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EFFECT OF CLADDING PROCEDURES ON MECHANICAL PROPERTIES OF HEAT TREATED DISSIMILAR JOINT

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The specimens plated by different cladding procedures (hot rolling, submerged arc welding surfacing using strip electrode (SAW) and explosion welding) were heat treated by annealing (650 °C through 2 hours). Charpy impact energy testing, as well as shear strength testing of clad joints were performed. Testing results indicated significance of cladding procedure and determined heat treatment influences on stated mechanical properties.

Key words: cladding, heat treatment by annealing, mechanical properties, dissimilar joint

Učinak postupka platiranja na mehanička svojstva toplinski obrađenog raznovrsnog spoja. Uzorci platirani različitim postupcima platiranja (toplim valjanjem, elektrolučnim postupkom navarivanja pod prahom elektrodnom trakom (EPP) i eksplozijskim zavarivanjem) toplinski su obrađivani žarenjem (650 °C tijekom 2 sata). Provedena su ispitivanja Charpy udarne radnje loma kao i smične čvrstoće platiranog spoja. Rezultati ispitivanja utvrđuju značajnost utjecaja postupka platiranja i toplinske obradbe na navedena mehanička svojstva.

Ključne riječi: platiranje, toplinska obradba žarenjem, mehanička svojstva, raznovrsni spoj

INTRODUCTION

Clad steel is a composite product developed to provide effective and economic utilisation of expensive materials. The cladding layer that will be in contact with the corrosive media is made of the corrosion resistant alloys, whilst the less expensive base steel covers the strength and toughness required to maintain the mechanical integrity. Clad steel plates are utilised in processing vessels, heat exchangers, tanks and storage facilities. Clad plates can be produced by hot rolling, weld surfacing and explosive bonding. More than 90 % of worldwide clad plate production relates on hot roll-bonding.

Cleaned surfaces of the cladding and base materials are assembled and form „sandwich“ of two clad slabs with the clad surfaces in common with a layer of a separating compound (such as Cr_2O_3 or ZrO_2 powder) to prevent the surfaces sticking jointly [1]. Two slabs are welded together around the edges to prevent separation during rolling. Surface oxidation of the cladding during rolling is prevented by evacuating „sandwich“- construction or replacing the air with argon [2-3]. Advantages of rolling the sandwich construction are primarily in the fact that cladding layer does not contact the steel rolls during the rolling, so it is not contaminated. Rolling two slabs together allows thinner plates producing and „sandwich“ does not distort, as the tendency for the clad plates to curl due to differential elongation of the cladding and base material is compensated [4]. The plate rolling process is normally followed by heat treatment, which is usually required to restore the cladding to the solution annealed condition and to provide for backing material correct heat treatment condition (normalised or quenched and tempered, etc). The solution annealed temperature depends upon cladding alloy type and is usually in the range of 950 ºC - 1150 ºC. Plates separation is followed by cleaning, cut sizing, and visually and ultrasonic inspection.

MATERIALS AND EXPERIMENTS

Presented experiment consisted of plate bonding by different cladding procedures (hot rolling, submerged arc welding-surfacing using strip electrode (SAW) and explosion welding). Afterwards, clad plates were heat treated by annealing (650 ºC through 2 hours). Significance of cladding procedure and heat treatment influences on mechanical properties was studied. Explosion bonding of metals [5-8] was performed on identical combination of materials and thicknesses as at samples plated by hot rolling. The following materials were used: low alloyed ferritic-pearlitic steel as base material, quality of which was in acc. with ASTM A387 Gr.12 thickness 14 mm, and austenitic high alloyed corrosion resistant steel as clad material, the quality of which was in acc. with ASTM A240 TP304L thickness 2 mm (Table 1). The base material was delivered in normalised condition, while cladding material was in quenched condition. Clad plates were tested on bonding defects by ultrasonic method with normal probes at 2 and 5

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MHz. Cladding by hot rolling was performed in acc. with producers patented procedure on temperature above 1100 °C. Rolling was finished on temperatures around 900 °C. Afterwards the package of two plates cooled down in still air.

Table 1 **Tested properties of used materials**

Base and cladding materials		ASTM A 387 Gr.12	ASTM A 240 TP304L
Elements content, cwt / %	C	0,013	0,021
	Si	0,29	0,94
	Mn	1,68	1,00
	P	0,013	0,017
	S	0,003	0,006
	Cr	23,92	20,50
	Ni	13,05	11,40
Yield strength R_e / MPa		421	218
Tensile strength R_m / MPa		598	591
Elongation δ5 / %		26	63
Charpy impact energy / J		169	210

Submerged arc welding (SAW)-surfacing was performed by using strip electrodes (Table 2). Choice of strip electrodes was done in acc. with WRC-1992 diagram with intention to avoid an overlay brittleness (Figure 1) [9-10]. Surfacing was performed in two beads. In that way it was possible to obtain joint chemical homogeneity, as well as to prevent under-cladding cracks appearance (reheat cracking) by normalisation of previous bead with the next bead deposit (Table 3) [11-13].

Table 2 **Composition of filler materials**

Filler material for SAW		1 Strip 60x0,5 UTP 6824 LC Flux UP flux 6824	2 Strip 60x0,5 UTP 6820 LC Flux UP flux 6820
Overlaying-surfacing		AWS / E 309L Creq./Nieq=1,77	AWS / E 308L Creq./Nieq=1,69
Elements content, cwt / %	C	0,013	0,021
	Si	0,29	0,94
	Mn	1,68	1,00
	P	0,013	0,017
	S	0,003	0,006
	Cr	23,92	20,50
	Ni	13,05	11,40
	Fe	Rem.	Rem.

Overlaying was performed in a device to prevent plate distortion. Afterwards clad plate was tested by dye penetrates method, with intention to discover surface errors. Ultrasound method tandem-technique with 70° - angle probes frequency 2 MHz was used to discover under-cladding cracks caused by heat affected zone (HAZ) reheating. Control of δ - ferrite content at surface bead is performed by the Foerster measuring device, where 5,4 % was measured. Charpy impact energy was tested in acc. with EN 10045/DIN 50115, with notch positioned in thicknesses direction on device RPSW30 with energy capacity of 300 J. Shear strength testing was performed on testing equipment MWM type EU40 with measuring range 100 kN according to ASTM A264) [14].

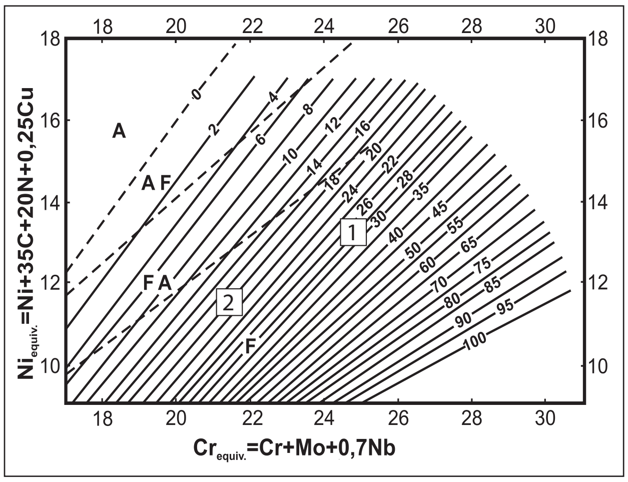

Figure 1 WRC1992-diagram [9] with position of beads deposits selected in Table 3. (1Creq./Nieq=1,77 and 2Creq./Nieq=1,69)

Table 3 **Review of SAW characteristics**

Parameters and characteristic of SAW (submerged arc welding) overlaying	
Electrode strip and flux (1. bead, dim. 60 x 0,5 mm) -dim. 60 x 0.5 mm)	UTP 6824LC; UP Flux 6824
Electrode strip and flux (2.bead,-dim. 60 x 0,5 mm)	UTP 6824LC; UP Flux 6820
Overlaying current strength /A	580...600
Overlaying current tension /V	29...30
Overlaying velocity /cm x min $^{-1}$	≅ 20
Preheating temperature ϑp /°C	≅ 150
Interlayer temperature ϑm /°C	≅ ϑp /°C
Beads overlapping /mm	3...4
Total overlay elevation /mm	6...7

RESULTS AND DISCUSSION

Charpy impact energy testing. Necessity of heat treatment application at low alloyed ferritic-pearlitic steel joints was estimated by value of Charpy impact energy, which was the material base indicator of brittle fracture. Heat treatment at clad materials had probably favourable influence on base low alloyed ferritic-pearlitic steel material, but it could have had damaging influence on clad high alloyed austenitic corrosion resistant material. Therefore the testing on specimens with different volume share (10 %; 25 %) of clad austenite materials was performed. The results achieved by using high energy device capacity had qualitative value (Table 4). Influence of cladding procedures and clad material volume share, as well as applied heat treatment on Charpy impact energy values was presented in the Figure 2. The testing led to conclusion that clad austenite material volume share had no significant influence on Charpy impact energy values, which can be explained with small volume share (10 %; 25 %) of cladding austenite materials. That justified the standardised method of clad materials impact energy testing, which was performed only on the base-backing material.

Main influence on Charpy impact energy values of clad specimens was the heat treatment related to clad-

Table 4 **Charpy impact testing results**

Charpy Impact Energy / J	B1 delivered status		B2 annealed 650 ^{0}C /2 h	
	C3 25 %	C2 10 %	C3 25 %	C2 10 %
A1 Hot rolling	5	5	3	5
	5	5	5	4
	5	5	5	5
A2 SAW overlayed	6	5	5	6
	5	5	4	4
	5	5	4	4
A3 Explosion cladded	6	5	3	3
	7	4	2	4
	6	6	4	5

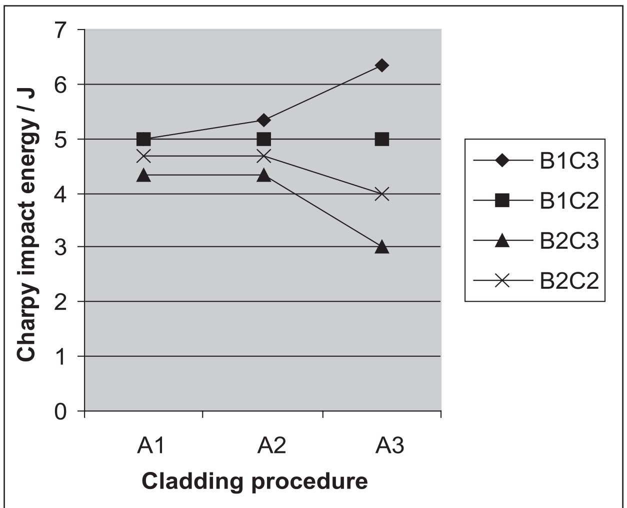

Figure 2 Significance of tested factors' influences on Charpy impact energy

ding procedure. Applied heat treatment had beneficial influence on base low alloyed ferritic-pearlitic steel brittleness reduce, but it was partly detrimental to clad austenitic stainless steel. Due to applied heat treatment the volume of delta-ferrite was decreased, what caused cladding brittleness and possible stress corrosion cracking as a consequence of decomposition and transformation into carbides and intermetallic phases (σ-phase).

The most characteristic drop of Charpy impact energy values was noticed at heat treated explosion clad specimens. It could be concluded that the post heat treatment was not advisable at explosion clad plates. That could be explained by nature of explosion welding process as solid state process at high rate deformation after shock wave loading.

Shear strength testing. Successfulness of applied procedure, i.e. cladding procedure verified the joint strength testing. The joint strength of dissimilar clad steel was estimated by shear strength testing. Shear strength testing results were shown in Table 5.

Histograms of clad joint strength dependence upon applied cladding and heat treatment procedures are presented in Figure 3. Results indicated 10-15 % lower values of shear strength test of heat treated specimens related to non-treated specimens. That fact was particularly expressed at specimens clad by hot rolling. These values were on average the lowest, but still above standard limit (140 MPa). This could be explained by assumption that all as-delivered status hot-rolled clad specimens had characteristic decarbonised zone.

Table 5 **Shear strength testing results**

Shear strength / MPa (ASTMA 264)	B1 no annealed	B2 annealed 650 ^{0}C /2 hours
A1 Hot rolled	328	307
	394	298
	369	343
A2 SAW overlayed	405	361
	362	376
	401	301
A3 Explosion cladded	440	417
	528	432
	369	349

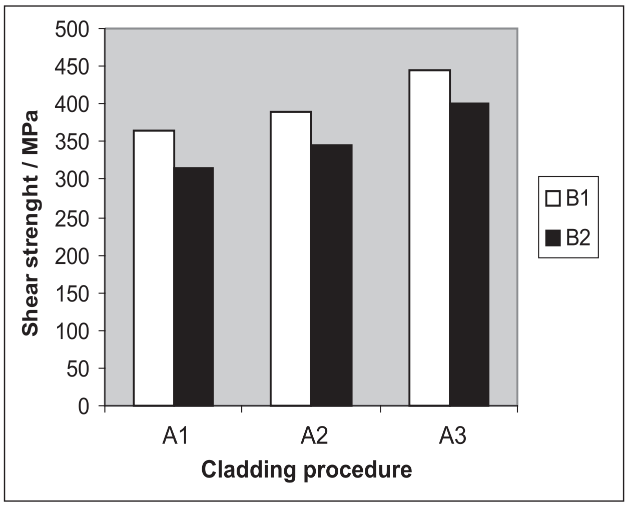

Figure 3 Clad joint strength dependence upon applied cladding and heat treatment

Formation of the bond in hot rolled plate depended on diffusion between the cladding and base materials, which can result, in certain combinations, in hardening at the interface due to precipitation of intermetallic phases or carbides. In cases where the initial slab was plated before hot rolling or inserted metal was used, such intermetallic phases did not form since the nickel or iron layer acted as a buffer. Careful control of material chemistry, particularly the base steel carbon content, can also reduce the risk of precipitates at the interface in absence of an intermediate nickel or iron layer (made by electroplating or inserting).

Upon analysis of the results, it was noticed that highest values of shear strength testing were obtained at explosion clad specimens. Explosion cladding process is procedure of cold pressure bonding at high velocity with no time for diffusion developing. Influence of cladding procedure and applied heat treatment procedure were directly in connection with heat inputting. Diffusion process on bond surfaces between two materials during cladding process with heat treatment was intensified and directly influenced bond strength. Heat treatment had the major influence on Charpy impact energy values of clad specimens. Clad austenite material volume share had no significant influence on Charpy impact energy values.

Examination of factors (cladding procedure and applied heat treatment) influencing shear strength properties of clad specimens results proved significant influence of both factors: cladding procedure and applied post heat treatment. Influence of applied cladding procedure related to used heat treatment procedure was more expressed. Applied cladding procedures and heat treatment of clad plates with their influence on mechanical properties had direct effect on clad materials designing rules, as well as on clad materials construction reliability in exploitation.

REFERENCES

[1] A. Knauschner: Oberflaechen-Veredeln und Plattieren von Metallen, WEB Deutscher Verlag fuer Grundstoffindustrie, Leipzig, 1983.
[2] L. M. Smith: Offshore Technology Conference, Houston, 1992.
[3] Plattierte Bleche, prospekt material,Voest-Alpine Stahl, Linz, 2000.
[4] E.M. Horn; J. Korkhaus; P. Mattern: Chem.-Ing- Tech, 63 (1991), 10, 977-985.
[5] B. Crossland : Explosive welding of metals and its application, Claredonpress, Oxford, 1982.
[6] B. Mateša: CIM 93, C17-C26, Zagreb, 1993
[7] S. Petrović, et al.: Strojniški Vestnik- Journal of Mechanical Engineering, 41 (1995), 11-12, 397 - 406.
[8] S. Petrović, et al.: Welding in the world (0043-2288) 51 (2007); 509-518.
[9] D. J. Kotecki, T. E. Siewert: Welding Journal, 71 (1992)5, 171-178.
[10] B. Mateša; I.Samardžić; M. Dunđer: Metalurgija, 51 (2012), 2, 229-232.
[11] R. Demuzere: S.A. Soudometal, No 930067 rev.3, N.V.B. – 1.7., Brussels, March 1984.
[12] A. Dhooge, A. Vinckier: Int. J. Pres. Ves. & Piping 27 (1987), 4, 239 – 269
[13] E. Folkhard: Metallurgie der Schweissung nichtrostender Staehle, Springer-Verlag, Wien, 1984
[14] Welding Handbook, 8 th Edition, Vol. 4, Materials and Applications, Part 2, AWS, Miami, FL. 1998.

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