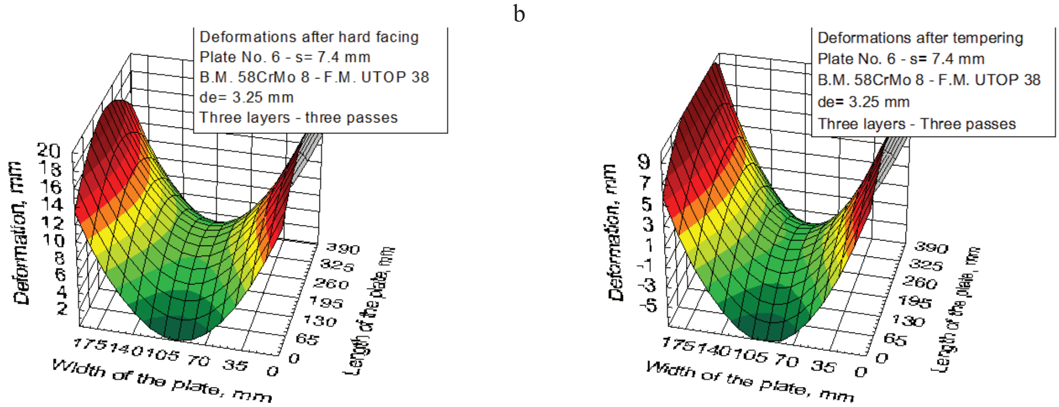


Fig. 8. 3D deformation of plate no 6 – 7.4 *mm*; (a) after hard facing; (b) after tempering.

## 6. Conclusion

Technology of hard facing of the thick and thin plate is presented in this paper in details. The deformations were measured and the influence of the hard facing technology (the heat input) on the level of deformation was investigated, as well as the influence of the additional heat treatment – tempering on level of deformation in the hard faced layers. Through the deformation measurements, it was established that they are the most prominent in hard facing of the thin plates, when deformations increase excessively in all the points of the hard faced joint, both in lateral (Fig. 5) and longitudinal direction (Fig. 6). The case of thick plates is somewhat different, since deformation increase is not so drastic in the lateral direction (Fig. 3), while in the longitudinal direction (Fig. 4) it is also very noticeable. All these observations were confirmed by the 3D diagrams (Figs. 7 and 8), where the total deformations are shown, what justifies the conclusion that the thin plates deform significantly more than the thick ones.

What concerns the investigated influence of tempering on deformation, it was concluded that the strongest influence is imposed to decrease of the longitudinal deformations in thin plates (Figs. 6 and 8). While the influence on thick plates deformations is practically negligible.

## Acknowledgements

This research was partially financially supported by European regional development fund and Slovak state budget by the project "Research Centre of the University of Žilina" - ITMS 26220220183 and by the Ministry of Education, Science and Technological Development of Republic of Serbia through grants: ON174004, TR32036, TR35024 and TR33015. The authors are very grateful for this funding.

## References

[1] R. Wasserman, How to save millions by reparatory welding in machine maintenance, Castolin Eutectic, Institute for advancement of reparatory welding technique and welding technique in machine maintenance, Bor, (2003) (in Serbian).
[2] V. Lazić, R. R. Nikolić, S. Aleksandrović, D. Milosavljević, R. Čukić, D. Arsić, M. Djordjević, Application of hard-facing in reparation of damaged forging dies, Analysis of Technology in Various Industries, SMJiP (editors S. Borkowski, R. Ulewicz), (2014) 127-143.
[3] V. Lazić, M. Jovanović, D. Adamović, N. Ratković, Selection of the optimum technology of the forging dies reparation from the aspect of tribological characteristics, Tribologia - teoria i praktika, 28/2 (2005) 11-31.
[4] V. Lazić, A. Sedmak, S. Aleksandrović, D. Milosavljević, R. Čukić, V. Grabulov, Reparation of damaged mallet for hammer forging by hard facing and weld cladding, Technical Gazette 16/4 (2009) 107-113.
[5] D. Arsić, V. Lazić, R. Nikolić, A. Sedmak, S. Aleksandrović, M. Djordjević, R. Bakić, I. Samardžić, Selection of the optimal hard facing (HF) technology of damaged forging dies based on cooling time $t_{8/5}$, Metalurgija - Metallurgy, 54 (2015) (In press)
[6] V. Lazić, M. Mutavdžić, D. Milosavljević, S. Aleksandrović, B. Nedeljković, P. Marinković, R. Čukić, Selection of the most appropriate technology of reparatory hard facing of working parts on universal construction machinery, Tribology in Industry, 33/1 (2011) 18-27.
[7] S. Marković, LJ. Milović, A. Marinković, T. Lazović, Tribological aspect of selecting filler metal for repair surfacing of gears by hard facing Structural Integrity and Life, 11 (2011) 127-130.
[8] V. Lazić, M. Jovanović, J. Ristović, B. Nedeljković, D. Josifović, D. Adamović, Influence of heat treatment after hard facing on working characteristics of the hard faced forging dies, Welding and welded structures, 46/1-2 (2001) 5-11. (In Serbian)
[9] 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, 19/3 (2012) 95-103.
[10] V. Lazić, A. Sedmak, B. Krstić, R. Nikolić, S. Aleksandrović, R. Čukić, Determination of the cooling rate and its influence on the hard-faced forging dies properties, Materials Engineering, 16/3a (2009) 124-131.
[11] E. I. Beljski, Persistence of forging dies, "Science and technics" Publishing, Minsk, 1975. (in Belarus)
[12] R. Pasierb, Welding of chromium-molybdenum steels for operating at elevated temperatures, WNT, Warszawa, 1982.
[13] D. Deng, Influence of deposition sequence on welding residual stress and deformation in an austenitic stainless steel J-groove welded joint, Materials and Design 49 (2013) 1022–1033.
[14] Standards and catalogues of the base materials:
1. Steel mill "Ravne", Slovenia
2. Thyssen Marathon Edelstahl: Verkaufsgesellschaft M.B.H., Vosendorf, Germany
3. Atlas zur Wärmebehandlung der stähle, Verlag stahleisen M.B.H Düsseldorf, Germany
[15] Catalogues of the filler metals:
1. Steel mill "Jesenice-Fiprom", Slovenia
2. Bohler-Kapfenberg, Messer Griesheim-Frakfurt am Main, Germany
3. Esab-Göteborg, Lincoln Electric-USA.