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Study of the Thermal Diffusivity Variation in Thin Duplex Steel Plates Welded by GTAW Process

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Abstract. This study describes the thermal diffusivity of thin duplex steel plates in the thickness direction measured using the laser-flash method after welding. The work reports the experimental efforts in recording temperature profiles of the grade UNS S32304 duplex steel during autogenous welding. The butt weld autogenous joints were carried out by the GTAW (gas tungsten arc welding) process with either argon or argon - 2% nitrogen atmospheres. The amount of nitrogen in the heat affected regions, after welding, was measured and correlated with the variation of the thermal diffusivity of the studied material. The temperature profiles were obtained using k-type thermocouples connected to a digital data acquisition system. Different thermal cycles and thermal diffusivity values were observed in the heat-affected zone (HAZ) for both samples. In the solidified zone (SZ) was observed similar increase of the thermal diffusivity values for the plates welded with pure argon and argon plus nitrogen atmosphere.

Introduction

The heat transfer processes and the thermal cycles for a given dimension of a metal part are sensitive to variations in its thermal diffusivity and thermal capacity [1]. The microstructure and mechanical properties of a metallic component are dependent upon the processes and further thermal treatment that the part is subjected. In duplex stainless steel, the thermal diffusivity values at elevated temperatures are especially needed when the mechanical properties are analyzed [2].

The weldability of modern duplex stainless steel is satisfactory, although the heat affected zone and weld metal generally exhibit higher ferrite content and coarser grains than the original material. Duplex steel with moderate nitrogen content solidifies ferritically. During welding the austenite dissolves while been heated, it followed by grain growth in the delta ferrite region, and finally restoring to the austenitic phase during cooling [2,3]. However, an increased amount of N is beneficial for the austenite restoring. The addition of N should be optimized, close to the upper limit, and losses of N during welding should be minimized. The desired ferrite-austenite phase balance can also be achieved by a high heat input, which provides a slow cooling and promotes the desired phase balance [3].

F. H. Ley et al. [4] studied the effect of the protection gas variation in the thermal properties of addition metal soldering in the GMAW welding process. It was observed a huge influence of the shielding gas on the thermal properties (thermal expansion, thermal diffusivity and thermal conductivity) of the weld metal in relation to the base metal (DH36 steel plate). Abas R. H. and Taieh, N. K. [5] measured the thermal diffusivity and thermal capacity in a temperature range (from 1473 K until ambient temperature) for different duplex steels in order to complement thermophysical data of these alloys. Betini et al [6] found low value for thermal diffusivity for pure argon as shielding gas using conventional GTA welding process in heat-affected region. Matteis P.

et al. [7] reported the variation of the thermal diffusivity occurring in austenitic steels during the cooling process. Furthermore, it was defined that the thermal diffusivity is the most influent thermophysical property in quenching processes that can be analyzed by thermo-metallurgical models.

In the present work is proposed the study of the thermal diffusivity of the UNS S32304 in the thickness direction at the solidified zone (SZ), heat affected zone (HAZ) and base metal (BM) after welding. The thin stainless duplex steel plates UNS S32304 were subjected to the GTAW welding process (butt joint) without metal addition (autogenous). The shielding gas was varied and the amount of nitrogen was measured. Temperature curves were acquired during welding in regions near the melting pool.

Experimental

The specimens were obtained with dimensions of 36 x 72 x 1.8 mm^3. Table 1 shows the chemical composition of UNS S32304 duplex stainless steel used in the experimental work. The alloy chemical composition was certified by the commercial supplier Aperam Inox América do Sul S/A.

Table 1. Chemical composition (% mass and ppm) of the duplex stainless steel UNS S32304.

Cr	Ni	Mo	Mn	Si	C	P	S	Ti	Cu	Co	N ppm
22.201	3.521	0.255	1.402	0.250	0.016	0.023	0.001	0.004	0.417	0.091	1030

It was welded at the Welding Laboratory of the Federal University of Espírito Santo (LabSolda/DEM/UFES). The pulsed current and direct polarity were used with automatic drive systems. The samples were fixed in order to reproduce the conventional welding process, as shown in Figure 1. A batch of samples was welded with commercial argon protection gas and one with a mixture of argon and 2% of nitrogen. The gas flow rate in both cases was 10 L/min.

The electrical current and voltage values were measured for each welding step. Regarding the parameters such as voltage (V), current (I) and the welding speed (v) along with 0.5 arc efficiency (η) for the GTAW welding, it was possible to calculate the welding heat input (Q_w) per mm using Eq. 1 [8]. The welding heat input shown in Table 2 was determined using the average voltage; current and the average weld speed.

$$Q_w = \eta VI/v \tag{1}$$

The temperature was measured and recorded using thermocouples type k attached to a digital data logging system. Six thermocouples were positioned and fixed to the sample plate surface using spot welding at different distances, along a line transversal to the weld bead. Three thermocouples were attached on one side (1-3 - side A) of the board and other three thermocouples on the other side (4-6 - side B) being given the distances from the center of the weld nugget, as shown in Figure 1. The thermocouples distance from the melting zone were: 8 mm, 13 mm and 18 mm for the thermocouples 1, 2 and 3, respectively from side A, and: 10.5 mm, 13 mm and 18 mm for thermocouples 4, 5 and 6, respectively from side B.

The signals from the thermocouples were acquired with a 6-channel digital universal data acquisition system (DAQ) amplifier using MX board - PT1000 for room temperature automatic conditioning. The measured total error limit at 300 K ambient temperature is ± 1 K and the temperature drift (type k) was used K/10K ratio where the uncertainty was ≤ ± 0.5. Table 2 shows the welding parameters used for the GTAW using dc current and direct polarity, the sample W1 was welded using 99% pure argon as shielding gas and sample W2 was welded using a mixture of 98% pure argon with 2% N_2 as shielding gas.

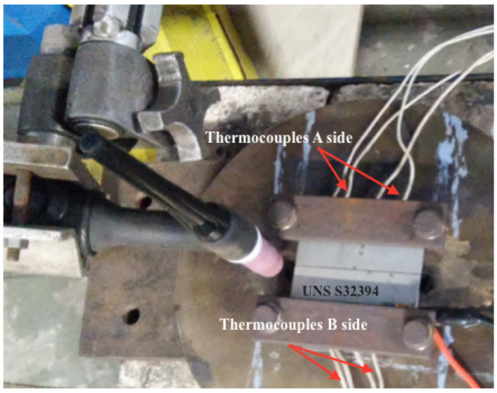


Fig. 1. Welding arrangement for the duplex stainless steel UNS S32304 thin plates.

Table 2. Welding parameters used for the GTAW using dc current and direct polarity.

Sample	W1	W2
Voltage	13.8 V	13.5 V
Current	110 A	110 A
Speed	35 cm.min^{-1}	35 cm.min^{-1}
Arc efficiency	50 %	50 %
Shielding gas	(Pure Ar)	(Ar + 2 % N_2)
Heat input	0.129 kJmm^{-1}	0.124 kJmm^{-1}

Among the methods for simultaneously obtaining important thermodynamic parameters in a short time interval of transient heat, the laser flash method (LFM) proves to be more advantageous. In this method, a flash of intense light energy is evenly applied to one face of a small sample. The energy pulse diffuses unidirectionally to the opposite face allowing the recording of the transient temperature rise of this face [9]. The principle of thermal diffusivity measurement by the laser-flash method is well established and the Equation 2 usually gives thermal diffusivity,

$$\alpha = 1.37L^2/\pi^2\, t_{1/2} \qquad (2)$$

where L is the sample thickness, $t_{1/2}$ is the elapsed time for the rear-surface temperature to reach half its maximum temperature rise [9].

The measurement apparatus precision was verified by performing two successive series of standard flash laser measurements according to ASTM 1461 on thin plates of UNS S32304 as received in room temperature (see Table 3). The difference between the measured diffusivity values and the literature data is lower than 5%, which is the repeatability of the standard laser flash measurements [5,10,11].

Table 3. Experimental verification measurements of thermal diffusivity (in room temperature) via laser flash method.

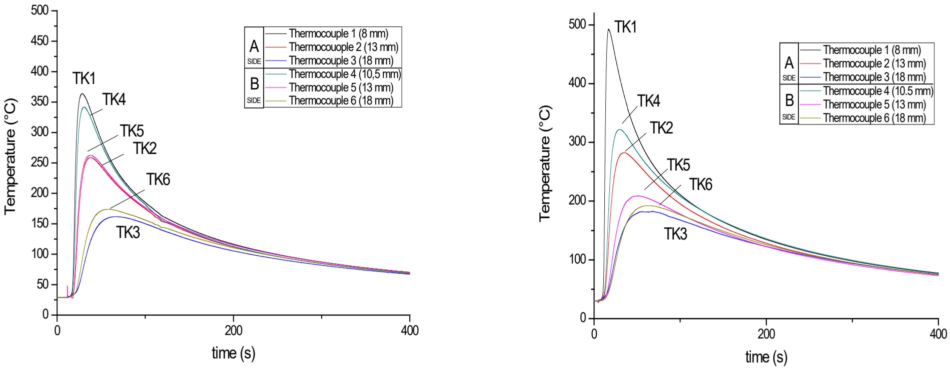
UNS S32304	α (10^{-6} m²/s)
Ref. 5	4.2 ± 0.2
As received	4.2 ± 0.2

It was used a carbon dioxide (CO_2) laser with a Gaussian profile. It is responsible for issuing the energy pulse on the sample surface. The laser light wavelength is in the order of 10^{-6} m with an intensity of $10\sqrt{2}$ W/m² and a focus diameter 2 mm. The temperature variations were recorded by a j type thermocouple capable of measuring temperatures in the range of 0 °C up to 480 °C. The BD model T422 amplifying board was used to enhance the signal from the thermocouple and send it to a computer. The board had an amplification rate of 1,000 times. A model PCI AD converter 711 with 8-bit resolution processed the analogic signal. Software developed by the High Pressure Laboratory - PRESLAB of the Federal University of Espírito Santo [12], was used to analyze the thermal profile.

The gas analysis was carried out by LECO, which is equipment capable of determining the hydrogen, nitrogen and oxygen content within a sample. Nitrogen content was measured in a thermal conductivity cell (TC cell). The TC cell can determine the differences in the thermal conductivity of gases. Sample made of gases pass through heated copper oxide, which converts CO to CO_2 and hydrogen into water. CO_2 and water were then removed with a Lecosorb/Anhydrone trap to prevent detection by the TC cell. Then, a gas flow passed through the TC cell for nitrogen detection [13].

Results and Discussion

In Figure 2 it is shown the temperature distributions for six thermocouples, it was plotted for both specimens WI and W2. First, for Figure 2 (a) the thermocouples number 1 (8 mm distant from the melting pool) and number 4 (10.5 mm) were placed closer to the weld bead where the temperatures were near to 360 °C and 350 °C, respectively. Furthermore, the curves for thermocouples numbers 2 and 5 (distance of 13 mm) exhibits very close values for the temperature peaks since they were symmetric placed from the center of weld bead. This result was important for the validation of the measurements and for the credibility of the experimental arrangement.



a) b)

Fig. 2. Distribution of temperature for samples (a) W1 (pure argon) and (b) W2 (Ar + 2% N_2), showing the temperature variation measured with each thermocouple for the UNS 32304 duplex stainless steel, 1.8 mm long stripe, while being welded.

In the temperature distribution for sample W2 shown in Figure 2 (b), a temperature peak near 500 °C is observed for thermocouple 1 (8 mm distant from the joint line) being about 140 °C higher than sample W1 considering the same region. It has occurred due to the influence of the shielding gas used for sample W2. According to Muthupandi et al. [14], the Ar-N_2 mixture has a higher ionization potential, increasing the welding energy and the peak temperature. Lin et al. [15] observed that with the addition of nitrogen the temperature peak increases and consequently the residual stresses of the austenitic steels also increase. Furthermore, Machado et al. [16] observed that the use of Ar + 2%N_2 as shield gas causes an increase of the residual stress in solidified zone when compared with a plate welded with pure argon.

In Table 4 it can be observed the quantity in ppm of N_2 contained within the sample as received and after welding. The increase in mass of N_2 noticed in the region of melting (solidified zone) in sample W2 (Ar + 2% N_2) was expected. This increase is related to the incidence of the shielding gas used in welding. In addition, a higher value of about 350 ppm N_2 was found in comparison to the supplier's given values.

Table 4. Amount of nitrogen mass (ppm) for each region after welding process and as received of the duplex stainless steel UNS S32304.

Position	N_2 (ppm)	
	W1 (Pure Ar)	W2 (Ar + 2 % N_2)
Melting zone (MZ)	1382 ± 15	1927 ± 32
HAZ (5 mm)	1408 ± 20	1456 ± 44
Base metal (18 mm)	1412 ± 15	1409 ± 33
As received	1030	1030

Through thermal diffusivity measurements, as shown in Figure 3, it is possible to observe a wide variation in the thermal diffusivity of the welded samples, mainly at the regions with higher incidence of heat during welding. It was noticed the highest value of thermal diffusivity at the molten region and a sharp decrease in this property regarding the heat affected zone (5 mm from the molten zone). The lowest value of thermal diffusivity (2.0×10^{-6} m².s^{-1}) was obtained in this region. For W2 sample, the change is slightly lower (3.1×10^{-6} m².s^{-1} at 5 mm from the weld bead) where the temperature during welding also was greater than that one of W1.

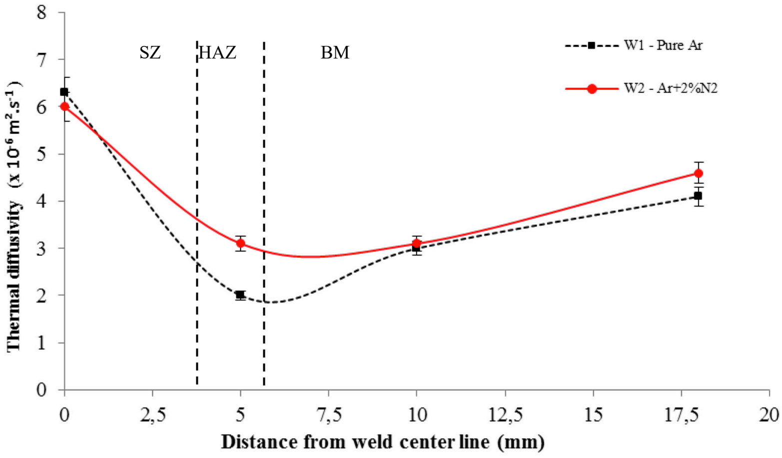


Fig. 3. Thermal diffusivity after GTAW process for each region from the weld centerline for both W1 and W2 thin plates of UNS S32304.

The region distant from the weld bead remained close to the values obtained for the as received samples. The thermal diffusivity measurement error bars were between 2-5% due to the heat convection effects [10]. In addition, the value of 4.2×10^{-6} m^2.s^{-1} obtained by Abas R. H. and Taieh, N. K. for the thermal diffusivity for duplex stainless steel 2304 at room temperature also converge with the results achieved at the present work, see Table 3.

Conclusion

The study of the thermal diffusivity on the three main regions of thin welded plates was investigated. As well known, the welding process results in several changes in microstructure and mechanical properties of the welded joint. The results above suggest that the changes in thermophysical properties must be considered at this region.

An increase of thermal diffusivity (around of 40%) in the molten region was observed for both W1 and W2 samples. In the heat-affected zone (HAZ) the thermal diffusivity was more affected when the welding occurred under pure argon atmosphere. Also, using the pure argon atmosphere it was observed lower temperature peaks in the HAZ that would lead to different cooling rates in comparison with Ar+2%N_2 welded plate.

Regarding the content of nitrogen in the solidified zone for sample W2, it did not change the values of thermal diffusivity in comparison with pure argon welds (W1).

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References

[1] G.E. Totten, C.E. Bates, N.A. Clinton: *Handbook of Quenchants and Quenching Technology*. (ASM International, 1993).

[2] J.O. Nilsson: Mat. Sci. and Tech. Vol. 8 (8) (1992), p. 685.

[3] Y.H. Park, Z.H. Lee: Mat. Sci. Eng. A Vol. 297 (1-2) (2001), p. 78.

[4] F.H. Ley, S.W. Campbell: The Inter. J. Adv. Manuf. Tech. Vol. 80 (5-8) (2015), p. 1213.

[5] R.H.A. Abas, N.K. Taieh: Khzwarizmi Eng. J.Vol. 11 (2) (2015), p. 51.

[6] P. Matteis, E. Campagnoli, D. Firrão, G. Ruscica: Inter. J. of Therm. Sci. Vol. 47 (6) (2008), p. 695.

[7] E.G. Betini et al.: SAE Tech. Paper Vol. 01 (2016), p. 0503.

[8] C.S.C. Machado et al.: Blucher Phys. Proc. Vol. 1 (2) (2014), p. 1

[9] X.K. Zhu, Y.J. Chao: Comput. Struct. Vol. 80 (2002), p. 967.

[10] W.J. Parker, R.J. Jenkins, C.P. Butler, G.L. Abbott: J. Appl. Physics Vol. 32 (9) (1961), p. 1679.

[11] Standard, ASTM. E1461-01, 2001. Standard Test Method for Thermal Diffusivity by the Flash Method.

[12] ASM Specialty Handbook: Stainless Steels. Ed. Davies, J. R., ASM International,

[13] Betini, E. G. Determination of some thermal properties of advanced ceramics doped with rare earth ion Ce4+. Master (Dissertation). Vitória, 2013. Federal University of Espírito Santo. (BR) (In Portuguese).

[14] O. Vega, K. Imakuma: Revista Brasileira de Aplicação de Vácuo Vol. 3 (1-2) (1983), p. 153.

[15] V. Muthupandi, P. Bala Srinivasan, S.K. Seshadri, S. Sundaresan: Sci. and Tech. Weld. and Join. Vol. 9 (1) (2004), p. 47.

[16] Y.C. Lin, P.Y. Chen: Mat. Sci. and Eng. Vol. 307 (2001), p. 165.