Microstructural Changes of Ni-Based Superalloy After GTA Welding with Induction Preheating

Rafał Cygan[1], Konrad Chrzan[2], Krzysztof Jaśkowiec[2], and Małgorzata Grudzień-Rakoczy[2*],
1. Rzeszow University of Technology, Research and Development Laboratory for Aerospace Materials, Żwirki i Wigury 4, 35-959 Rzeszów
2. Łukasiewicz Research Network-Kraków Institute of Technology, Zakopiańska 73, 30-418, Kraków, Poland
*Corresponding address: e-mail: malgorzata.grudzien@kit.lukasiewicz.gov.pl

Abstract: This work presents the influence of high-frequency induction preheating on the weldability of Alloy 700 Ni-based superalloy. The investigation was divided into the characterization of the material's microstructure after preheating and determining the influence of preheating on constitutional liquation during gas tungsten arc welding. Microstructure investigation confirmed that the induction preheating allows to prevent liquation cracking formation in HAZ. The eutectic γ–γ' re-solidification products were visible on the liquated edges and allowed for a self-healing effect.

Keywords: superalloy, Alloy 700, aerospace, investment casting

1 Introduction

The use of welding or cladding is desirable for enhancing manufacturing process efficiency and repairing serviced components to extend their lifetime. However, this is very challenging due to the high susceptibility of Ni-based superalloys to liquation cracking during welding [1-2]. Although solidification cracks in the fusion zone are also observed, they are not as problematic as cracks in the heat-affected zone (HAZ). Cracking in the fusion zone can be mitigated by selecting the correct filler metal. However, the chemical composition and microstructure of the base material, in most cases, cannot be arbitrarily altered. Liquation cracks are significantly more challenging because numerous strengthening phases, characterized by a complex chemical composition that decreases weldability, contribute to their occurrence. Nevertheless, these phases are necessary to achieve stability and heat resistance during long-term service. Ni-based superalloys containing substantial amounts of Al and Ti (more than 6 wt%) are generally considered very difficult to weld due to their high susceptibility to cracking. This criterion does not consider other microstructural constituents like carbides and borides [3-5]. Consequently, superalloys with theoretically good weldability unexpectedly crack during welding or repairing. A characteristic feature of cast Ni-based superalloys is their complex chemical composition, resulting from more than 10 alloying elements with significantly different properties. This leads to the formation of various phases, usually with complex morphologies and a high tendency to segregation [6-8]. Therefore, the weldability of each superalloy should be considered individually. This work aims to reveal the role of induction preheat in reducing the susceptibility to liquation cracking formation in the heat-affected zone.

2 Experimental procedure

The lost-wax castings of Alloy 700 nickel-based superalloy were fabricated in vacuum condition. The nominal chemical composition is presented in Table 1.

Table 1. Composition of Alloy 700, wt%

Cr	Co	Ti	Mo	Fe
15.0	18.5	3.4	5.0	<1.0
Al	C	B	Ni	-
4.3	0.07	3.4	Bal.	-

The superalloy was subjected to the gas tungsten arc welding with high-temperature preheating. For microscopic examinations, they were mounted in resin, ground, polished, and chemically etched in Kalling reagent for light microscopy (LM) and in HNO_3, H_3PO_4 and H_2SO_4 for SEM. LM images were captured by microscope Leica. SEM observations were conducted using a Phenom Desktop XL instrument with a CeB6 electron source. The accelerating voltage during SEM-BSE (backscattered electrons) observations and X-ray energy dispersive spectroscopy (SEM-EDX) was 20 kV.

3 Result and discussion

Fig. 1 shows the cross-section microstructure of the preheated Alloy 700 superalloy after GTA welding. The fusion zone and heat-affected zone (HAZ) are free from hot solidification and liquation cracking.

Preheating effectively eliminated liquation cracks in the heat-affected zone (Fig. 2). The preheating temperature facilitated the dissolution of additional γ' precipitates and the generation of a substantial volume of non-equilibrium liquid. Constitutional liquation of the γ' precipitates occurred at the grain boundaries and in areas adjacent to these boundaries. This resulted in the formation of a new eutectic γ–γ' layer at the grain boundaries, with varying thickness likely due to local changes in chemical composition. There was no observed correlation between the thickness or morphology of the newly formed eutectic γ–γ' layer and the distance from the fusion line, where the welding temperature was the highest in the HAZ.

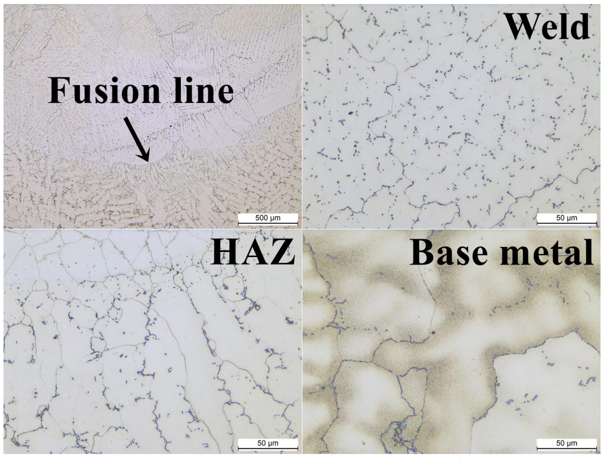

Figure 1. Microstructure of Ni-based superalloy after welding with induction preheating, LM.

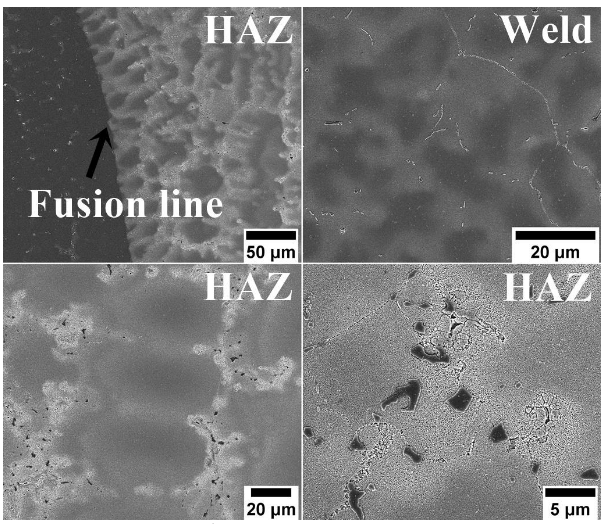

Figure 2. Morphology of the strengthening phases in the Alloy 700 Ni-based superalloy after welding with induction preheating, SEM-BSE.

4 Conclusions

This work focused on analyzing the effects of induction preheating on the improvement of the Alloy 700 superalloy resistance to liquation cracking in HAZ during gas tungsten arc welding. The main conclusions are as followed:

- The partial dissolution of γ' phase precipitates occurred during preheating.
- Rapid heating above the γ' solvus temperature caused the formation of eutectic liquid due to the reaction between partially dissolved γ' precipitates and the matrix.
- A sufficiently high preheating temperature could contribute to eliminating liquation cracks through intensified γ' precipitate dissolution, thermal stress reduction, and microcrack self-healing with a liquid eutectic.

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