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ANALYSIS OF THE THERMAL FIELD FOR TIG WELDING BY USING INFRARED THERMOGRAPHY

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Lucrarea prezintă modul de analiză a câmpului termic obţinut prin sudarea rectilinie cu o sursă concentrată (TIG), pe componente din oţel slab aliat termorezistent. Se analizează evoluţia distribuţiei de temperatură şi se estimează parametrul $t_{8/5}$, pentru topiri superficiale fără material de adaos, în condiţii de temperaturi de preîncălzire diferite (30^0C, 100^0C, 300^0C).

Compararea rezultatelor obţinute prin vizualizarea câmpului termic cu ajutorul unei camere în infraroşu, ThermaCAM SC 640, cu cele obţinute prin calcule analitice a dus la concluzia ca, pentru soluţia analizată, există o bună suprapunere a rezultatelor şi metoda utilizată poate permite optimizarea parametrilor regimului de sudare.

This paper presents the analysis method for the thermal field resulted from tungsten inert gas welding (TIG) the components made of heat-resistant low alloy steel. We are going to analyze the evolution of the heat distribution and estimate $t_{8/5}$ parameter for superficial melts without filler material under various preheating temperature conditions (30^0C, 100^0C, 300^0C).

The comparison between the results obtained by visualizing the thermal field with the help of an infrared camera - ThermaCAM SC 640 - and those obtained by analytical calculations led to the conclusion that there is a good overlapping of the results for the analyzed solution and the used method permits the optimization of the welding process parameters.

Key words: $t_{8/5}$, thermal field, HAZ, TIG, welding

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1. Introduction

The characteristics of the welded joints are directly influenced by the thermal processes that occur during the welding operations. At the same time the welding procedures influence the geometry of the joint, the nature and extent of the structural transformations, the level of the tensions and deformations and the value of the resulted mechanical characteristics (hardness, resilience).

The local and concentrated action of the thermal sources on the welding material lead to the occurrence of complex, irregular and non-stationary thermal fields in the welding process [1].

The thermal field in welding processes consists of the total amount of heat transfer phenomena between the thermal source and the parts subject to the welding process. The temperature distribution in the welded joints is influenced by the linear energy of the thermal source, by the thermophysical properties of the base material (specific heat, conduction of heat, material density and thermal diffusivity) and the heat losses to the environment [2].

The thermal field determines residual stresses both through the thermal stresses caused by the linear energy introduced by the welding thermal source and through the transformation tensions that accompany the phase and microstructure changes.

The experimental analyses of the thermal field are carried out with the help of the thermocouples attached to the surface of the parts or in the parts, at the level of the heat affected zone, as the case may be. The thermal field in the welding bath can be determined with the help of certain special methods. Infrared technologies or calorimetric methods are other possibilities to determine the thermal field during welding by experiments.

The analytical observance, in accordance with the requirements of the industrial practice, of the thermal cycles during welding requires the consideration of three ways of heat propagation during welding and according to certain simplified physical models: three-dimensional propagation, two-dimensional propagation and intermediary propagation.

In order to analyze the characteristic of the thermal cycle during welding based on one indicator, the cooling time between the successive temperatures of 800^0C respectively 500^0C, marked with $t_{8/5}$ is used at present. We noticed that the cooling time is an inverse value in relation to the cooling speed, i.e. a higher $t_{8/5}$ value means a lower cooling speed and vice versa [3].

We would like to mention that all the calculation relations for $t_{8/5}$, as well as its measuring zones by thermographic method presented below refer exclusively to the quasi-stationary thermal fields. At the beginning and end of the layer (non-stationary field) the cooling speeds can also be twice as high as in the middle of a long layer.

Measuring $t_{8/5}$ time by installing several thermocouples in various interest spots has the disadvantage that two thermocouples (even of the same type) may produce output signals that are much more differentiated between them. In order to obtain better precision we have to resume the calibration process for each thermocouple.

By visualizing with the help of an infrared camera we obtained an overview of the thermal field of a welded joint, the advantage being the possibility of analysis by a single recording of the entire interest zone.

2. Theoretical considerations

From the point of view of the metallurgic effects the cooling time $t_{8/5}$ is used for the characterization of the thermal cycle of a TIG welded joint. Its calculation is carried out differently, depending on the type of heat propagation.

For the welded joints we used samples made of low alloy heat-resistant steel (13CrMo4.4), whose chemical composition is presented in table 1 and had the dimensions 125 x 300 x 10 mm.

Table 1

Chemical composition of the low alloy heat resistant steel 13CrMo4.4

Element	C Max. [%]	Mn [%]	P max. [%]	S max. [%]	Si [%]	Mo [%]	Cr [%]
Content	0.17	0.40÷0.65	0.035	0.040	0.15÷0.40	0.45÷0.60	0.80÷1.15

Considering the thickness of the parts to be welded, for the calculation of the cooling time $t_{8/5}$ was used the following calculation formula for the two-dimensional propagation:

$$t_{8/5} = (4300 - 4{,}3T_0) \cdot 10^3 \cdot \frac{Q^2}{d^2} \cdot \left[\frac{1}{(500 - T_0)^2} - \frac{1}{(800 - T_0)^2} \right] \cdot F_2 \quad (1)$$

Where: $t_{8/5}$ = cooling time between 800^0C and 500^0C [s]

T_0 = initial temperature of the sample [^{0}C]

Q = linear energy [kJ/mm]

$$Q = \frac{U \cdot I}{v_s} \cdot \eta \cdot 10^{-3} \quad \text{[kJ/mm]} \quad (2)$$

U = voltage of the electric arc [V]

I = intensity of the welding current [A]

v_s = welding speed [cm/min.]

η = efficiency of the welding procedure (TIG welding, according to EN 1011-1/98 - η=0,6)

d = thickness of the sample to be welded [mm]

F_2 = shape factor that takes into account the deviations from the idealized physical model (for depositing a layer on a plate it is equal to 1) [4].

After introducing the values of the welding process parameters (presented in table 2) in formula 1 we obtained 10 seconds for $t_{8/5}$.

Table 2

Parameters of the welding process

Parameter	I [A]	U [V]	v_s [cm/min]	Q [kJ/mm]	T_0 [^{0}C]	d [mm]	$t_{8/5}$ [s]
Value	153	15	14	5,9	200	10	10

3. Experimental procedure

During the experiments the welding source is considered mobile and located in the middle of the plates. The thermal field is observed in the middle area of the joint so that the measurements are not influenced by the phenomena occurring in the beginning and end areas of the bead.

The welding operation was carried out in direct current, with direct polarity by using a TIG welding source with dropping external characteristic.

For the welded joints we used the stand presented in figure 1:

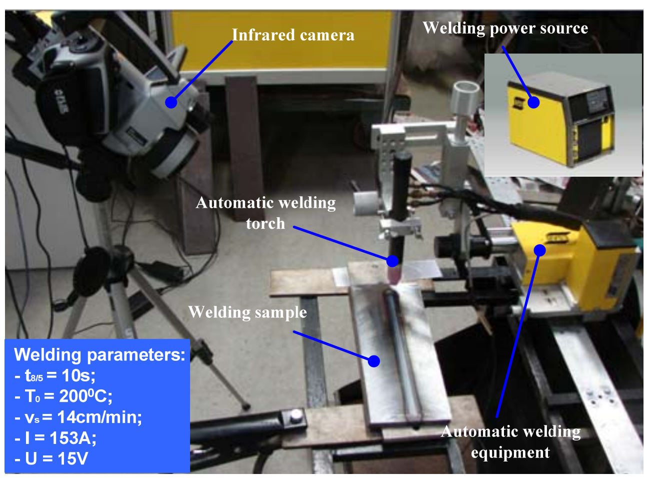

Fig. 1- experimental stand for automated WIG welding

By using the infrared camera ThermaCAM SC 640 we carried out the infrared thermography method of the welding process, thus we obtained the temperature distribution in the base material resulted following the welding process with a rectilinear WIG source without filler material. The obtained image represents the thermal cycle at a certain time. The acquisition soft has the possibility to record images either as film (without the possibility of analyzing the recorded images) or in the form of successive images, thus offering the possibility to analyze them both at a certain moment in time and along the entire process.

Figure 2 presents the thermogram of the temperature isotherm recorded 45 s after the beginning of the welding process. The figure shows that in the welding arc area the temperature is lower than in the adjacent areas, this being due to the fact that the recorded image is an image of the surface area and is influenced by the cooling effect of the protection gas.

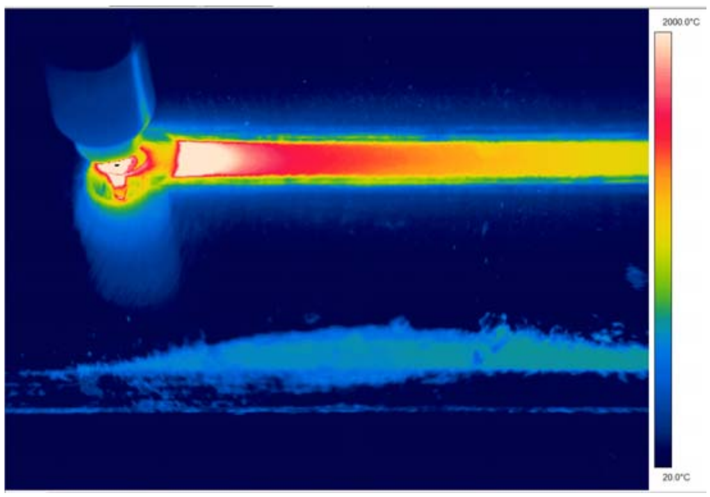

Fig. 2 – Visualization of the thermal field of the welded joint area

4. Results

Figure 2 shows the heat propagation in the entire sample area, the heat being concentrated in the welded joint area. It shows the thermal source in ellipsoidal form and the more concentrated temperature isotherms before the source and more extended behind it.

Figure 3 shows the graph of the temperature variation in a spot situated on the area of the sample to be welded in the middle of the bead. Considering the indications of the analysis soft the time necessary for the cooling of the analyzed spot may be determined with precision from 800^0C to 500^0C. This shows that the value of the $t_{8/5}$ time resulted following the thermographic infrared analysis is approximately equal to 10s.

Following the analysis of the recorded data we can draw the map for the temperature distribution, at a certain point, on the area of the sample to be welded.

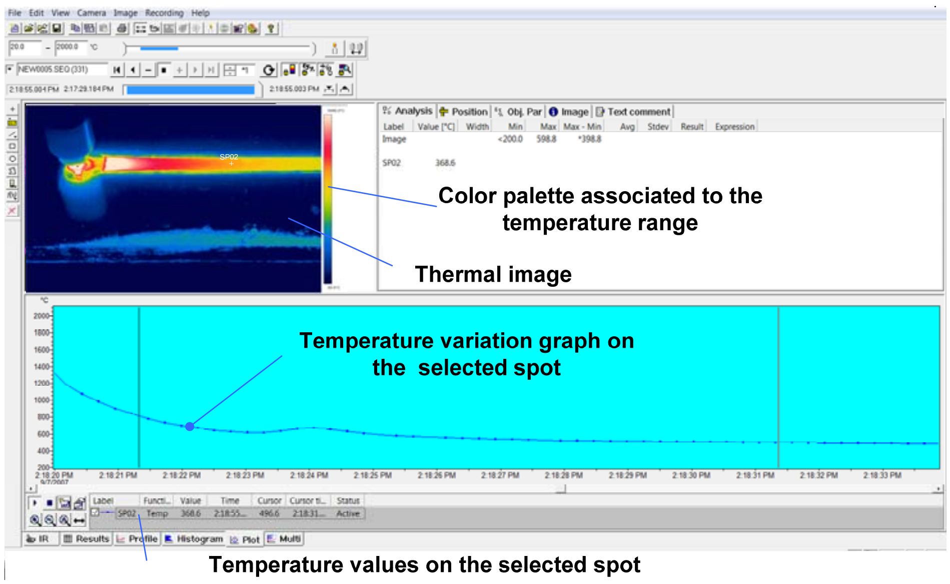

Fig. 3 – Identification and processing elements (interpretation) of a thermographic image

5. Conclusions

By using the infrared thermography method:

- We can determine with an acceptable margin of error the cooling time t8/5, thus carrying out a practical control of the welding technology;
- We can monitor the thermal evolution of a spot or an area in the interest area;
- Considering the melting temperature of the analyzed material we can determine the width of the bead;
- Starting from the temperature distribution along the welded joint area we can create mathematical models and models for the analysis with finite element to help us estimate the value of the bead elements.

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