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THE INFLUENCE OF HEAT TREATMENT BY ANNEALING ON CLAD PLATES RESIDUAL STRESSES

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The influence of applied clad procedure as well as heat treatment by annealing (650 °C/2h) on level and nature of residual stresses was researched. Three clad procedures are used i.e. hot rolling, submerged arc welding (SAW) with strip electrode and explosion welding. The relaxed deformation measurement on clad plate surfaces was performed by applying centre-hole drilling method using special measuring electrical resistance strain gauges (rosettes). After performed measuring, size and nature of residual stresses were determined using analytical method. Depending of residual stresses on depth of drilled blind-hole is studied.

Key words: residual stresses, heat treated clad plates; centre-blind holes drilling, electrical resistance strain gauges (rosettes)

Utjecaj toplinske obradbe žarenjem na zaostala naprezanja platiranih ploča. U članku su prikazani rezultati istraživanja utjecaja toplinske obradbe žarenjem(650 °C/2h) na veličinu i narav zaostalih naprezanja platiranih limova. Korištena su tri postupka platiranja tj. toplo valjanje, elektrolučno navarivanje pod praškom (EPP) elektrodnim trakama te platiranje eksplozijom. Provedena su mjerenja relaksiranih deformacija metodom bušenja središnjeg provrta koristeći elektro-otporničke mjerne rozete. Nakon provedenih mjerenja, veličina i narav zaostalih naprezanja su određeni koristeći analitičku metodu. Istraživana je ovisnost vrijednosti zaostalih naprezanja o dubini zabušivanja središnje rupe.

Ključne riječi: zaostala naprezanja, toplinska obradba platiranih ploča, bušenje središnjeg provrta, elektro-otporničke mjerne rozete

INTRODUCTION

Establishing size and nature of residual stresses at plated construction of dissimilar steel is very important. Knowledge of tensile residual stresses is essentially due to possible appearance of cracking tendency of corrosion resistant steel to stress corrosion, while knowledge of pressured residual stresses is important because of their influence on construction stability [1-2].

Quantitatively, determination residual stresses on surface of plated austenite corrosion resistant steel was performed using semi-destructive method i.e. centre blind-hole drilling procedure by relaxed deformations with electrical gauge measurement (rosettes).

MEASUREMENT OF RESIDUAL STRESSES AND ANALYSIS

Intention of specified experiment was establishing of annealing influence on residual stresses of plating stainless steel surface depending on clad procedure.

The experiments plan of measuring residual stresses by centre-hole drilling using electric-resistant measuring strain gauges (rosettes) is presented in the Table1.

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Dimensions of examined plates were 100 × 100 × δ mm. The base material ASTM A387 Gr.12 is delivered in normalised and plating ASTM A240 TP304L in quenched state (Tables 2-3).

Table 1 **Plan of performed experiments on residual stresses measurement**

Residual stresses measurement	B1 no heat treatment	B2 heat treatment / 650 °C/2h
Sample plated by hot rolling A1	A1B1	A1B2
Sample plated by SAW with striped electrodes A2	A2B1	A2B2
Sample plated by explosion welding A3	A3B1	A3B2

The procedure is established on fact that using hole-drilling in elastic body in which exist strain state, changing of strain state the elastic deformations occurs on surface of body. Drilling of very small holes dimension in elastic body it could be established strain state practically in one point and by in this resulting in insignificantly damage of construction. The great influence on accuracy of measured relaxed deformation by centre hole-drilling method has possible un-centricity of centre-drilled blind hole. Improved method use very pre-

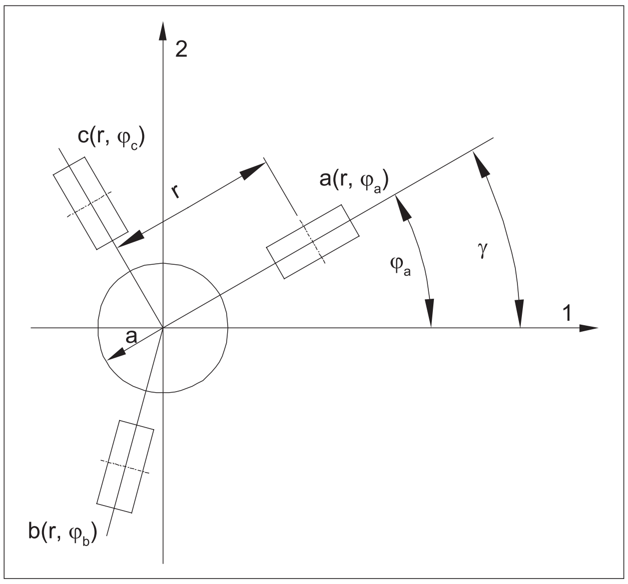

Figure 1 Rosettes plan for measurement of residual stresses using centre-hole drilling procedure

ciously optical devices as well as rosettes are supplied with special centric alignment in her centre. Today technique will lead to slight misalignment errors reflecting the skill of the operator. Concentricity misalignment (within 0,15 mm) will produce much lower errors in recorded strain values than will the holes oval (typically 0,24 mm).When the workpiece is thick, it's enough to drill a hole no deeper than its diameter, this leads to the relaxation of the major part of residual stresses [3-5]. If the depth of the hole is smaller, an amount of the stresses may not be released. In case of the thin plates, when the diameter of the hole is larger than the thickness, the relaxation of the residual stresses appears when the hole is drilled. Using this method, the determination of residual stresses by drilling of very small holes depth is enabled. Use of rosettes with electrical measuring strain gauges and angles between ones 0/90/225 ° are common. Using this configuration of tension gauges, three radial deformations could be measured (Figure 1).

In case of drilling penetrate-hole, with radius 'a' (Figure 1), the base stress distribution in accordance with Kirsch's solution will be determined by equations [2-4]:

$$\sigma_r = \frac{\sigma_1 + \sigma_2}{2}\left(1 - \frac{a^2}{r^2}\right) + \frac{\sigma_1 - \sigma_2}{2}\left(1 - 4\frac{a^2}{r^2}\right)\cos 2\varphi$$

$$\sigma_\varphi = \frac{\sigma_1 + \sigma_2}{2}\left(1 + \frac{a^2}{r^2}\right) - \frac{\sigma_1 - \sigma_2}{2}\left(1 + 3\frac{a^4}{r^4}\right)\cos 2\varphi \qquad (1)$$

$$\tau_{r\varphi} = -\frac{\sigma_1 - \sigma_2}{2}\left(1 - \frac{a^2}{r^2}\right)\left(1 + 3\frac{a^2}{r^2}\right)\sin 2\varphi$$

as well as deformations are determined with:

$$E \cdot \varepsilon_r = \frac{\sigma_1 + \sigma_2}{2}\left[\left(1 - \frac{a^2}{r^2}\right) + \nu\left(1 + \frac{a^2}{r^2}\right)\right] +$$

$$+ \frac{\sigma_1 - \sigma_2}{2}\left[\left(1 - 4\frac{a^2}{r^2} + 3\frac{a^4}{r^4}\right) + \nu\left(1 + 3\frac{a^4}{r^4}\right)\right]\cos 2\varphi$$

$$E \cdot \varepsilon_\varphi = \frac{\sigma_1 + \sigma_2}{2}\left[\left(1 + \frac{a^2}{r^2}\right) - \nu\left(1 - \frac{a^2}{r^2}\right)\right] - \qquad (2)$$

$$- \frac{\sigma_1 - \sigma_2}{2}\left[\left(1 - 3\frac{a^4}{r^4}\right) + \nu\left(1 - 4\frac{a^2}{r^2} + 3\frac{a^4}{r^4}\right)\right]\cos 2\varphi$$

$$E \cdot \gamma_{r\varphi} = -2(1+\nu)\frac{\sigma_1 - \sigma_2}{2}\left(1 - \frac{a^2}{r^2}\right) + \left(1 + 3\frac{a^2}{r^2}\right)\sin 2\varphi$$

The equipment used for this work is known as the RESTAN (REsidual Stress ANalysis) system and was purchased from HBM of Germany [6-8]. Deformations determination is on plated samples surfaces performed and at the same time for each level of influences factors are (joints procedure and heat treatment) two plates examined. On Figure 2 is presented plan of rosettes connection with measuring amplifier. The greases and surfaces impurities are cleaned and the measurement gauges (rosettes) bond by viscous adhesive HBM Z70.

Table 2 **Mechanical properties of base and plating materials**

Mechanical properties of materials	Yield Strength $R_{p0,2}$/MPa	Tensile Strength R_m/MPa	Elongation A_5/%	Impact Energy K_v/ J
ASTM A387, Gr. 12, (δ=14mm)	421	598	26	169
ASTM A240 TP304L (δ=2mm)	218	591	63	210

Table 3 **Chemical analysis of materials in joints**

Materials	Chemical compositon of elements / %							
	C	Si	Mn	P	S	Cr	Mo	Ni
ASTM A 387 Gr.12, δ=14mm	0,13	0,28	0,78	0,008	0,010	1,07	0,52	-
ASTM A 240 TP 304L, δ=2mm	0,026	0,48	1,33	0,030	0,030	18,7	-	10,8
First bead SAW strip 60x0,5mm, AWS E 309L, δ=3mm	0,013	0,29	1,68	0,013	0,003	23,92	-	13,05
Second bead, δ=3mm SAWstrip 60x0,5mm, AWS E 308L	0,021	0,94	1,00	0,017	0,006	20,50	-	11,4

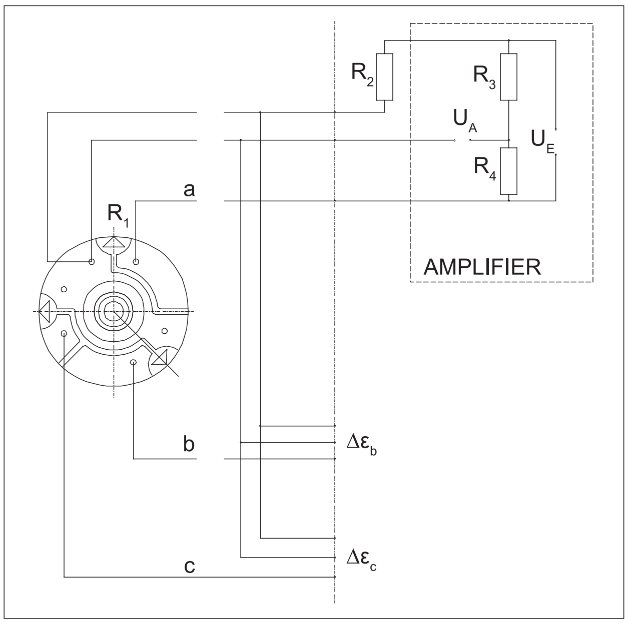

Figure 2 Connection plan of measurement gauges (rosettes) type HBM 1.5 / 120RY61, with measuring amplifier KWS 3050.

Compensative measurement gauge HBM 1,5 / 120 LY11 is placed on extra tile from austenite corrosion resistant steel.

The rosettes are connected with measuring devices by classic telephone wiring 1 mm of diameter and 50 m of length. The others installed equipment was digital indicator DA 3415A and installed printer D21.

Holes drilling device is centered and stick on surface of corrosion resistant steel.

After bringing into balance of measuring amplifier the drilling was performed using special drill 1,5 mm of diameter.

The drilling was performed manually by low number of revolutions per minute as well as the measurement of elastic deformations simultaneous. The elastic deformations are measured on drill deepness (Z): 0,5; 1,0; 1,5 and 2,0 mm (Figure 3).

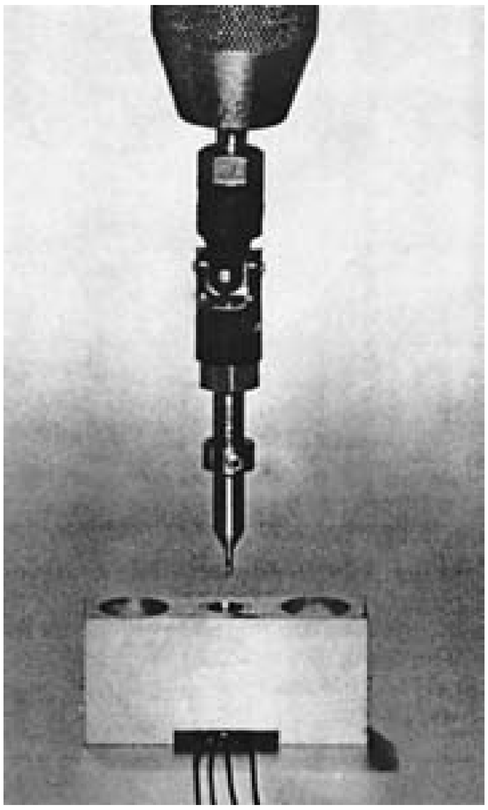

Figure 3 Photographs record of HBM manual mechanical drilling and centre alignment device

The principal stresses are calculated in accordance with equation (Table 4):

$$\sigma_{1,2} = A \cdot (\Delta\varepsilon_a + \Delta\varepsilon_c) \pm$$
$$\pm B \cdot \sqrt{(\Delta\varepsilon_c + \Delta\varepsilon_a)^2 + (\Delta\varepsilon_a - 2\Delta\varepsilon_b + \Delta\varepsilon_c)^2}$$

Table 4 **Calculated values of maximum and minimum principal stresses $\sigma_{1(SIGMA1)}$, $\sigma_{2(SIGMA2)}$ at surface of clad plate depend on blind hole depth *Z***

Residual stresses measurement by centre hole drilling procedure Principal stresses σ_1; σ_2; MPa depth of holes *Z*		no heat treatment B1 (delivered condition)				heat treatment by annealing B2(650 C / 2 hours)			
		Plate1,(P1)		Plate2,(P2)		Plate1,(P1)		Plate 2,(P2)	
		σ_1	σ_2	σ_1	σ_2	σ_1	σ_2	σ_1	σ_2
Samplesplated by hot rolling A1	*Z*1=0,5mm	-	-	-21	-39	-	-	-65	- 97
	*Z*2=1,0mm	+68	- 15	-39	-92	+65	-139	-120	164
	Z3=1,5mm	-	-	-32	-82	-	-	-130	-174
	Z4=2,0mm	+86	- 26	-50	-101	+59	-145	-127	-170
Samples plated by SAW stripped-2beads beads electrode A2	Z1=0,5mm	-	-	+69	+29	-	-	+44	+20
	Z2=1,0mm	+44	- 64	+70	-35	+71	-60	+34	+19
	Z3=1,5mm	-	-	+87	-41	-	-	+85	+8
	Z4=2,0mm	+50	- 58	+108	-31	+36	-87	+92	+5
Samples plated by explosion welding A3	Z1=0,5mm	-	-	-	-	-	-	-	-
	Z2=1,0mm	-139	+279	-	-	-191	-235	-	-
	Z3=1,5mm	-	-	-	-	-	-	-	-
	Z4=2,0mm	+208	-324	-258	+444	-233	-297	-369	-440

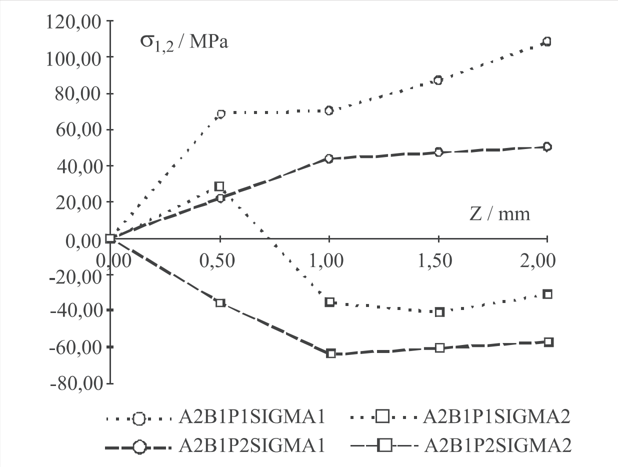

Figure 4 Maximum and minimum principal stress distribution σ_1 σ_2 at surface of clad plate for model A2B1 depending on depth blind hole Z (plated-overlayed by SAW strip-electrode- clad state)

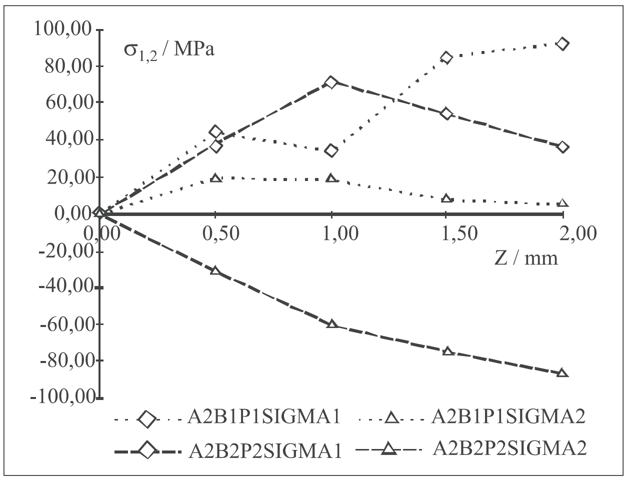

Figure 5 Maximum and minimum principal stress distribution σ_1 σ_2 at surface of clad plate for model A2B2 depending on depth blind hole Z (plated-overlayed by SAW strip-electrode-anealed state)

THE RESULTS ANALYSES OF RESIDUAL STRESSES MEASUREMENT

On the basis after drilling measured relieved deformations values εa, εb and εc as well as materials and measuring rosettes characteristics, calculated residual stresses (in acc. with equation 3) depend on blind- and for rosettes HBM 1.5 / 120 RY61 are:

$$A^* = \frac{E}{4A} = \frac{E}{0.1894(1+\nu)}$$
$$B^* = \frac{E}{4B} = \frac{E}{0.7576 - 0.0606\cdot(1+\nu)} \quad (3)$$

for clad material: E_a = 190 x 10^3 MPa; ν = 0,3.

On the basis after drilling measured relieved deformations values ε_a, ε_b and ε_c as well as materials and measuring rosettes characteristics, calculated residual stresses in accordance with equation (3) depending on blind hole depth (Z), are presented on Table 4.

At all applied kind of cladding procedures using heat reatment by anealing a drop of residual stresses is established.

The changing of residual stresses (size and nature) specimens plated by submerged-arc welding(SAW) by striped electrodes in two beads are graphicaly presented in Figures 4-5.

Even the nature of residual stresses changed from pressured into tensile stresses by anealling.

This alternation is unfavourable from the standpoint of plating corrosion resistant steel inclination to stress corrosion fissure.

CONCLUSIONS

Type of plating procedures has significantly influence on value of residual stresses more than applied heat treatment by anealing.

At specimens plated by rolling and explosion procedure high pressured residual stresses are not significantly changend (in range and nature) after used heat treatment.

Significant influence of used heat treatment on range and nature of plating surface residual stresses is present at specimens plated by submerged-arc welding (SAW) with strip electrodes in two beads.

The transformation of pressured stresses into tensile stresses is very unfavourable from viewpoint tendency of plating corrosion resistant steel to stress corrosion cracking.

After drilling max. depth of holes Z_{max} = 2 mm the major part of residual stresses is relaxed.

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