Welding of Nickel based Superalloys by GTAW Process

P. Archunan[1] M. Dinesh[2] R. Karthikeyan[3] S. Saroja[4]
[1,2,3,4]Department of Metallurgical Engineering
[1,2,3,4]GCE, Salem-11, India

Abstract— The study the weldability and the susceptibility of hot cracking in Nickel base super alloys by Gas Tungsten Arc welding process. The Super alloys are primarily used in gas turbines, coal conversion plants and chemical processing industries and for other specialized applications requiring heat and corrosion resistance. The γ' phase in the Nickel base super alloys is reasonable for the elevated temperature strength of the material and its incredible resistance to creep deformation and grain boundary dislocation. The effect of alloying elements on the Ni base super alloys were studied. The possible welding problems of Ni based super alloys were studied .The Nickel base super alloys are mostly prone to the strain age cracking .The presence of the carbides MC,M23C6,M6C,M7C3 and the laves phases are leads to hot cracking. To overcome those possible problems the welding parameters should be decided. The microstructure appears with γ', carbides, laves phases.

Key words: Nickel Based Super Alloys, GTAW, Process Parameters, Hot Cracking Susceptibility, Effect of Alloy Elements

I. INTRODUCTION

The super alloys are have the base element as major proportion in its composition. The super alloys are have the base metal 50 % or more than 50% in its composition. The three major group of super alloys are Nickel based, Cobalt based and Iron based super alloys. Super alloys are heat-resisting alloys based on nickel, nickel-iron, or cobalt that exhibit a combination of mechanical strength and resistance to surface degradation. Super alloys are primarily used in gas turbine, coal conversion plant, and chemical process industry, and other specialized applications requiring heat and/or corrosion resistance. A feature of Ni-base alloys is their use in load-bearing applications at temperatures in excess of 80% of their incipient melting temperatures, a fraction that is higher than for any other class of engineering alloys. Nickel-base super alloys are the most complex, the most widely used for the hottest parts, and, too many metallurgists, the most interesting of all super alloys. They currently constitute over 50% of the weight of advanced aircraft engines. The principal characteristics of nickel as an alloy base are the high phase stability of the face-centered cubic (FCC) nickel matrix and the capability to be strengthened by a variety of direct and indirect means. Further, the surface stability of nickel is readily improved by alloying with chromium and/or aluminum. The essential solutes in nickel based super alloys are aluminium and/or titanium, with a total concentration which is typically less than 10 atomic percent. This generates a two-phase equilibrium microstructure, consisting of gamma (γ) and gamma-prime (γ').

II. NICKEL BASED SUPER ALLOYS

In Nickel based alloys γ' which is largely responsible for the elevated-temperature strength of the material and its incredible resistance to creep deformation. . The intermetallic like NiAl, Ni_3(Al,Ti) are formed which act as major strengthening phase in these type of super alloys. In addition, deleterious elements such as silicon, phosphorus, sulphur, oxygen, and nitrogen must be controlled through appropriate melting practices. Other trace elements. Such as selenium, bismuth, and lead, must be held to very small (ppm) levels in critical parts. Many wrought nickel-base super alloys contain 10 to 20% Cr, up to about 8% Al and Ti combined, 5 to 15% Co, and small amounts of boron, zirconium, magnesium, and carbon. Other common additions are molybdenum, niobium, and tungsten, all of which play dual roles as strengthening solutes and carbide formers. Chromium and aluminium are also necessary to improve surface stability through the formation of Cr_2O3 and Al_2O_3, respectively. A dislocation travels more easily through the unreformed gamma matrix of super alloy. Since the gamma phase is ordered, although a single dislocation cannot travel through it conveniently and hence the cuboids of gamma' in the matrix pin traveling dislocations in place, making it more difficult to deform the material. When a second moving dislocation welds the first one, the dislocation group can travel together across gamma prime cuboids with a nominal high energy antiphase boundary between them. The super alloy hence prevents deformation and is tougher than a traditional alloy. The carbides may offer controlled reinforcing directly or higher indirectly. Directly refers to dispersion hardening and indirectly refers to stabilized grain boundaries against excessive shear. Moreover those elements that offer solid solution hardening and enhance carbide and gamma production, elements like boron, zirconium, hafnium, cerium etc. are included to improve the mechanical and chemical functionality.

III. EFFECT OF ALLOYING ELEMENTS

Nickel is able to dissolve larger amounts of alloying elements in it than iron, especially chromium, molybdenum and tungsten which allows for its application in much more aggressive environments than stainless steels. In the following enumeration of selected additives, specific effects on nickel alloys are stated.

Copper improved the resistant to non-oxidizing acids; addition of 30-40 % of Cu increases resistance to deoxygenated H_2SO_4 and HF; 2-3% of Cu increases resistance to HCl, H_2SO_4 and H_3PO_4.

Chromium increases resistance to oxidizing environments (HNO_3, H_2CrO_4), but also to H_3PO_4, as well as high temperature oxidation (formation of a passivation coating on the surface). Amounts of Cr are up to 50%, common number is around 15-30 % of Cr.

Iron primarily decreases cost and price of the alloy but it does not improve and anti-corrosive properties of nickel. An exception is an amount more than 50 % of Fe, which is a cause for increased resistance to H_2SO_4. Iron also increases solubility of carbon in nickel and therefore the resistance against high-temperature carburizing.

Cobalt increases solubility of carbon in nickel, similar to Fe, which increases resistance to high temperature carburizing; it also increases resistance against high-temperature sulfurization (with the melting temperature of Co sulfide is higher than Ni sulfide).

Molybdenum increases resistance against non-oxidizing acids. With 28 % of Mo (Hastelloy B alloy) the alloys resist the environment of HCl, HF, H_3PO_4 and H_2SO_4 with up to 60 % concentration. Molybdenum increases resistance against pitting and crevice corrosion. Molybdenum is an important strengthening element for alloys with increased firmness at high-temperature applications.

Tungsten increases resistance to non-oxidizing acids and local corrosion, similar to Mo. It is also a significant strengthening element, however it has higher atomic mass and is more expensive, therefore Mo is chosen if necessary, or a combination of W and Mo.

Silicon is contained in nickel only in small amounts either as a trace element from the deoxidation process or as an additive to improve the resistance to high-temperature oxidation. In alloys with higher content of Fe, Co, Mo, W and other metals difficult to melt, their amounts are rigorously checked, because Si stabilizes carbides and harmful intermetallic phases

IV. GAS TUNGSTEN ARC WELDING PROCESS

The Gas Tungsten Arc Welding (GTAW) process is sometimes referred to as TIG, or Heliarc. TIG is short for Tungsten Inert Gas Welding, and the term Heliarc was used because helium was the first gas used for the process. The aircraft industry developed the GTAW process for welding magnesium during the late 1930's and the early 1940's. During that time, helium was the primary shielding gas used, along with DCEP welding current. These caused many problems that limited application of GTAW welding process. But improve the process effectiveness and reduced its cost. Before the development of the GTAW process, welding aluminum and magnesium was difficult. The weld produced was porous and corrosion prone. Ceramic gas−nozzle directs the flow of shielding gas around the electrode, the arc and the molten weld pool. Standard nozzles are 6.5 mm diameter for air−cooled torches and 10.0 mm diameter for water−cooled torches

Fig. 1: Gas Nozzles

Various types of welding torch are available for TIG welding. They may be air−cooled or water−cooled and are usually fitted to the hose assembly. A remote control switch is fitted on some torches.

Fig. 2: Welding Torch

1) Shielding Gases

GAS	COMPATABILITY
Argon & Helium	For all materials
Mixing of Oxygen	Plain carbon steel and S.S
Mixing of Carbon dioxide	Copper
Mixing of Hydrogen	Austenitic S.S and Ni alloy

Table 1:

GAS	IONISATION POTENTIAL (ev)	DENSITY (Kg/m^3)
He	24.58	0.178
Ar	15.75	1.784
Co_2	14	1.977
O_2	13.61	1.326
N_2	14.54	1.161
H_2	13.59	0.083

Table 2:

B. Electrodes

EWP: Pure Tungsten electrode-Green tip.
EWTh-1: Tungsten + 1% Thorium electrode-Yellow tip
EWTh-2: Tungsten +2 % Thoriated tungsten electrodes -Red tip.
EWzr-Tungsten +1 % Zirconiated tungsten electrodes: Brown tip.

V. SELECTION OF WELDING PROCESS AND VARIABLES

Ni alloys are joined by arc welding processes .Precipitation hardening alloys are require closer closer control of the welding variables because of the possibility of ageing and the formation of refractory oxides during welding. GTAW process is preparable for precipitation hardening alloys of having high power density and lower weld deposition. GMAW preparable for solid solution strengthening alloys.

A. Joint Design

Ni base alloys have low flowability and wettability. Ni base alloy weld metal do not flow and wet the B.M easily so as carbon steel and stainless steel. The groove angle should be larger enough to permit manipulation of filler metal and deposition of stringer weld bead. V groove included angle 70-80˚& U groove included angle 30-40˚ at the sections having thickness than 13mm .Convex weld profile is suitable to reduce stress concentration. Stringer beads should be used to fill convex bead shape helps in minimising the hot cracking tendencies. Fillet, flare, edge welds should not exposed to above 540˚c, because the built in notch at the root joint. The filler metal must be tolerate of notches at elevated temperature to avoid cracking at the weld metal during heat treatment.

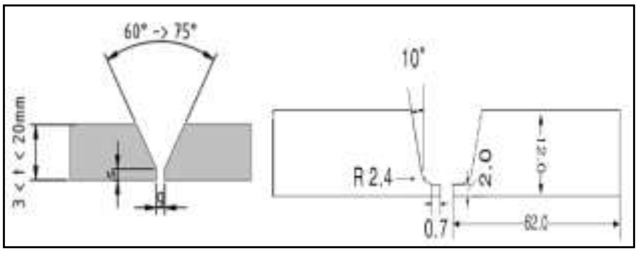

Fig. 3: Joint Design

B. Surface Preparation

Ni alloys are susceptible to embrittlement by lead, sulphur, phosphorus and low melting point alloys .Paint, oil, grease, marking cryons, inks should be removed by degreasing or swapping with acetone. Oxides should be removed by grinding, abrasive blasting, swapping with 10% of HCL, pickling. Grind wheel should be Aluminum oxide or silicon carbide wheel. Wire brushes are using for cleaning should be low austenitic stainless steel.

VI. PREHEAT AND INTERPASS TEMPERATURE

Preheat is does not required nor recommended for welding of Ni base alloys. However area should be at 16˚c or above to avoid moisture condensate that may produce porosity in weld metal. Interpass temperature should be low to help minimise total heat input. A maximum interpass temperature of 93˚c-150˚c is recommended for corrosion resistant alloys. Heat input limited approximately 8-12 KJ/cm.

A. Backing Plates

The backing plates used Ni alloys welding should be copper or stainless steel or Ni alloy[5].

B. Power Source & Shielding Gas

The DCEN polarity is recommended for welding for Ni alloys.Shielding gas recommended for Ni alloys ultra-pure Ar or mixing of Ar+(5-10%)of H_2.For example welding of 13 mm plates

Process	GTAW
Design	U groove / 11mm thick
Filler wire	Same composition & Φ 2mm
Shielding gas	100 %Ar(99.99% purity)
Shielding gas flow rate	15 lit/min
Polarity	DCEN
Current&Voltage	110-150 Amp&9-13 V
Electrode	Φ2.4 mm &2 %thoriated
Travel speed	2-6 cm/min
No of pass	6
Interpass temperature	400˚c
Orifice size	Φ10-12mm
Preheat temperature	150˚c
Preheat temperature	Atm temperature

Table 3: Welding parameters

C. U Groove Design

1) Included angle- 30˚
2) U groove depth- 9 mm
3) Root gap- 2 mm
4) Root face- 2 mm
5) Root Radius- 6.4mm

D. Etchants

ASTM E340: Standard Test Method for Macroetching Metals and Alloys

VII. RESULT & DISCUSSION

The studies were done on the Nickel based super alloys .Based on the study γ` precipitates, which is promoted by the Al, Ti alloys. Also inhibit the grain boundary sliding. The γ` influence to provide the grain boundary sliding. The formation of M_6C, M_7C_3, $M_{23}C_6$ are leads to embrittlement. The carbide phases and the leaves are responsible for the embrittlement. The laves phases leads to strain age cracking. The as cast microstructure appeared as dentrides of γ` phases with more white phases as laves phases and carbides. The suppression of the embrittlement promoting phases are controllable by homogenization. The reduced amount of carbides and laves phases are appeared in homogenized microstructure. The welded plate microstructure appears with the carbides and laves phases. There is need to control those phases. So heat treatment before the welding is necessary.

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