CGHAZ MICROSTRUCTURAL ANALYSIS IN SEMI-V JOINTS OF A AISI 4140 STEEL WELDED BY DOUBLE LAYER TECHNIQUE

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Abstract. *The present paper evaluated the efficiency of refine and tempering produced by double layer technique on the coarsening grain heat-affected zone (CGHAZ) of the first layer of a semi-V joint in a AISI 4140 steel, welded with different energy relationships between the first and second layer. The energy levels selected from the Higuchi test were 5/5, 5/10 and 15/5 kJ/cm. Refine and/or tempering evaluation of first layer CGHAZ was accomplished through metallographics analysis and microhardness measurements. It was observed that inside the samples the wanted effect of refine and/or tempering of the first layer CGHAZ was reached. However, in the first layer CGHAZ extremities was preserved part of his coarsening grain, showing that there is need of a corrective action in the sense of promooting it refining and/or tempering this specific area for not harming the hardness and toughness of the material. A rigorous control of the welding parameters and qualified welders guarantee the efficiency of the double layer technique.*

Keywords: *AISI 4140 steel, double layer technique, microstructure*

1. INTRODUCTION

The steels C-Mn and low alloy are used enough to produce parts and equipments in the petroleum, industry (Farraro, 1999). These steels are submitted to severe conditions of work and in many cases it can cause consuming or failure of the component. In these cases, recovering the part by welding is the most common repairing process, however, some aspects related to the welding process of these materials must be evaluated. In general, the most important problems related to welding of these steels are the excessive grain growing and the formation of martensite with high hardness in the heat-affected zone (HAZ), which associated with the presence of hydrogen and tensile stresses, can cause the appearance of cold cracks (Linnert, 1967; Easterling, 1983; Liu and Indacochea, 1992).

In general, the steels C-Mn and low alloy, as well as, AISI 4130, 4140, 4340 and 1045, have around 0,4% of carbon content and carbon equivalent (CE) presence between 0,6 e 0,9%, which, according to the literature, are extremely susceptible to cracks, so they need special attention when choosing the correct filler metal and welding parameters, use of pre-heating, control of interpasse temperature, use of Post Welding Heat Treatment (PWHT)(Liu and Indacochea, 1992; Irving, 1995).

Post welding heat treatment is, in many cases, undesirable because of the long period of time that the equipment is stopped, high cost for its completion or else for its impossibility of completion. The wish to eliminate the PWHT has motivated the development of new techniques of welding which promote the refine and tempering of HAZ during the welding. Between these techniques developed, it's possible to detach the double layer, which consists of deposition of two layers weld, where the heat generated through deposition of the second layer be sufficient to promote the refine and the tempering of CGHAZ from the first layer, reducing the hardness and increasing the tenacity (Bailey *et al*, 1994). This technique, which was initially developed to avoid cracks from reheating, has been used with success to make processes of welding from low alloy steels without PWHT (Niño, Corrêa and Buschinelli, 1992; Teixeira and Pope, 1992; Niño and Buschinelli, 1995; Still, 1997; Still and Blackwood, 1998; Bueno, 1999; Aguiar, Farias and Silva, 2003; Azevedo *et al*, 2004; Albuquerque *et al*, 2006).

To the correct choice of welding energies from the first and the second layers, it is used the test developed by Higuchi and collaborators (Higuchi, Sakamoto and Tanioka, 1980), which is based in attending two basic conditions:

1) $SZD2 > HZD1,$ (1)

where $SZD2$ is the soft zone depth in the second layer and $HZD1$ hard zone depth in the first layer.

2) $HZD2 < R1 + P1,$ (2)

where $HZD2$ is the hard zone depth in the second layer, $R1$ first layer reinforcement and $P1$ first layer penetration.

The achievement of the first condition makes the heat of this HAZ band from the second layer refines and tempers the hard zone from the first layer, while the achievement of the second condition guarantees that the hard zone from the first layer will not be retempered. In this case, the fusion zone from the first layer will be austempering, providing a recrystallization and formation of some martensite which, because of the carbon low percentage, does not show a high hardness. Despite Higuchi test expresses results good concerned to the tempering of HAZ, the same thing can not be said about the grain refine. Moreover, in many cases, it has been noticed in regions between passes an inadequate refine degree and tempering, these regions are considered as localized brittle zones, which reduce the technique efficiency.

The present paper intends to evaluate the double-layer technique about the microstructure and hardness aspect of HAZ in AISI 4140 steel welded joints without PWHT, comparing the results with welded joints in the same conditions and submitted to PWHT, through metallographic analysis and optical microscopy. A bigger approach is given to the formation of possible localized brittle zones, through the mapping of the entire heat-affected zone of the joints.

2. MATERIALS AND METHODS

2.1 Materials

Test were done in AISI 4140 steel discs with 150x25 mm diameter extracted from heating plated bars, with 150 mm diameter, whose chemical composition can be seen in Table (1). The used filler material was the AWS E8018 B2 electrode coated with 2.5 mm of diameter, whose chemical composition of the deposited metal, according to manufacturer, can be seen in Table (1). This electrode was suggested by technicians from Petrobrás, a Brazilian petroleum company, therefore it is the same used in welding repairing of the AISI 4140 steels.

Table 1. Chemical composition of the base metal and filler metal (% in weight).

Material	C	Mn	Si	P	S	Cr	Mo
Base Metal	0.45	0.86	0.29	0.03	0.02	1.1	0.23
Filler Metal	0.08	0.90	0.60	-	-	1.0	0.5

2.2 Methods

Developed methodology was based on two stages, they were: Higuchi test, where the welding were done in Automatic Positioner for Experimental Welding with Coated Electrode, and test with Semi -V joint processed by a qualified welder. To follow, it will be exposed each one of the stages.

2.3 Higuchi Test (1st stage)

At this stage, weldings from simple deposits and isolated lace were done, in quenching test bodies (quenching 860 ^{o}C in salt baths for 20 minutes and cooled in oil). Four welding energy levels were tested, whose parameters can be found in Table (2). After that, in three different regions, the determined the cross section HAZ microhardnees profile of HAZ, lines 1, 2 e 3, with 45 ^{o} angulations, according to Fig. 1, intending to get the extension of hardened and soft zones to each welding energy. In the microhardnesses test, the charge used was 100g and the distance between the impressions equals 0.2 mm. The reinforcement and the weld laces penetration were measured through the optical microscopy, using a zoom of 25X. According to the results of reinforcement, penetration and extensions from hard and soft zones, it was built the Higuchi graphics.

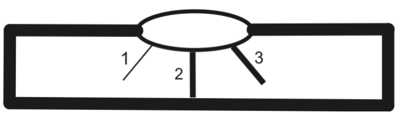


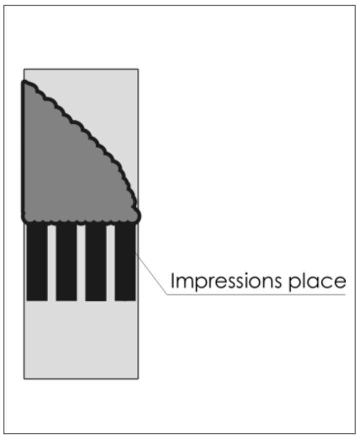
Figure 1. Test specimen to the Higuchi test.

Table 2. Welding parameters to Higuchi test.

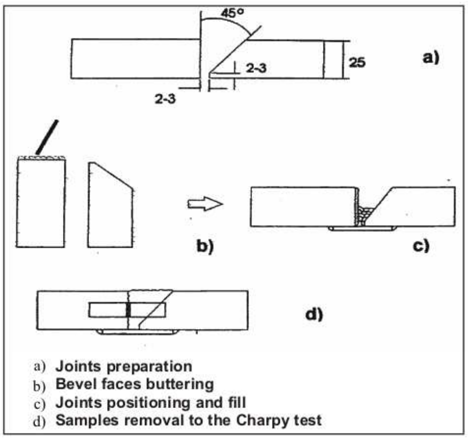
Test Specimen	Efficient Current (A)	Efficient Tension (V)	Speed Welding (mm/min)	Welding Energy (kJ/cm)
H5	102	26	300	5
H10	103	25	150	10
H15	97	26	100	15
H18	115	26	100	18

2.4 Test with Semi -V Joint (2nd Stage)

To evaluate the viability of the welding process with double-layer, quenching AISI 4140 steel semi-V joints (quenching 860 ^{o}C in salt baths for 20 minutes and cooled in oil) and quenching (200 ^{o}C for 1 hour), according to the sequence shown in Fig. 2. Bevel faces buttering in two layers was done using the energy ratios selected at Higuchi test. The weld parameters used in the buttering are indicated in Table (3). After it, it was done the fulfilling joint according with the welding parameters in Table (4). During the welding, the pre-heating temperature and interpasse were kept between 250 ^{o}C and 300 ^{o}C. Recommended values by Bueno (1999).



(a)



(b)

Figure 2. Semi - V test specimen: a) impressions place, b) deposition sequence.

Table 3. Welding parameters for buttering.

Test Specimen		Efficient Current (A)	Efficient Tension (V)	Speed Welding (mm/min)	Welding Energy (kJ/cm)
Semi -V5/5	1st layer	102	26	300	5.0
	2nd layer	99	25	300	5.0
Semi -V5/10	1st layer	103	25	300	5. 0
	2nd layer	100	25	150	10.0
Semi -V15/5	1st layer	99	25	100	15.0
	2nd layer	99	25	300	5.0

Table 4. Welding parameters for fulfilling semi - V joint.

Parameters	Root Pass	Fulfilling Pass
Efficient current (A)	70	109
Efficient tension (V)	22	23
Speed welding (mm/min)	200	welder
Pre-heating temperature (^{o}C)	250 to 300	250 to 300
Interpasse temperature (^{o}C)	250 to 300	250 to 300
Electrode diameter (mm)	2.5	3.25

3. RESULTS AND DISCUSSIONS

3.1 Higuchi Test

Quenching test bodies microstructure to do the Higuchi test has clear stages in the direction of lamination (banding), according to Fig. 3, characterizing homogenization lack of steel chemical composition, despite of the correct process in the heat tempering treatment. These bands, post welding, showed martensite of high hardness, characterizing a higher tempering in these HAZ regions. Determined cross section hard bands microhardness profiles, composing the most critical situation to Higuchi test, therefore it implicates in more extensive hard zones, that appear in fine granulation zone (intercritical heat-affected zone - ICHAZ), according to what can seen in Fig. 4. The reinforcement and penetration values for each welding energy, necessary to build Higuchi graphics, can be seen in Table (5). Four energy levels for microhardness profiles are shown in Fig. 4.

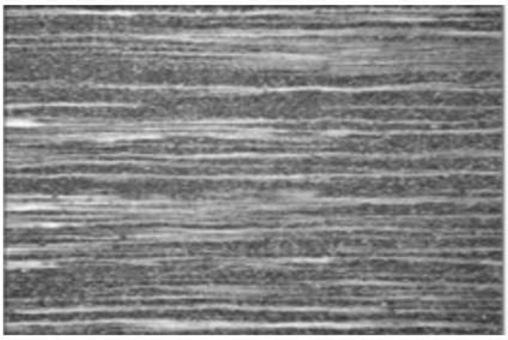


Figure 3. quenching AISI 4140 steel microstructure. Presence of clear bands with hardness in the direction of lamination. Increasing: 25 X. Etched: nital 2%.

Table 5. Reinforcement values and penetration.

Test Specimen	Welding Energy (kJ/cm)	Reinforcement (mm)	Penetration (mm)
H5	5	1.2	1.5
H10	10	2.2	1.5
H15	15	2.5	1.1
H18	18	3.1	1.6

According to the microhardness profiles, Fig. 4, and reinforcement and penetration measures, according to Table (6), was built the Higuchi graphics in Fig. 5. In these graphics, R represents the reinforcement, P the penetration, HZ the hard zone and SZ the soft zone. In virtue of presence das clear bands with high hardness, Fig. 3, and determined the cross section HAZ microhardness profile about the same, it is observed that, with the increasing of welding energy, there is also an increasing of the hard and soft zones extensions, according to Fig. 5.

3.2 Test with Semi -V Joint

According to the Higuchi test, the 5/5, 5/10 and 15/5 kJ/cm energy ratios were chosen. Microhardness profiles to the test bodies without PWHT show the effectiveness of the double-layer technique. It is possible to notice, through microhardness values, that in all situations there was softness of hard zone from the first layer because of the perfect wedding with the second layer, according to seen in Fig. 6. For the test bodies with PWHT, the Fig. 7 shows that the heat treatment provides decline in hardness and a bigger uniformity of HAZ, comparing with the without PWHT.

Figure (8) shows many regions of HAZ along the plain face of the joint, to the energy ratio 5/5 kJ/cm without PWHT. It is noticed the presence of coarsing microstructures which were not refined enough as in the other regions (point A), showing hardness 387 HV. On the other hand, other regions of HAZ were quenching and satisfactorily refined, with hardness between 248 a 257 HV (points B and C). It was also noticed that the right side of the semi-V bevel extremity (point D) was not totally refined, but it had hardness 267 HV, compatible with quenching and/or refined regions. Fig. 9 shows the enlargements of the regions said before.

Figure (10), it is presented the scanning along all extension of HAZ to the welded test with energy ratio 5/5 kJ/cm with PWHT. In a general way, welded sample with this energy ratio (5/5 kJ/cm), with and without PWHT, where the ones which presented the best refining degree, with very little regions with coarsing microstructures (points A and D), as seen in Fig. 8 and 10. The hardness in these regions are also satisfactory, having values around 260 HV to point A. The hardness in points B and C were 219 HV and 226 HV, respectively, and the region from the right extremity of the semi-V bevel (point D) had hardness 254 HV.

Welded samples with energy ratio 5/10 kJ/cm, with and without PWHT, had very similar results, not only about the refine point of view but also about the tempering. On the left extremity (point A), it was possible to see the same hardness value for both samples: without and with PWHT (284 HV). The hardness values in region of point B had hardness

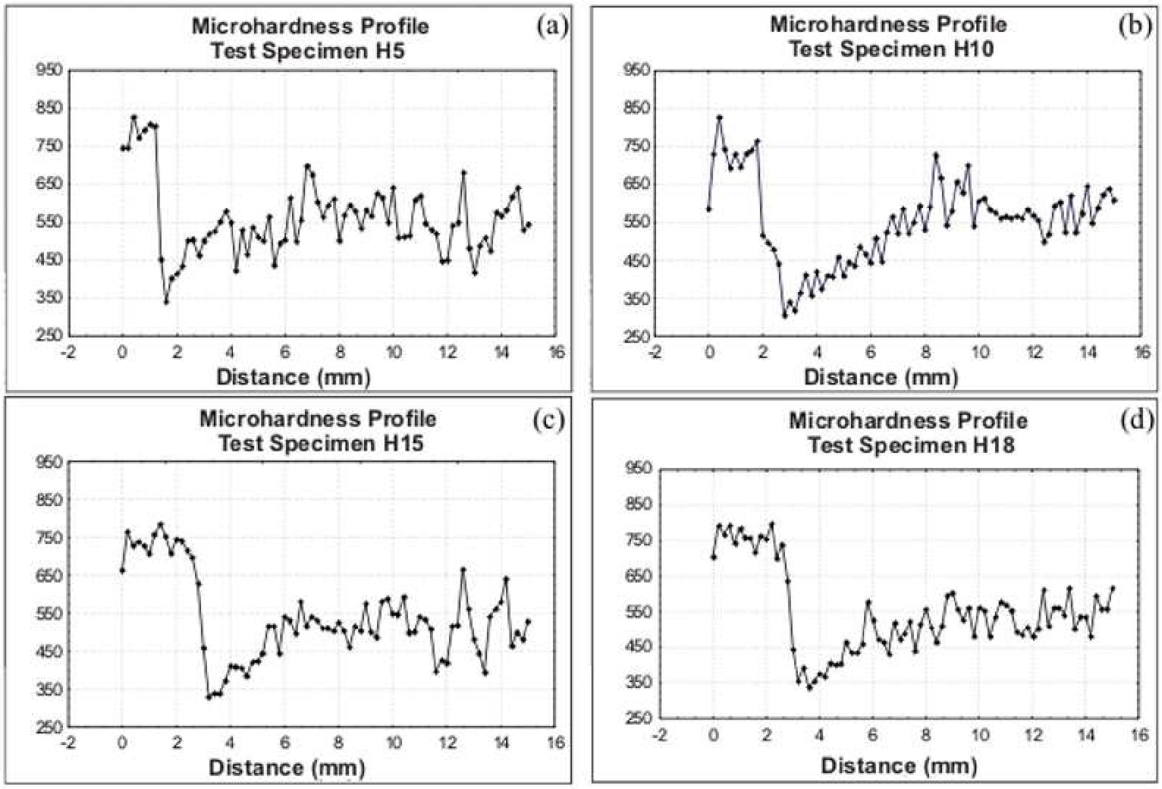


Figure 4. Microhardness profile: a) energy 5 kJ/cm, b) energy 10 kJ/cm, c) energy 15 kJ/cm and d) energy 18 kJ/cm.

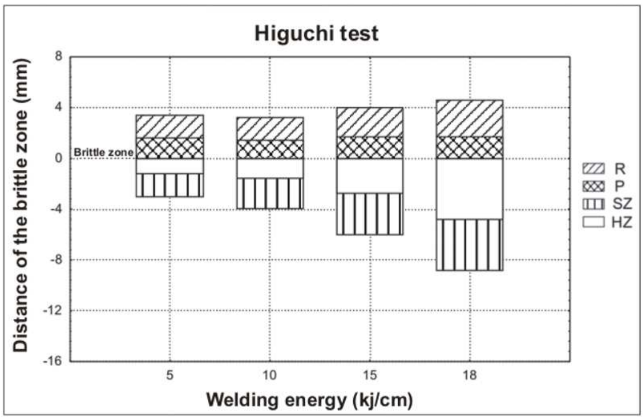


Figure 5. Higuchi graphics.

values 214 and 218 HV to samples with and without treatment, respectively. In region C, the refine degree was almost as effective as the one noticed in welded sample with energy 5/5 kJ/cm, Fig. 8 and 10. The hardness values did not vary either between samples with and without PWHT, being 218 HV for test without PWHT and 221 for sample with PWHT. It has been noticed yet that on the extreme right region the refine grain degree was good, having a small region with coarsing granulation. The hardness was around 268 HV for sample without PWHT and 273 HV for sample with PWHT.

Welded sample with energy ratio 15/5 kJ/cm without PWHT presented regions partially refined (point A), but with a satisfactory tempering degree, having hardness values 279 HV, according to what is noticed in Fig. 11. As well as in point A, in point C indicated in Fig. 11 it was noticed the presence of regions refined but with low hardness, around 260 HV. In point B, there are regions with a complete refine and microstructure tempering with hardness values near 250 HV. On the joint right side, higher hardness values were seen (268 HV) and an unsatisfactory refine degree, with coarsing microstructure. Details about the microstructure of each detached region in Fig. 11 are shown in Fig. 12.

In samples with the same energy ratio (15/5 kJ/cm) and submitted to PWHT, hardness levels had values near the ones gotten in sample without PWHT. Joint extremities, values were 270 and 259 HV (points A and D, respectively). Regions indicated by points B and C had hardness values 230 and 234 HV, respectively.

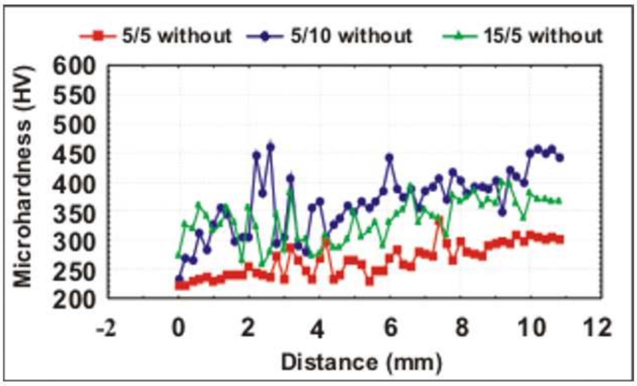


Figure 6. Microhardness profile of Semi - V test bodies 5/5 kJ/cm, 10/5 kJ/cm and 15/5 kJ/cm without PWHT.

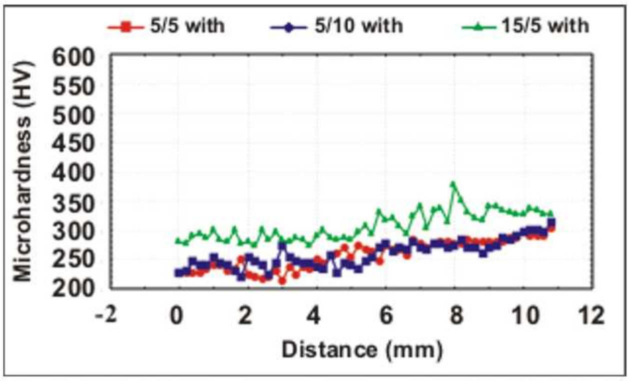


Figure 7. Microhardness profile of Semi - V test bodies 5/5 kJ/cm, 10/5 kJ/cm and 15/5 kJ/cm with PWHT.

Figure 8. CGHAZ extension with the energy ratio 5/5 kJ/cm without PWHT.

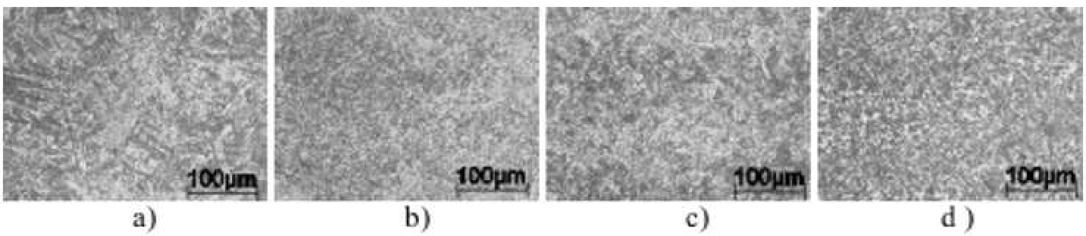


Figure 9. a) coarsing region - A, b) refined e quenching region - B, c) quenching e refined region- C and d) coarsing region - D.

4. CONCLUSIONS

According to the experimental results with the welding conditions used at this paper, it was possible to conclude that:

It was proved he efficiency of the double-layer technique related to AISI 4140 steel HAZ tempering, once that hardness in test bodies HAZ without PWHT was reduced to values from the same order of the base metal, and similar to test bodies submitted to PWHT.

Figure 10. CGHAZ extension with energy ratio 5/5 kJ/cm with PWHT.

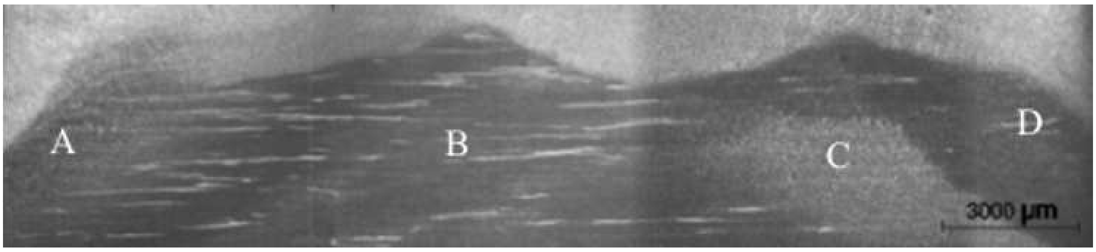


Figure 11. CGHAZ extension with energy ratio 15/5 kJ/cm without PWHT.

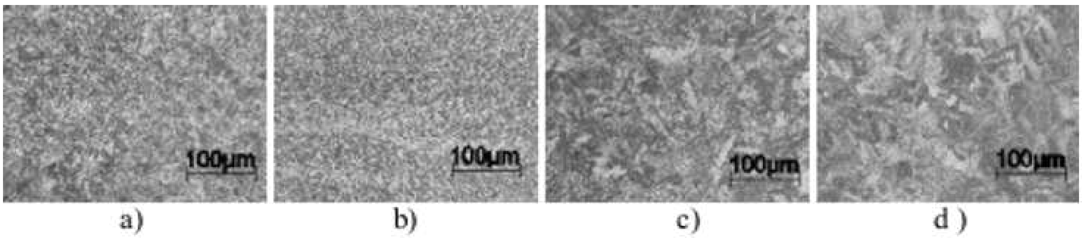


Figure 12. a) coarsing region - A, b) refined e quenching region - B, c) quenching e non refined region - C e d) coursing region - D.

In regions between passes and joint extremities, there was the appearance of regions with coarsing granulation that, even so they did not demonstrate high hardness, they can represent critical regions called localized brittle zones.

Determined the cross section HAZ microhardness profiles to make Higuchi graphics, it is necessary to consider the presence of hard bands aligned to the direction of lamination.

The results presented indicate that the best performance of double-layer technique is had when it is used low heat subsidy in the first layer, according to relationships from 1:1 to 1: 2.

Studies are being done intending to temper and/or refine the bevel extremities through the use of GTAW welding.

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