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Effect of TIG Welding Parameters on Strain-age cracking in Joining Nickel-based Superalloy, GTD-111 with Inconel 625

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Abstract

Excellent mechanical properties at high temperature of nickel-based superalloys brought them to extensive application in severe operating conditions. However, the great mechanical properties deteriorate after long-term exposure to high temperature and it frequently causes failure of the component e.g. cracking. TIG welding is considered as an economical way to refurbish the minor damage component as replacement with new one is costly due to high material cost and complexity in manufacturing processes. Unfortunately, heat from welding that applies to the component may create new cracks during and after process from liquation and strain-age cracking. This phenomena is problem especially in precipitation-hardened alloy e.g. GTD-111. Several mitigations, such as pre-weld heat treatment, are proposed to avoid weld cracking occurrence, but most of them require additional process which takes time and cost. In this work, four different TIG welding conditions were studied in non-pre-weld heat treated GTD-111 with IN-625 filler wire for their effect on crack occurrence after welding and after post-weld heat treatment (PWHT). Cracking in heat-affected zone (HAZ) was observed in none of as-welded condition specimens. After PWHT, cracking was found in condition in one condition with welding energy of 198 W. The microstructure study showed the possibility to produce crack-free TIG weld of GTD-111 without pre-weld heat treatment process.

Keywords : TIG welding, Strain-age cracking, Nickel-based superalloy

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Introduction

Gas turbine blade in land-based electricity generator has been exposed to severe condition during its service life; therefore, advanced material with high temperature creep resistance, hot corrosion resistance, tensile strength and ductility is required in the industry. One of the candidate materials for this specific application is nickel-based superalloy which gains its good properties at high temperature from existence of ordered gamma prime (γ'), metallic compounds and solid solution in the matrix. However, after long-term service, the desired microstructure of the superalloy could be gradually degenerated and cause significant deterioration of its exceptional mechanical properties and visible damage of the blades from localized erosion-corrosion. Refurbishment method of the Nickel-based superalloy has been extensively researched in effort to reduce total operating cost as it is costly and requires long lead time to replace the damaged component with the new one.

GTD-111 is commercial γ' precipitation-strengthened nickel-based superalloy that was developed from INCONEL 738 LC (IN738 LC) by GE in mid-1970s to improve local hot corrosion resistance by utilizing phase stability and other predictive techniques to balance the levels of critical elements (Cr, Mo, Co, Al, W and Ta).[1] The GTD-111 is known to be susceptible to cracking in heat-affected zone (HAZ) by two mechanisms; liquation cracking during TIG welding and strain-age cracking after post-weld heat treatment (PWHT) due to its significant amount of Ti and Al (> 6 Wt.%) which fall into difficult-to-weld region.[2] These cracking mechanisms were studiedand reported in many researches[3,4,5,6,7], some of them were aimed to find a way to minimize crack occurrence by deploying pre-weld heat treatment prior to welding process.[8] However, the methods require time and investment for additional processes and its optimization is still inconclusive.[8]

Therefore, this study purposes to seek for an opportunity to produce crack - free welding without having pre-weld heat treatment process by revisiting and searching for proper TIG welding parameters which minimize cracking occurrence during welding and after PWHT in non-pre-weld heat treated GTD-111 with INCONEL 625 (IN625) filler wire.

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Materials and Experimental Procedures

The cast GTD-111 turbine blade, with typical chemical composition in table 1, was provided by Electricity Generating Authority of Thailand (EGAT) after long service time at high temperature. The blade was mechanical sectioned to four pieces, wire brushed and subjected to various TIG welding conditions stated in table 2 with IN625 filler wire under argon atmosphere. After TIG welding, each sample was prepared by standard metallographic techniques - grounded with silicon carbide paper up to 1200 grits, mirror finishing by cloth polishing with colloidal silica, and etched with Marble's Reagent. The microstructure and element quantification of as-welded condition was observed by Scanning Electron Microscope (SEM) that is equipped with Energy Dispersive X-ray spectroscopy (EDX).

After investigating as-welded condition, all samples were post-weld heat treated in 2 stages those were solution treatment at 1200°C for 2 hours + AC (air cooling) and aged at 845°C for 24 hours +AC. The heat treated samples were metallographic prepared and studied by similar proceduresto investigation of as-welded condition.

Table 1. Chemical composition of GTD-111

Ni	Cr	Co	*Ti*	W	*Al*	Ta	Mo	C	B
Bal.	14	9.5	***4.9***	3.8	***3.0***	2.8	1.5	0.1	0.01

Table 2. TIG welding parameters used in experiment

Condition	Voltage (V)	Current (A)	Welding Energy (Watt)
1	9	35	315
2	9	27	243
3	9	22	198
4	9	20	180

Results and Discussion

3.1 As-received condition

The received GTD-111 had been operating in gas turbine engine at high temperature for several hours. The microstructure was clearly non-uniform. Figure 1(a) showed that the microstructure was in dendritic structure which indicated that the blade was formed by conventional casting process. The higher magnification SEM micrographin figure 1(b) revealed the complicated microstructure of the as-received GTD-111 to be consisted of elongated grain with MC carbides, overaged-γ' precipitates and γ-γ' eutectics. Etching with Marble's reagent removed γ' precipitates from their sites, therefore the existence of the particles was represented by holes as shown in figure 1(c). The SEM micrograph also indicated γ' precipitates coalescence and coarsening which caused mechanical properties deterioration after long-term thermal exposure.

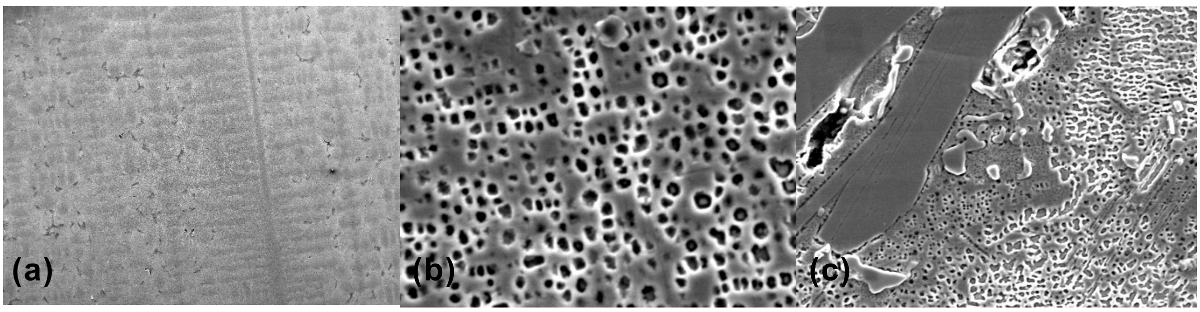


Figure 1 : As-received condition

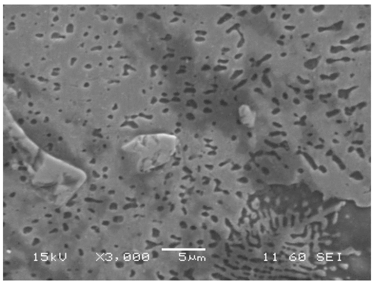
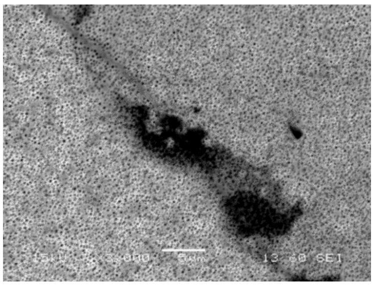
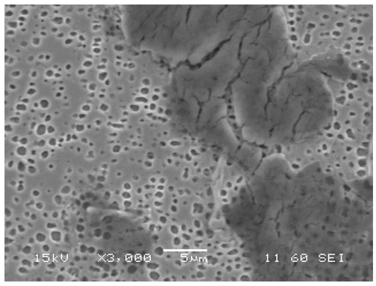
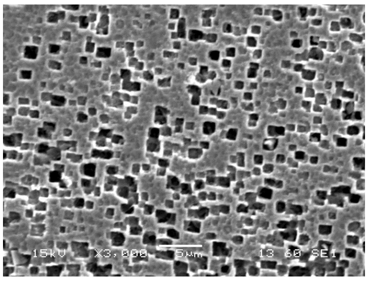
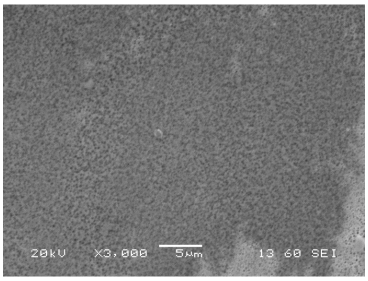
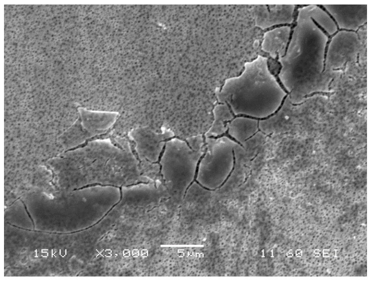
3.2 After TIG welding condition

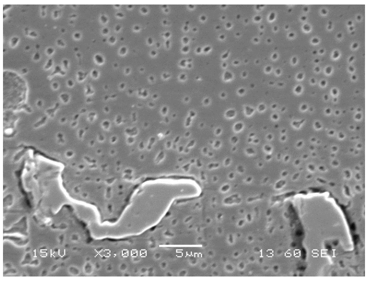
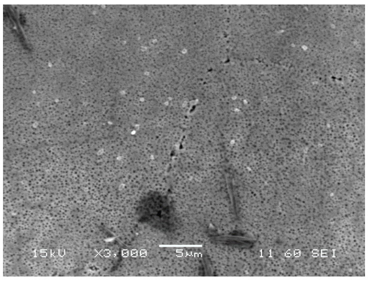
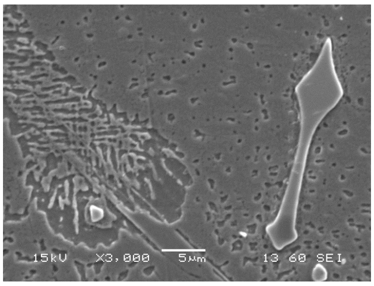
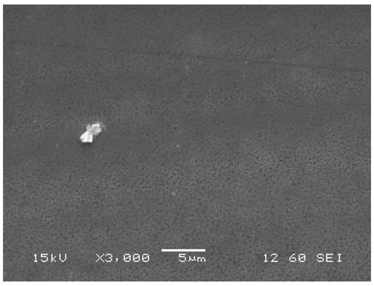
Due to different sensitivity to etchant, boundary between base metal and weld bead can be observed by naked eye in all samples. Unfortunately, the weld boundaries were unclear under higher magnification of microscope as presented in the left column of table 3. SEM micrographs with higher magnification might give more detail about the microstructure of the weld band as it was expected to consist of very fine γ’ precipitations; however, the study was aimed to investigate crack occurrence in each condition so the higher magnification micrographs were not taken.

It was reported that heat-affected zone (HAZ) of GTD-111 was restricted to an area within 1 mm from weld junction(9) which was consistent with results in all samples in this study.Irregular shape MC carbides and γ-γ’ eutectics located at HAZ can be observed in all samples. The size of γ’ precipitates were varied from very fine particles near the weld bead and coarser as nearer to base metal. Nevertheless, it can be seen that γ’ precipitates morphology near the weld band was cuboidal, which was expected as it was newly precipitated due to heat from welding process.The average sizes of γ’ precipitates in the weld band area were similar in condition 3 and 4 while it was greater in condition 1 and 2 with higher heat input. The higher heat might also affect to occurrence of γ’ precipitate in cuboidal morphology which could be seen in condition 1 and 2.

Crack occurrence was also investigated in all as-welded samples to study if the heat from welding process would cause liquation cracking. The studies of liquation cracking in IN738LC in laser welding process by other authors in pre-weld heat treated samples showed that the liquation cracking could be seen in SEM micrograph at moderate magnification of 500Xand could be originated by liquated phases/structures those were γ-γ’eutectic, MC carbides and Cr-Mo Borides.(10) However, thosetype of cracks were not found in any TIG welding conditions in this study even at higher magnification. This result is expected to be due to low welding power used in the study compared to the condition used in the cited research. It is noteworthy that MC carbides were found crack in condition 1 and 2 which might indicate localized contraction of the carbide during cooling from welding temperature. SEM micrographs of the cracks were shown in right column of table 3.

Table 3. SEM Micrographs of as-welded and after PWHT samples in each condition

No	AS-WELDED CONDITION	AFTER PWHT CONDITION	CRACK OCCURRENCE
1			
2			

3			**No crack found**
4			**No crack found**

3.3 After PWHT condition

After PWHT with solutionizing at 1200°C for 2 hours and aged at 845°C for 24 hours which is the condition that was reported to successfully provide homogeneous microstructure of GTD-111[7], the microstructure of samples was investigated and compared with as-welded sample with the same TIG welding parameters. The SEM micrographs of each as-PWHT samples were presented in middle column of table 3.

One of the most noticeable differences in microstructure between as-welded and after PWHT condition is the size of γ' precipitates that was much smaller and more uniformly distributed as they were homogeneously dissolved into matrix and re-precipitated during PWHT process. The uniformity of γ' particles were crucial to overall mechanical properties which was the key reason of material refurbishment. There was no significant difference in γ' precipitate size between samples with each welding condition. The MC carbide and eutectic structure were also found in all samples. Moreover, it can be seen that dendritic structure in as-received condition were destroyed in all samples and it was difficult to identify the segregation pattern. MC carbide precipitations at grain boundary near weld band can be observed in all samples. The blocky type MC carbide precipitates was reported to improve mechanical properties of Rene 80 (which was closed in chemical composition to GTD-111) since the precipitation of carbide s would prevent dislocation moving and grain boundary sliding.[11]

Cracking was also investigated in after-PWHT condition, however, there was no intergranular cracking which is typical pattern of strain-age cracking found in any samples. Carbide cracking due to localized contraction was still observed similar to samples in as-welded condition.

Conclusions

The study aimed to investigate crack occurrence from various TIG welding condition in non-pre-weld heat treated GTD-111 samples which were exposed to high temperature for several hours. The experimental results showed that the welding power at 180, 198, 243 and 315 Watts created liquation crack-free weldment in as-welded condition. Post-weld heat treatment (PWHT) by solutionizing at 1200°C for 2 hours and corresponding by aging at 845°C for 24 hours could produce fine and uniform γ' precipitates in base metal which was desired condition. With the mentioned welding parameters, there were no observed liquation and strain-age cracking in any samples, it might be possible to find very fine microcracks at higher magnification that was not conducted in this study.

Based on the results in this study, it could be said that it is possible to produce crack-free TIG welding without pre-weld heat treatment process if the welding parameters were carefully selected. This could be the opportunity to minimize time and cost for GTD-111 repair or refurbishment process.

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