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GTA remelting of surface spot defects

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ABSTRACT

Purpose: A statistical model that explains the interaction between cross-section dimensions of a GTA remelted spot area and remelting parameters is presented. It will be utilized in the repair of an investment casting made of nickel-based superalloys.
Design/methodology/approach: An experimental design of response surface was used to elaborate the model of GTA remelting. Results of experiments were verified experimentally.
Findings: The dimensions and volume of a remelted area are a linear function of the GTA welding process parameters. It is possible to remelt small surface defects and keep a smooth surface.
Research limitations/implications: Research results are limited to the tested range of parameters and base material properties. Changes in thermal conductivity can strongly influence the presented results. Crack sensitivity of material can restrict the range of parameters.
Practical implications: Results of the research will help in the repair of surface spot defects of nickel-based superalloys. The proposed method of repair can help to minimize the number of rejected parts.
Originality/value: A new approach to welding technology is presented. A statistical model of GTA remelting process could be a useful tool for the precise selection of process parameters.
Keywords: Welding; GTA; Remelting; Cast repair

1. Introduction

Gas turbine components made of nickel-based superalloys produced by investment casting are often rejected because of minor surface defects. These defects could be repaired or at least minimized by using welding technologies, but the limited weldability of nickel-based precipitation hardened superalloys creates serious metallurgical problems [1,2].

The results of a preliminary investigation presented in this paper concern the repair of minor surface defects on the cast nickel-based superalloy Inconel 713C. This part of the work is concentrated on the geometrical questions of defect remelting. A statistical model of GTA remelting of surface spot defects was tested. The model describes the interaction between the remelting parameters and the dimensions of the remelted zone. The results help to fit the size of melted zone to the defect dimension. Tests were completed on AISI 316 sheet metal to avoid metallurgical problems but were verified on the cast metal Inconel 713C.

2. Previous works

Nickel-based superalloys work at a temperature slightly lower than their melting temperature. They have to hold creep, oxidation resistance and strength at a high temperature [3,4,5].

These alloys consist mainly of gamma and gamma prime phases. The gamma prime phase ($Ni_3(Al,Ti)$) is responsible for high temperature properties. Tantalum, niobium and other alloying elements can also participate in the gamma prime phase. The fraction of the gamma prime phase need not exceed 0,2 in superalloys suitable for welding. The content of Al+Ti in Inconel 713C exceeds 4 % and that is the reason why this alloy is thought to be non-weldable [6,7].

There are a few types of cracks that can be found in nickel-based superalloys [8,9,10,11,12,13]:

- hot cracks situated in the center of weld,
- liquation cracks created in heat-affected zone (HAZ),
- post-weld heat treatment (PWHT) cracks.

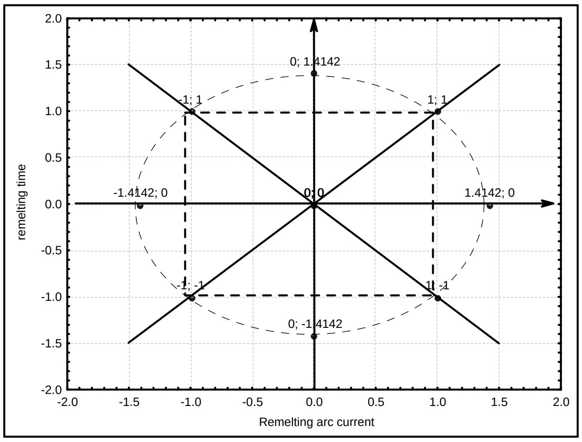

Fig. 1. Program of the experiment. Distribution of the welding tests in the plane of factors: remelting arc current and remelting time

The first type of cracks are generated mainly by γ - γ' eutectic melted at a low temperature in the presence of thermal tensile stress. The presence of liquid eutectics at grain boundaries makes for an area of null ductility, very sensitive to cracking. A well-known method of avoiding this kind of crack is to use a filler metal that changes the chemical composition of weld.

Liquation cracks in the heat-affected zone are more difficult to avoid. The welding thermal cycle is characterized by a short heating time and a high temperature gradient. The second phase which is concentrated along the grain boundaries in HAZ does not have enough time to dissolve but its surfaces are wet and create areas of limited strength, which are prone to cracking. This type of cracking can be avoided by a reduction of the thermal stresses and using welding methods that have a very narrow heat-affected zone.

Nickel-based superalloys are heat treated after welding to recover the original structure damaged by welding or to remove residual stress. This process can create PWHT cracks. The temperature range of PWHT overlaps the temperature range of the precipitated strengthened phase γ'. These two processes disturb each other and as a result cracks longer than the hot cracks are created.

There are a few welding processes that are reported to produce sound welds on nickel-based superalloys. Electron beam welding (power density 10^7-10^9 kW/m^2) and friction inertia welding have been proved to secure a good weld quality, but even these methods do not ensure welds without cracks. Laser welding (power density 10^6-10^9 kW/m^2) and plasma welding (power density 10^4-10^6 kW/m^2) can also be used. Traditional welding methods like GTA welding (power density 10^4-10^5 kW/m^2) can be used in a limited range on the mechanized stands because the welding parameters need to be controlled very precisely [14,15].

3. Design of experiment

The ranges of the remelting arc current and remelting time were limited during the preliminary test to 40 A – 80 A for the remelting arc current and 1s – 6s for the remelting time.

A statistical design of the experiment was used to find the interaction between the welding parameters and the dimensions of the remelted area and to limit the number of tests. A second-order interaction was expected so the response surface design was used, Fig. 1. The factors were remelting arc current and remelting time. The dependent variables were: the diameter of remelted area measured on surface of specimen – D and the depth of remelted area – H.

4. Experiments

Welded samples were produced on AISI 316 sheet metal of the dimensions 40x40x3 mm. Twelve spot remelts were made using the GTA welding method. Remelting parameters were computed using the design of the experiment, Fig. 1. The true values of remelting parameters can be found in columns two and three of Table 1.

Tests were completed in a robotized welding cell, which made it possible to set the remelting arc current and remelting time very precisely. A wolfram lanthaneted electrode 1mm in diameter and argon as shielding gas was used. The welding arc length was 1,5 mm.

The diameters of melted areas were measured on the surface of specimens and the depths of melted areas were measured on the etched cross-section of specimens, Table 1.

Table 1.
Results of experiments

	Remelting arc current [A]	Remelting time [s]	Diameter of remelted area [mm]	Depth of remelted area [mm]
1	2	3	4	5
1	46.0	1.7	2.4	0.6
2	74.0	1.7	3.5	1.5
3	46.0	5.3	2.9	0.6
4	74.0	5.3	4.6	2.9
5	60.0	3.5	3.0	1.0
6	60.0	3.5	3.0	0.6
7	40.0	3.5	2.0	0.5
8	80.0	3.5	4.2	2.0
9	60.0	1.0	1.0	0.1
10	60.0	6.0	3.9	1.5
11	60.0	3.5	3.5	1.0
12	60.0	3.5	3.2	0.8

5. Interaction of welding parameters and remelted area dimensions

The results of welding tests were used to compute the interaction between welding parameters and the dimensions of melted area.

Computations were completed using the Statistica program at a 95% confidence level. A second-level interaction was assumed but analysis of the results shows that:

- the dimensions of remelted area are a linear function of the welding parameters, Fig. 2, 3,
- the second-level interaction between the welding parameters and the depth of remelted area is insignificant. The same is

true for the rectangle circumscribed about the remelted cross-section area,

- there is no interaction between the remelting parameters and the shape coefficient B/H.

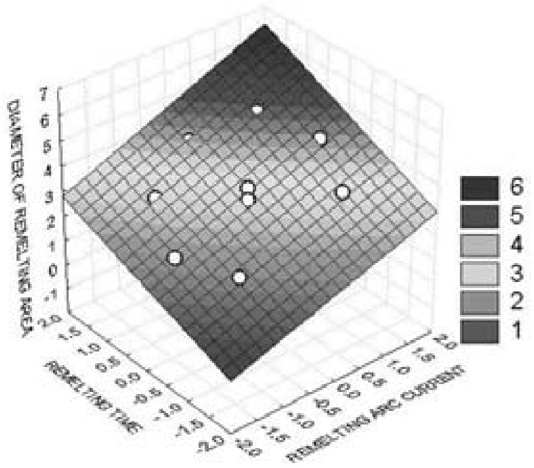

Fig. 2. The response surface of the diameter of remelted area

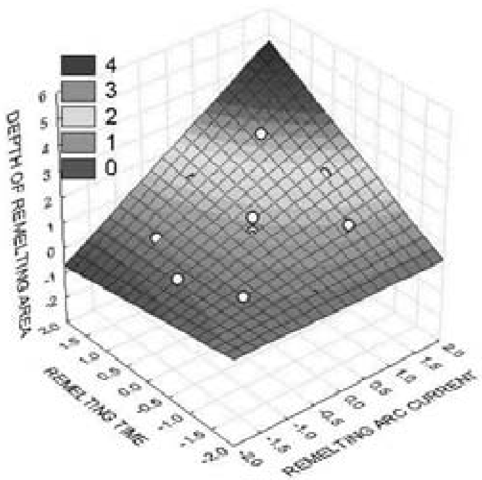

Fig. 3. The response surface of the depth of remelted area

6. Verification of model

Three tests were completed to verify the model:

- remelting of AISI 316 sheet metal, Fig. 4,
- remelting of an artificial defect in AISI 316 sheet metal, Fig. 5,
- remelting of Inclonel 713C cast metal, Fig. 6.

The artificial defect was produced by drilling a 1,5 mm diameter hole of 0,5 mm depth.

The welding parameters, predicted dimension of the remelting area and measured dimension of remelted area are presented in Table 2.

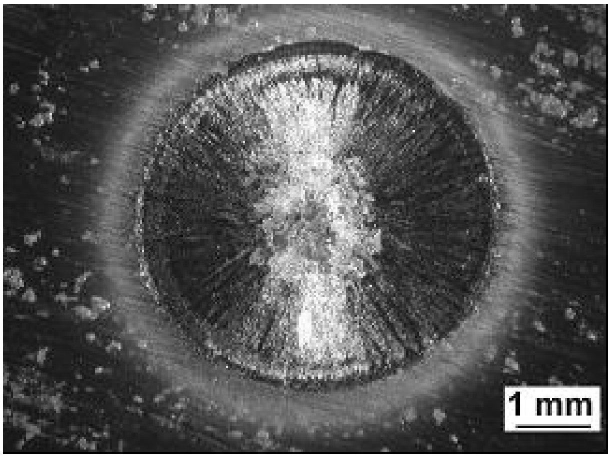

Fig. 4. Surface of GTA spot remelting. Material :AISI 316. Welding parameters: I= 74 A, T= 5,3 s

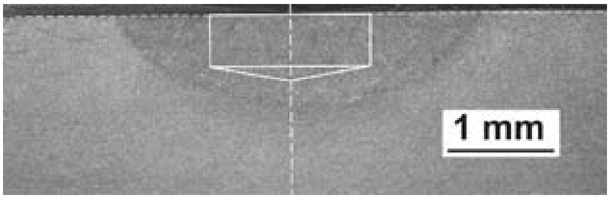

Fig. 5. Transverse macro-section of GTA remelted artificial defect. Dimensions of defect: D= 1,5 mm, H= 1,0 mm. Welding parameters I= 60 A, T= 3,5 s

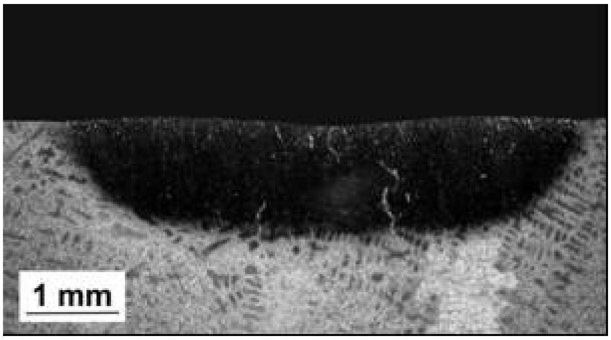

Fig. 6. Transverse macro-section of GTA remelted area. Material: Inconel 713C. Welding parameters I= 75A, T= 5,3s

7. Discussion and conclusions

The statistical model of GTA remelting of surface spot defects has sufficient accuracy to help in the selection of the optimal remelting parameters. Remelting of the same metal volume is

Table 2.
Results of the model verification

Description	Remelting arc current [A]	Remelting time [s]	Diameter of remelted area D [mm]		Depth of remelted area H [mm]	
			Predicted	Observed	Predicted	Observed
AISI 316 steel	74	5,3	4,73	4,6	2,9	2,9
AISI 316 steel + defect	60	3,5	3,1	3,4	1,18	0,90
Inconel 713C	80	3,5	4,2	4,9	2,1	1,2

possible using a different combination of welding parameters. The interaction between the welding parameters and the dimensions of the remelted area proved to be linear with a small contribution of interaction.

The thermal conductivity of stainless steel which was used for most experiments is lower than the thermal conductivity of Inconel 713C and the coefficient of thermal expansion of stainless steel is higher than the coefficient of thermal expansion of Inconel 713C, which means that the model should be calibrated. The thermal conductivity ratio of both alloys could be used as the calibration ratio. A comparison of the dimensions of spot remelting produced on AISI 316 sheet metal and Inconel 713C cast metal shows that results can be easily transferred, Fig. 4.

The main, metallurgical problem of remelting the surface defects of cast metal Inconel 713C is a great challenge. It will be solved in the next stage of the research.

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