# Studies On Microstructure And Pitting Corrosion Of As Welded In718 Gas Tungsten Arc Welds

Dilkush[a], Raffi Mohammed[b], K.S.S.Siva Prasad[a] , K.Jyothi[a] , G.Madhusudhan Reddy[d], K.Srinivasa Rao[c]
[a]Department of Metallurgical & Material Engineering, RGUKT, Nuzvid
[b]Department of Metallurgical & Materials Engineering, NIT Andhra Pradesh
[c]Department of Metallurgical Engineering, Andhra University, Visakhapatnam
[d]Defence Metallurgical Research Laboratory, Hyderabad, India.

**Abstract**

*Nickel based super alloy (IN718) is being extensively used for marine, aerospace, nuclear applications based critical structural components such as gas turbine blades, rocket motors, spacecrafts, nuclear reactors, pumps due to its excellent resistance to corrosion, wear and good weldability. Welding is the major fabrication method used for joining structural components. Problems during conventional fusion welding process can be overcome by the suitable filler wire. Even though base metal has superior corrosion resistance, welding resulted in significant loss in corrosion resistance. In the present study, nickel-base super alloy (IN718) of 3mm thick plates was welded using gas tungsten arc welding (GTAW) process. Welds were characterized for microstructural studies using optical microscopy in as welded condition to observe the changes in microstructural morphology. Vickers hardness testing was carried out in various zones of IN718 GTA welds. Potentio-dynamic polarization studies were done to study the pitting corrosion behaviour of base metal and welds in 3.5% NaCl solution. Results of the present study established that in as welded condition fusion zone revealed formation of brittle, dendritic and columnar laves phases along with presence of Nb segregation. Lower hardness is observed in fusion zone when compared to base metal and is attributed to laves phase and Nb segregation. Poor corrosion resistance is observed in fusion zone of IN718 GTA welds in as welded condition. Relative reduction in pitting corrosion resistance is observed in heat affected zone when compared to that of base metal and fusion zone. This may be attributed to the changes in microstructural morphology and presence of laves phase in various zones of the welds.*

*Keywords: Inconel 718 superalloy (IN718), Gas tungsten arc welding (GTAW), Optical microscopy (OM), Potentio-dynamic polarization testing and NaCl (Sodium chloride).*

## 1. INTRODUCTION

It is being extensively used for critical marine, aerospace, nuclear applications based components such as gas turbine blades, rocket motors, spacecrafts, nuclear reactors, pumps and tooling's due to its excellent resistance to hot corrosion, fatigue, wear and having good weldability with outstanding high strengths at elevated temperatures. Welding is the main fabrication method used for joining structural components. IN718 is reinforced by solid solution and precipitation of second phases, mainly by different heat treatments. The hardening mechanism is mainly contributed by the phase precipitates γ ' $Ni_3Al$ (cubic or spherical shape) and γ" $Ni_3Nb$. The meta stable γ" phase transforms to the $Ni_3Nb$- γ phase during exposure at temperatures above 650°C. During the super alloy manufacturing, control of microstructure is critical for achieving optical mechanical properties [1]. Alloying elements such as Fe, Cr, Mo, Al, and Ti also strengthen the alloy through solid solution mechanisms [2]. Even though there are a lot of better results shown by conventional fusion welding processes, there are few severe problems like solidification cracking in the weld zone and microfissuring in the heat affected zone, segregation of niobium and formation of brittle intermetallic laves phases. However the Nb segregation and consequent formation of Nb-rich, brittle, inter-metallic laves phase $((Ni, Fe, Cr)_2 (Nb , Mo, Ti))$ during solidification of weld metal leads to crack initiation and propagation by depleting the matrix of useful alloying elements [3,4]. Knorovsky et al. [5] conducted a detailed microstructural study on alloy 718 GTA as-weld fusion zones and found that the inter-dendritic regions became enriched with Nb, Mo, Ti, and Si, while the dendrite core regions were depleted of these elements with higher concentrations of Ni, Cr, and Fe. Laves phase is deleterious but the presence is unavoidable as it adversely affects the weld mechanical properties. [6,7]. In the present work an attempt has been made to weld IN718 alloy of 3mm thick plate using gas tungsten arc welding (GTAW) process to observe the microstructural changes and to correlate with observed mechanical and corrosion behavior of IN718 welds.

## 2. EXPERIMENTAL DETAILS

Nickel based super alloy (IN718) of 3mm thick plate was chosen for the present study and chemical composition and filler wire material were given in Table 1. Conventional fusion welding process of gas tungsten arc welding (GTAW) was performed on IN718 and is shown in Fig 1. The optimized welding parameters used are shown in Table 2. After the welding, weld specimens were cut using EDM wire cutting machine, the specimens were prepared according to the standard metallographic procedures followed by mechanically grinded, polished and etched by mixed acid solution (2mL HF + 20mL $HNO_3$ +100mL+76mL $H_2O$ ). Welds were characterized for microstructural studies using optical microscope. Hardness studies were done using vickers micro-hardness tester with load of 100g and 15s dwell time. Potentio-dynamic polarization studies were carried out to observe the pitting corrosion behavior of IN718 GTA welds in 3.5wt% NaCl solution at 30°C. The potential was swept from −250 to 250 mV (versus $E_{corr}$) at a rate of 3 mV $s^{-1}$. The time–voltage was recorded until the steady state potential was reached which is the open circuit potential ($E_{corr}$), the measurement was started from this potential first in the cathodic direction and then in the anodic direction. Accuracy was maintained with respect to the area of the sample exposed in the bath confining to $1cm^2$.

Table 1 CHEMICAL COMPOSITION (Wt %) of IN718 and filler wire

| Material | Chemical Composition(% Elements) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ni | Cr | Nb | Mo | Ti | Al | Si | C | B | S | P | Fe |
| IN718 | 53 | 18.2 | 5.08 | 3.13 | 0.97 | 0.51 | 0.12 | 0.02 | 0.003 | 0.002 | 0.005 | Bal |
| Filler wire (IN718) | 50 | 17 | 4.75 | 2.80 | 0.65 | 0.45 | 0.35 | 0.05 | 0.005 | 0.015 | 0.015 | Bal |

Table 2 OPTIMIZED WELDING PARAMETRES USED FOR CONVENTIONAL GTA WELDING

| Welding parameter | Selection |
|---|---|
| Current | 110 A |
| Speed | 6 mm/s |
| Voltage | 18 V |
| Polarity | DCEN |
| Electrode | Thoriated W, 2 mm dia |
| Shielding gas | Argon |
| Heat input (J/mm) | 330 |

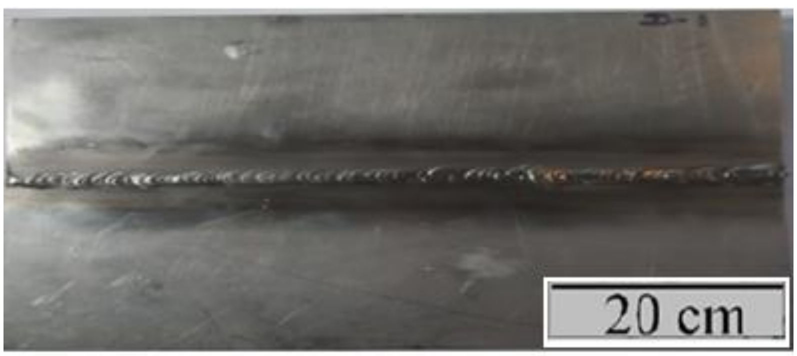


Fig 1 Gas tungsten arc welded IN718 alloy

## 3. RESULTS AND DISCUSSION

### *3.1 Base Metal Microstructure*

Optical microstructure of IN718 super alloy consists of fine equiaxed austenitic grains and is shown in Fig 2 and Fig.3 shows the optical macrostructure of IN718 GTA welds in as welded condition. Twin banded A number of MC type primary carbides randomly dispersed in the γ matrix was observed. Primary carbide particles are known to be rich in Nb and Ti. The base material was found to be free from Laves or any other undesirable phases. A delta phase on the grain boundary was also observed in the base material.

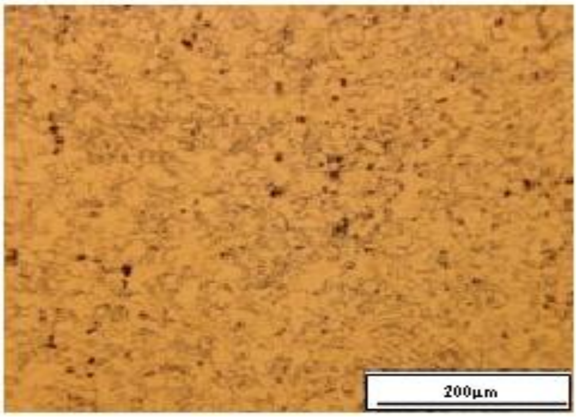


Fig 2 Optical Microstructure of IN718 alloy

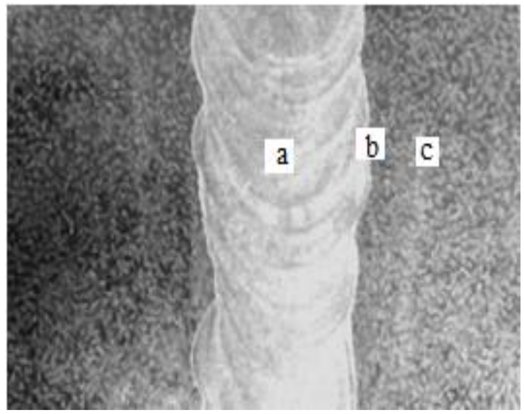


Fig 3 Optical Macrostructure of IN718 GTA welds

### *3.2 IN718 GTA weld Microstructure*

Figs.4 (a) (b) & (c) and 5(a) (b) & (c) shows the optical microstructure and scanning electron microstructure of respective fusion zone , weld Interface and base metal of IN718 GTA weld in As welded condition. It clearly shows the presences of prolonged laves formation and delta phases in the fusion zone, twin bands and MC type carbides in base metal, coarse grain structure was observed at heat affected zone.

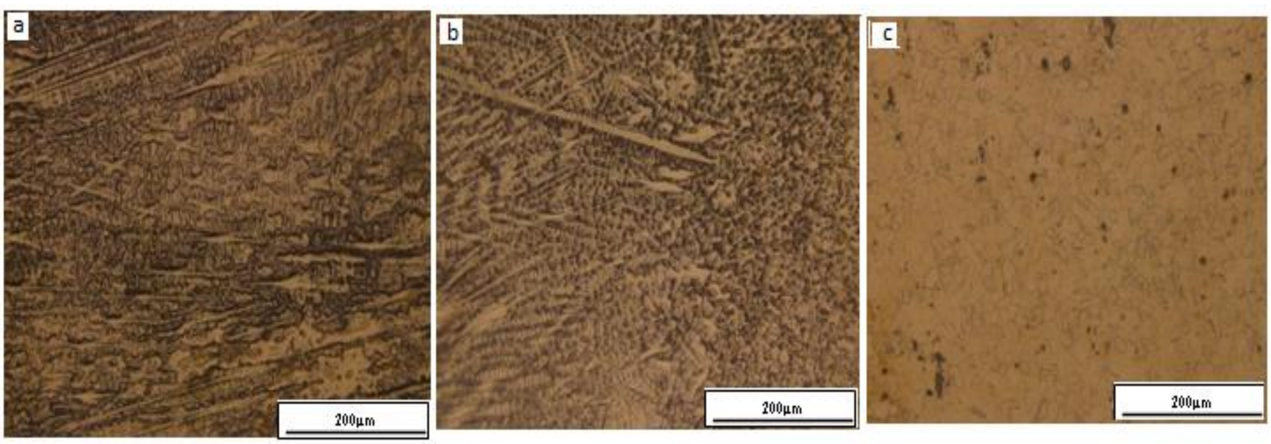


Fig 4 Optical microstructure of IN718 GTA weld (a). Fusion Zone (b). Weld Interface and (c). Base Metal

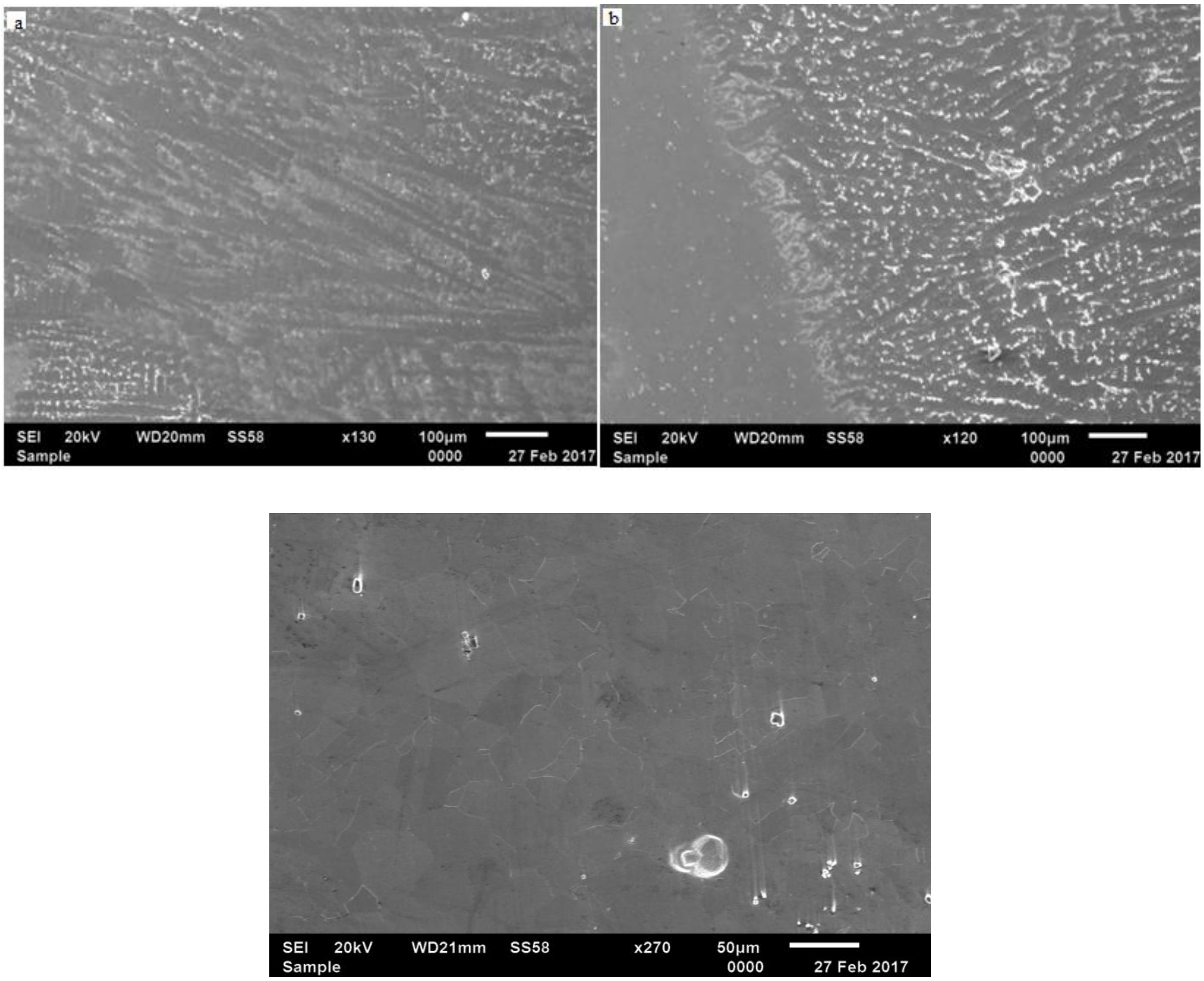


Fig 5 SEM microstructure of IN718 GTA welds (a) Fusion zone and (b) Weld interface and (c). Base Metal

### *3.3Microhardness*

Vickers hardness survey was across the weld perpendicular to the welding direction to observe the hardness profile and is shown in Fig. 6. Variation in hardness is observed in the fusion zone when compared to base metal and is given in Table 3. Relatively poor hardness was observed in fusion zone and weld interface/HAZ when compared to base metal. It is attributed to the formation of laves phase structure and absence of twin bands in the fusion zone.

Table 3 VICKERS MICROHARDNESS MEASUREMENTS OF IN718 GTA WELDS

| Specimen condition | Vickers Microhardness measurement values (VHN) | | |
|---|---|---|---|
| | Base zone | Heat affected Zone | Fusion zone |
| As welded | 310 | 292 | 287 |

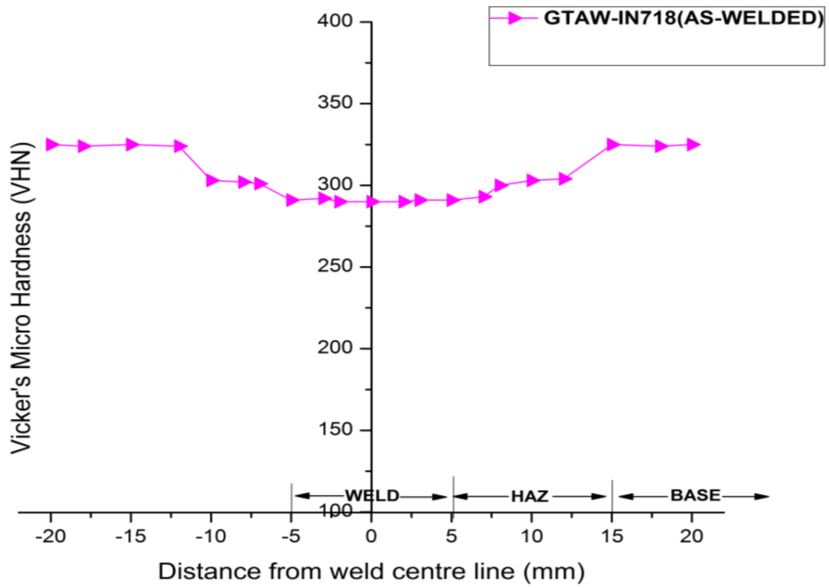


Fig 6 Vickers Micro-hardness survey of IN718 GTA welds

### *3.4 Pitting Corrosion*

Potentio-dynamic polarization studies were carried out to evaluate the pitting corrosion behavior of IN718 GTA welds. It was conducted on all the zones of GTA welds in as-welded condition with respect to fusion zone, heat affected zone and base metal. Potentio-dynamic polarization curves of GTA welds in as welded condition is shown in Fig.7. Corrosion potential is a static indicator of electrochemical corrosion resistance, which reveals the susceptibility of materials to corrosion. Generally, Materials exhibit high corrosion potential offer higher corrosion resistance [8]. The results showed that the corrosion potential (Ecorr) of the fusion zone is lower than that of base metal in as welded condition. The passivation behavior in anodic branch of the polarization curve of IN718 super alloy can be attributed to the high chromium contents in its chemical composition [9]. Table 4 gives the results of Tafel plot experiment showing corrosion kinetic parameters: corrosion potential (*E*corr), corrosion current density (*i*corr) and anodic Tafel slope ($\beta$a) of base metal, heat affected zone and fusion zone of IN718 GTA weld in 3.5 wt% NaCl solution at 30 ˚C and results are represented in pitting graph shown in Fig.7 . It is observed that pitting corrosion behaviour is sensitive to microstructural morphology.

Table 4 POTENTIO-DYNAMIC POLARIZATION VALUES OF BM, HAZ AND FZ OF IN718 GTA WELDS IN 3.5 Wt % NaCl solution

| Specimen with respective zones | $E_{corr}$ (mV) | $I_{corr}$ (mA/cm$^2$) | $\beta_a$(mV) |
|---|---|---|---|
| As Welded condition<br>BZ | -109.29 | 0.0001089 | 278 |
| HAZ | -249 | 0.000604 | 263 |
| FZ | -159 | 0.0002115 | 252 |

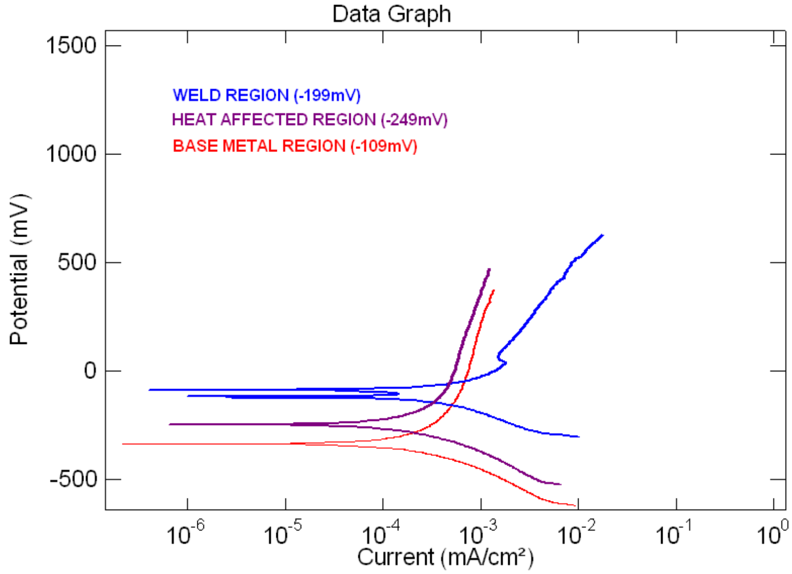


Fig 7 Potentio-dynamic polarization curves of IN718 GTA welds

## 4. CONCLUSIONS

1. Nickel based super alloy (IN718) is observed to have fine equiaxed austenite grains with twin bands and MC type carbides.

2. IN718 GTA weld resulted in the distribution of laves phase with coarser and columnar dendritic structure in as welded condition. The Nb segregation and the Laves problem is most acute in GTA welds.

3. Lower hardness is observed in fusion zone when compared to heat affected zone and base metal. It is attributed to the presence of coarse columnar dendritic structure.

4. Pitting corrosion resistance is relatively lower in fusion zone when compared to heat affected zone and base metal in as welded IN718 GTA welds.

5. Overall study concludes that mechanical properties and pitting corrosion resistance is sensitive to microstructural changes in as welded IN718 GTA welds.

## ACKNOWLEDGEMENTS

The authors would like to thank Director, Defence Metallurgical Research Laboratory Hyderabad, India for his continued encouragement and permission to publish this work.

## 5. REFERENCES

[1] H. C. Basoalto, J. W. Brooks and I. Di Martino, Multiscale microstructure modelling for nickel based superalloys, Materials Science and Technology 25 (2009) 221-227.

[2] Donachie Jr MJ, Introduction to superalloy, in Matthew' J. Donachie, Jr. (Ed,), Superalloys Source Book, ASM, OH (1984) 3-19.

[3] Mills WJ.Fracture toughness of thermally aged alloy 718 weld metal. Weld Res Suppl 1987:113-8.

[4] Radhakrishna CH.Prasad Rao K. The formation and control of laves phase in superalloy 718 welds.J Mater Sci 1997:32:1977-84.

[5]. G.A. Knorovsky, M.J. Cieslak, T.J. Headley, A.D. Romig, and W.F. Hammetter, Jr.: Metall. Trans. A, 1989, vol. 20A, pp. 2149–58.

[6]. G.R. Evers, H.H. Smith, and D.J. Michel: Metallography, 1978, vol. 11, pp. 441–57.

[7]. G.D. Janaki Ram: Ph.D. Thesis, Indian Institute of Technology Madras, Chennai, India, 2004.

[8] Wang S, Ma Q, Li Y. Characterization of microstructure, mechanical properties and corrosion resistance of dissimilar welded joint between 2205 duplex stainless steel and 16MnR. Mater Des 2011;32:831e7

[9] Lippold JC, Koteki DJ. Welding metallurgy and weldability of stainless steels. New Jersey: John Wiley & Sons Inc; 2005.