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HAZ CHARACTERIZATION OF GTD-111 NICKEL BASED SUPERALLOY WELDING

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Abstract

Heat Affected Zone (HAZ) of TIG welded Ni base GTD 111 superalloys using various filler materials is investigated. The characterization is done based on microstructure observation and hardness estimation. The micro-hardness mapping indicates that the HAZ's are restricted to an area within 1 mm from the weld junction, independent of filler materials used. The microstructure evaluation shows that size of γ', which precipitates coherently within the matrix, appear to be unchanged, while some MC type carbides break-up are detected within the HAZ. Fine intergranular microcracks associated with grain boundary liquation are observed at the weld junction transverse to the weld bead. Detailed chemical analysis indicates that the edge of cracks are Al and Ti rich, which are known to produce γ' precipitate in Ni superalloy. It is suggested that liquation of γ' along grain boundaries occurrs during welding and contributes to HAZ cracking in GTD 111 similar to other report on precipitation hardened Ni based superalloy.

Introduction

Turbine blade of heavy duty Industrial Gas Turbine (IGT) used in power generation is commonly made of special precipitation hardened nickel base

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superalloy. GTD 111, which is widely used as first stage turbine blade, belongs to this group of materials that are capable for retaining mechanical properties at elevated temperature and possess adequate corrosion and high temperature oxidation resistance (Sims et al. [8]). However, severe operating environment of IGT at temperature around 1000°C together with complex mechanical stresses demand turbine blade to be frequently inspected and refurbished at scheduled interval to repair defects and restore its mechanical properties. Without proper inspection and refurbishment, turbine blade may fail in operation that could lead to catastrophic failures.

The most common and cost-effective method of turbine refurbishment includes application of manual Tungsten Inert Gas (TIG) welding. Difficulty in welding of precipitation hardened nickel base superalloy including GTD 111, limit weld repair of turbine blade to less critical areas such as blade tip, as weaker nickel base alloy filler material is added during welding. Cracking, however, is very difficult to avoid during turbine blade welding. Micro cracking occurs in form of intergranular decohesion of grains due to large shrinkage stress which aided by liquation of carbides and other intermetallic phases at HAZ grain boundaries as reported in similar alloys. Ojo et al. [4] reported that HAZ cracking in cast Inconel 738 superalloy, predecessor of GTD 111, is associated with grain boundary liquation of γ'. Ironically, presence of fine distribution of γ' in nickel based superalloy is vital as the main strengthening mechanism. Liquation related HAZ cracking is also observed in nickel alloy 718 (Qian and Lippold [7]) and Waspaloy (Qian and Lippold [6]) as well as other alloy system such as aluminum (Cao and Kou [1]).

Presence of microcrack in turbine blade weldment is definitely not desirable as the crack may grow during turbine operation. Understanding HAZ characteristic and cracking morphology of weldment could provide us insight on how to improve reliability of gas turbine and security of electricity power supply. This paper discusses on HAZ characteristic of GTD 111 weldment using various filler materials in term of hardness variation and microstructure analysis.

Experimental Procedure

The material used in this study is nickel based GTD 111. It has been obtained from a scrap second stage bucket of General Electric MS9171E gas turbine. Five (5) sections of $100\,\text{mm} \times 25\,\text{mm} \times 5\,\text{mm}$ with $0.15\,\text{mm}$ V-groove in the middle are machined from the blade shank using Electro Dispersive Machine (EDM) wire cut. Chemical composition of the alloy, shown in Table 1, is determined by positive material identification (PMI) technique using Arcmet Spectrometer. All samples are subjected to standard solution heat treatment at 1120°C for 2 hours prior to welding application.

Table 1. The chemical composition of GTD 111 and selected TIG filler materials (wt.%)

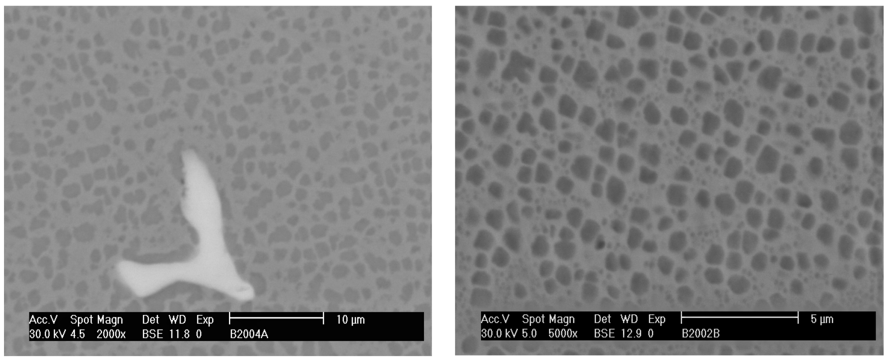
	Ni	Cr	Co	Ti	Al	W	Mo	Ta	Fe	C	Nb	Si
GTD 111	Bal.	12.7	11.2	4.2	2.3	3.0	1.8	3.1	-	0.09	-	-
Filler A	Bal.	20.7	10.3	0.5	1.7	0.5	11.5	0.8	0.5	-	1.9	0.2
Filler B	Bal.	18.7	17.4	2.0	1.1	-	10.3	-	0.9	-	3.2	0.3
Filler C	Bal.	21.4	0.7	0.3	0.6	0.5	10.2	1.5	0.4	-	2.6	0.4
Filler D	Bal.	21.3	0.5	0.5	-	0.6	11.1	-	0.8	-	3.6	-
Filler E	Bal.	19.5	18.7	2.1	0.8	1.6	7.3	0.7	0.9	-	2.4	0.3

Welding application is performed manually using TIG method with Argon shielding gas. Five (5) types of commercially available nickel based filler materials with composition shown in Table 1 are used. Single competent welder is employed for all weld specimens to minimize human error uncertainties. Weld specimens are then cut in transverse and longitudinal direction for metallographic analysis. All samples are molded in resin, ground, polished, and etched with Aqua Regia solution ($HCl + HNO_3$). Microstructure analyses are carried out using optical microscope (OM) and environmental scanning electron microscope (SEM) equipped with energy dispersive X-ray spectrometer (EDAX). Hardness across weldment and HAZ are measured using Vickers microhardness indenter.

Result and Discussion

Microstructure of GTD 111

GTD 111 is a multiphase structure consisted of γ matrix, fine γ' precipitate, γ-γ' eutectic, carbides and minor intermetallic phases similar to other precipitate hardened superalloy. Microstructure analysis using optical microscope shows that grain size, carbide particles, and γ-γ′ eutectic are unaffected by 2 hours solution heat treatment at 1120°C. Microstructure analysis using SEM shows that the received GTD 111 exhibits bimodal distribution of γ′ precipitate with size ranging from 0.5-3.0 μm as shown in Figure 1. After solution heat treatment, γ′ size become smaller to a range of 0.5-1.5 μm and their interparticle spacing increase resulted in reduced of γ′ volume fraction. No significant change is observed on the carbides and γ-γ′ eutectic. Hardness is found to slightly decrease from 425hv to 410hv on average after solution heat treatment.



(a) As received – 2000x (b) Heat treated – 5000x

Figure 1. SEM images of GTD 111.

HAZ microstructure and hardness variation

Microstructure variation on the HAZ is examined using SEM at 0 mm, 0.5 mm, 1.0 mm, and 2.0 mm from weld junction in transverse and longitudinal direction. For all welding samples, it is observed that there is no significant microstructure change at distance 0.5 mm from weld junction outwards. Hardness measurement indicates high hardness at weld junction, which slowly decreases and becomes stable at distance more than 0.8 mm outwards. The findings suggest that HAZ of GTD 111 superalloy is limited in the region of approximately 1.0 mm from the weld junction. Huang et al. [2] estimated HAZ of precipitation strengthen nickel alloy 718 is within 1.5 mm based on hardness distribution curve.

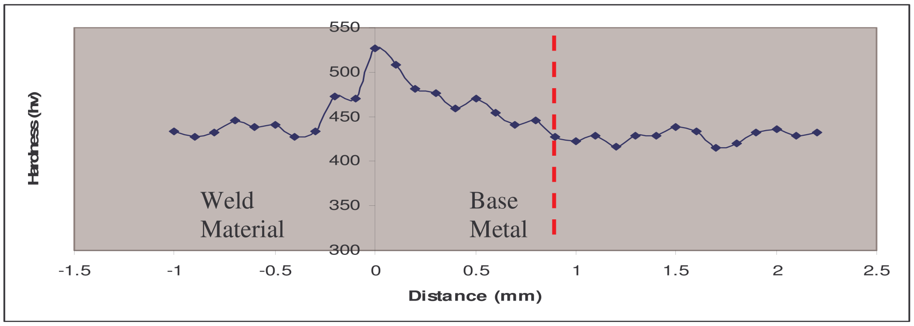


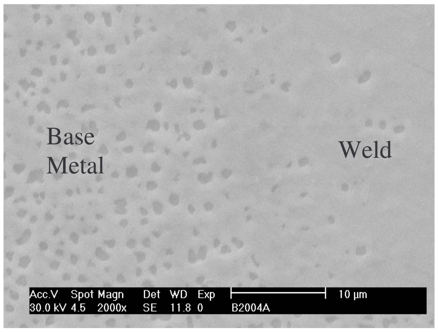
Figure 2. Hardness mapping at HAZ.

MC carbides break up and liquation cracking

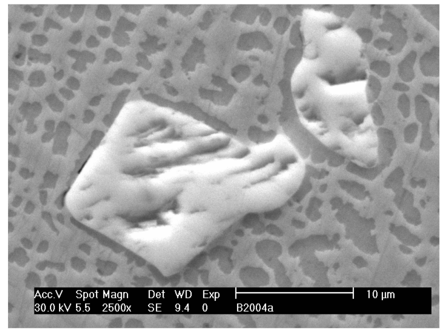
Figure 3(a) shows weld junction of GTD 111 material. Weldment microstructure possess fine grain of solidified microstructures with no evidence of γ' precipitation. The result is expected as added filler material contained lower amount of Al and Ti that are responsible in formation of γ' precipitate with empirical formula of Ni_3 (Al, Ti), where Al can be substituted for Ti. On the other hand, GTD 111 base metal contains uniform distribution of γ' precipitate within the matrix which serve as primary strengthening mechanism.

Detailed microstructure analysis on the HAZ region within 1.0mm from weld junction reveals presence of disintegrated carbide particle as shown in Figure 3(b). Surface crack and decohesion of carbide-matrix surface are clearly visible. The phenomenon could be explained due to brittle nature of carbides and its inability to absorb sudden stress changes as a result of temperature gradient due to welding. Chemical analysis of carbide particles confirms that the carbides are MC type with rich amount of Ti and Ta.

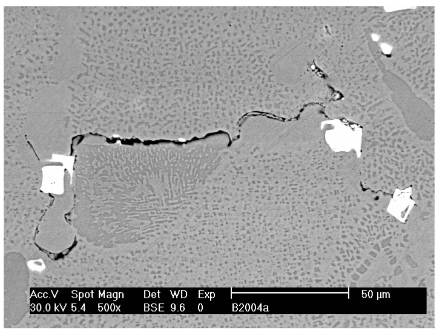
In addition to carbide break up, number of intergranular crack are observed on the HAZ. The crack appears to be associated with grain boundary liquation as evidenced in Figure 3(c). Chemical analysis on the edge of crack indicates presence of high amount of Al and Ti compare to the matrix. The finding suggests that constitutional γ' liquation may have taken place at HAZ grain boundary during welding, similar to previous studies by Ojo et al. [3-5]. On separate study, Zhong et al. [9] characterized boundary liquation in directionally solidified nickel based superalloy into five (5) types. Close examination of certain large γ' precipitate in the HAZ shows evidence of liquation and boundary decohesion as in Figure 3(d).



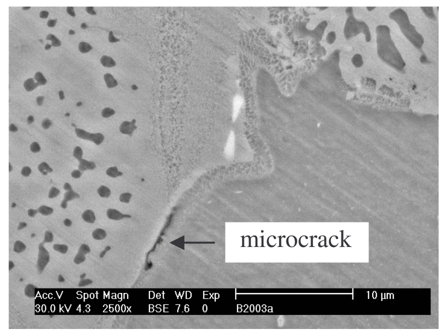
(a) Weld junction – 2000x



(b) Carbide break up – 2500x



(c) Intergranular crack – 500x



(d) γ' liquation – 2500x

Figure 3. SEM images in HAZ.

Conclusion

The HAZ of nickel based GTD 111 superalloy welded using various filler materials has been characterized using microstructure observation and hardness estimation. Micro-hardness mapping indicates that the HAZ's are restricted to an area within 1 mm from the weld junction, independent of filler materials used. Microstructure examination within the HAZ region indicates presence of carbide break up and grain boundary micro cracking while γ' precipitates appear to be unaffected. Higher content of Al and Ti along the crack edges has suggested that liquation of γ' along grain boundaries occurred during welding and contributed to HAZ cracking in GTD 111.

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