

# A study on corrosion resistance of dissimilar welds between Monel 400 and 316L austenitic stainless steel

**Cherish Mani , R Karthikeyan, S Vincent**

Department of Mechanical Engineering  
BITS PILANI, Dubai Campus, Dubai, UAE

**Abstract:** An attempt has been made to study the corrosion resistance of bi-metal weld joints of Monel 400 tube to stainless steel 316 tube by GTAW process. The present research paper contributes to the ongoing research work on the use of Monel400 and 316L austenitic stainless steel in industrial environments. Potentiodynamic method is used to investigate the corrosion behavior of Monel 400 and 316L austenitic stainless steel welded joints. The analysis has been performed on the base metal, heat affected zone and weld zone after post weld heat treatment. Optical microscopy was also performed to correlate the results. The heat affected zone of Monel 400 alloy seems to have the lowest corrosion resistance whereas 316L stainless steel base metal has the highest corrosion resistance.

**Keyword:** Monel 400, 316L austenitic stainless steel, Potentiodynamic techniques, Optical Microscopy, post weld heat treatment

## 1. Introduction

Stainless steels are an important class of engineering materials which has been used widely in a variety of industries and environments, especially due to good mechanical properties and corrosion resistance. Austenitic stainless steels, due to excellent properties such as corrosion resistance, ductility, toughness, and weld ability, represent the largest general groups of stainless steels. Dissimilar metal welding (DMW) is frequently used to join different stainless steels together or to other materials in different situations such as chemical, petrochemical, nuclear industries whose environments demand heat resistance, corrosion resistance, tolerance to thermal cycles and creep, and good mechanical properties. Apart from these requirements, the dissimilar welds result in saving of novel and expensive materials reducing cost thereby. Monel 400 - AISI 316L bimetallic joints were employed in the Umbilical Interface Assembly of NASA for carrying high pressure oxygen gas during service [1]. It was reported by Sadek [2] et al. that the dissimilar combinations of Monel 400 and low carbon steel has been employed in oil gasification plants where the weldments are vulnerable to high temperature corrosion. Devendra Nath [3] et al. (2014) investigated the performance of Monel 400 and AISI 304 weldments exposed in the high temperature environments at 600 °C. Further the authors employed gas tungsten arc welding process for joining these dissimilar metals using filler wires such as ER309L and ERNiCu-7. Stainless steels may be involved in joints of varying degrees of dissimilarity.

Post weld treatment and cryogenic treatment are being studied by many researchers for improvement of material properties. Patil and Tated (2012) [4] comparatively analysed the effects of cryogenic treatments on different types of steels. Cryogenic treatment (CT) has considered as the supplementary process to conventional process of heat treatment in steels by deep freezing materials at cryogenic temperatures to enhance both the mechanical and the physical properties. CT has done in metal



improve their mechanical properties without decrease in their strength with respect to thickness reduction. Shallow cryogenics, flooding and deep cryogenic treatment are the types of cryogenic treatment which are playing a potential role to enhance the corrosion resistance and stabilization in higher level et al Senthoooran and Raja, 2011 [5] . The authors have observed ultimate tensile stress at all aging times when subjected to deep CT. In addition, the hardness has increased at 13% with increase in aging time of Al-Mg-Si alloy.

The purpose of present study is to analyse the corrosion resistance of Bi metal weld joints of Monel 400 tubes to stainless steel 316L by GTAW process with specific reference to Tubular butt weld joints used in heat exchanger and process vessels. Optical microscopy and micro hardness measurement will be used to validate the results obtained.

## 2. Materials & Composition

**Stainless Steel 316L** : 316L is basically an Austenitic Cr-Ni stainless steel. High ductility, excellent drawing, forming, and spinning properties are present in this material. They are essentially non-magnetic, become slightly magnetic when cold worked. Low carbon content means less carbide precipitation in the heat-affected zone during welding and a lower susceptibility to inter granular corrosion.

**Monel 400:** Monel nickel-copper alloy 400 is a solid-solution alloy that can be hardened only by cold working. It has high strength and toughness over a wide range and excellent resistance to many corrosive environments. Monel 400 is used widely in several fields particularly chemical processing and marine applications. Typical applications are pumps and valves, propeller and pump shafts, fasteners and marine fixtures, electronic and electrical components, chemical processing equipment, springs, fresh water tanks and gasoline, process vessels, crude petroleum stills, piping, De-aerating heaters, heat exchangers and boiler feed water heaters.

**ERNiCrFe-3:** ENiCrFe-3 electrode is used for welding of nickel-chromium-iron alloys to themselves and dissimilar welding between nickel-chromium-iron alloys and stainless steels alloys. Its high manganese content lessens the possibility of micro fissures and reduces creep strength which limits its usage to 900°F. Application for this alloy include surfacing as well as clad side welding. Tables 1 & 2 are showing the chemical composition of all the constituent materials used and weld metal Properties.

**Table 1 Chemical composition of SS316L, Monel 400, 3ERNiCrFe-3 Source: SMC, 2005[6]**

CHEMICAL COMPOSITION	SS-316L	MONEL 400	ERNiCrFe-3
Component	Wt%	Wt%	Wt%
C	Max 0.08	0.3 Max	0.10 Max
Cr	18 - 20	---	13.0-17.0
Fe	66.345 - 74	2.5 Max	10.0 Max
Mn	Max 2	2.0 Max	5.0-9.5
Ni	8 - 10.5	63.0 Min	59.05 Min
P	Max 0.045	---	0.03Max
S	Max 0.03	0.024	0.015 Max
Si	Max 1	0.5 Max	1.0 Max
Cu	---	28.0-34.0	0.50 Max

Cb/Ta	---	---	1.0-2.5
Ti	---	---	1.0 Max
Other	---	---	Max

**Table 2 Properties of the welded joint**

Tensile Strength	586 MPa
Yield Strength	372 MPa
Elongation	35%

### 3. Gas Tungsten Arc Welding

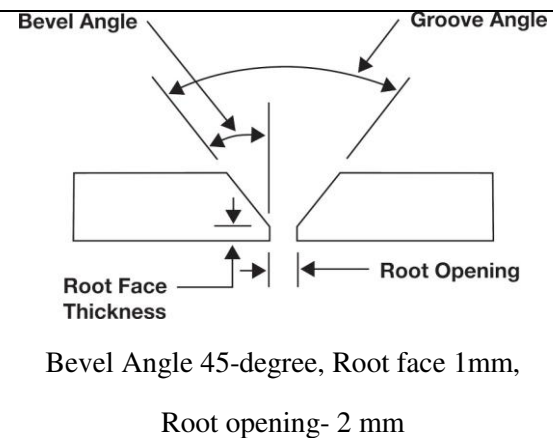
Welding is normally done by melting the work pieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld. TIG Welding (GTAW) is a process that uses the non-consumable tungsten electrode to produce a weld with or without a filler material. TIG welding produces an electric arc maintained between a non consumable tungsten electrode and the part to be welded. When stainless steel is joined to Monel is often “buttered” with stainless steel. This technique consists of depositing a layer of filler alloy on stainless steel surface followed by filling on Monel and complete the joint is commonly known as buttering. The weld parameters used for the study are listed in Table 3. Figure 1 shows the welded joint produced whereas Figure 2 shows the weld joint design used for welding.

**Table 3 Welding Parameters**

WELDING CURRENT	80 Amps
FILLER WIRE	E NICK3
GROVE DESIGN	V TYPE
PASS	MULTIPLE,2
POLARITY	DCEN
MINIMUM METAL TEMP.:	50° F
INTERPASS TEMP.(MAX):	350° F
SHIELDING GAS:	ARGON, 30 TO 40 CFH
BACKING GAS: ARGON,	15 TO 40 CFH

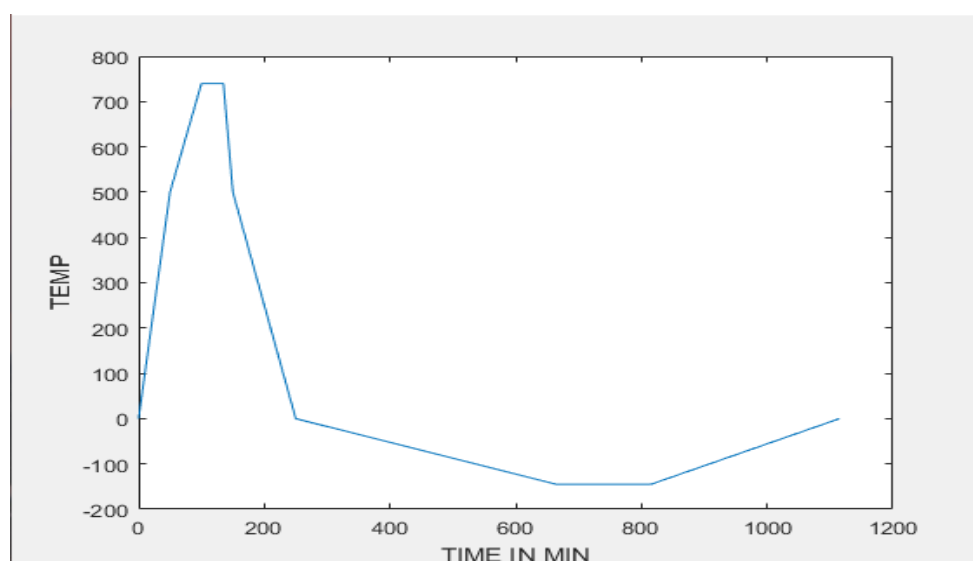
TUNGSTEN SIZE AND TYPE:

1/8 ,2 % THORATED TUNGSTEN

**Figure 1: Welding joint (pipe joint)****Figure 2 : Joint Configuration**

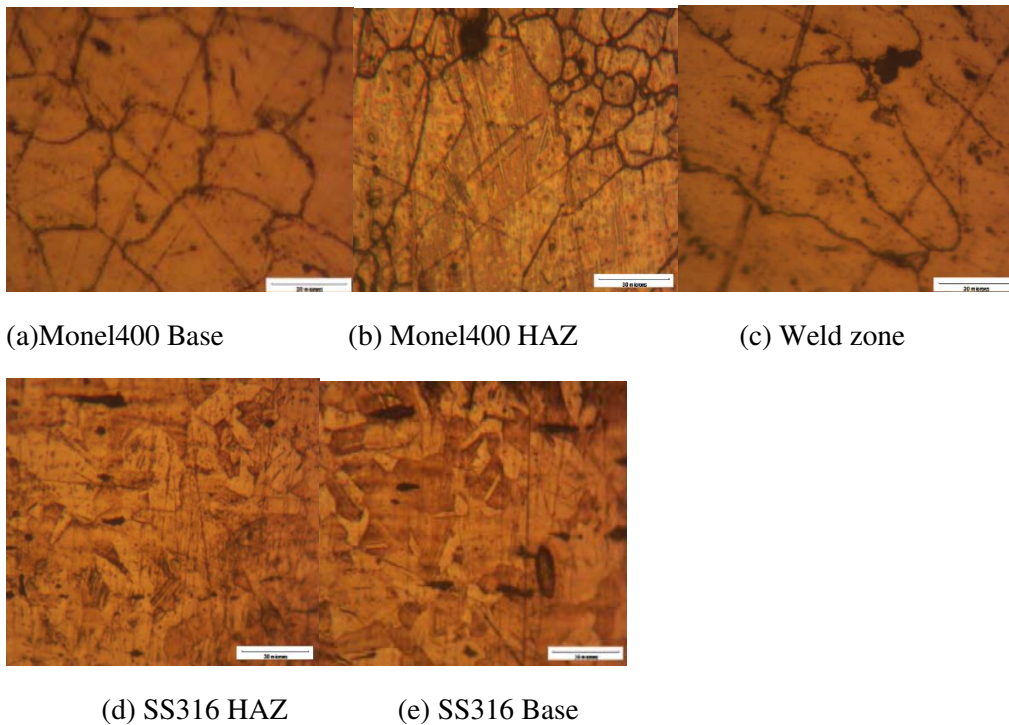
#### 4. Post Welding Heat Treatment

Heat treatment of material is processes of heating and cooling the material. Heat treatment processes is used to change material mechanical and physical properties without changing the material shape. In this paper heat treatment process is carried out for improving mechanical and physical properties as well reducing residual weld stress of monel400 and AISI316L stainless steel. Heat Treatment performed by heating to 730-740 °C at 150 deg per hour. Initial heating was carried out at vacuum till 200°C and then at inert atmosphere(Argon) till at 730-740 °C. After that we had Soaked specimen for 15 minutes at 730-740 °C temperature below graph is shown the heat treatment processes on Monel 400 and 316L austenitic stainless steel. The specimen was further furnace cools to ambient at 200 °C per hour. A Cryo treatment to -195 °C was also followed. Then Soak for 15 minutes, Return to ambient temperature. Figure 3 shows the sequence of treatment involved.

**Figure 3: Heat treatment graph**

## 5. Optical Microscopy

Optical or light microscopy involves passing visible light transmitted through or reflected from the sample through a single or multiple lens to allow a magnified view (400X) of the sample. The resulting image can be detected directly by the eye, imaged on a photographic plate or captured digitally. The image is shown on a computer screen, so eye-pieces are unnecessary. Optical Microscopy observed Monel 400 and 316L austenitic stainless-steel welded specimen's Micro structure at 40 $\mu$ m Magnification power on CHENNAI METCO inverted metallurgical optical microscope after finishing workpiece with different grades of SiC abrasive papers and Marbles reagent is used as the etchant for selectively corroding microstructural features. Micro structure of Monel 400 and 316L austenitic stainless steel is shown in the following Fig.4 (a) (b) (c) (d) (e) along different regions of the weld after heat treatment.

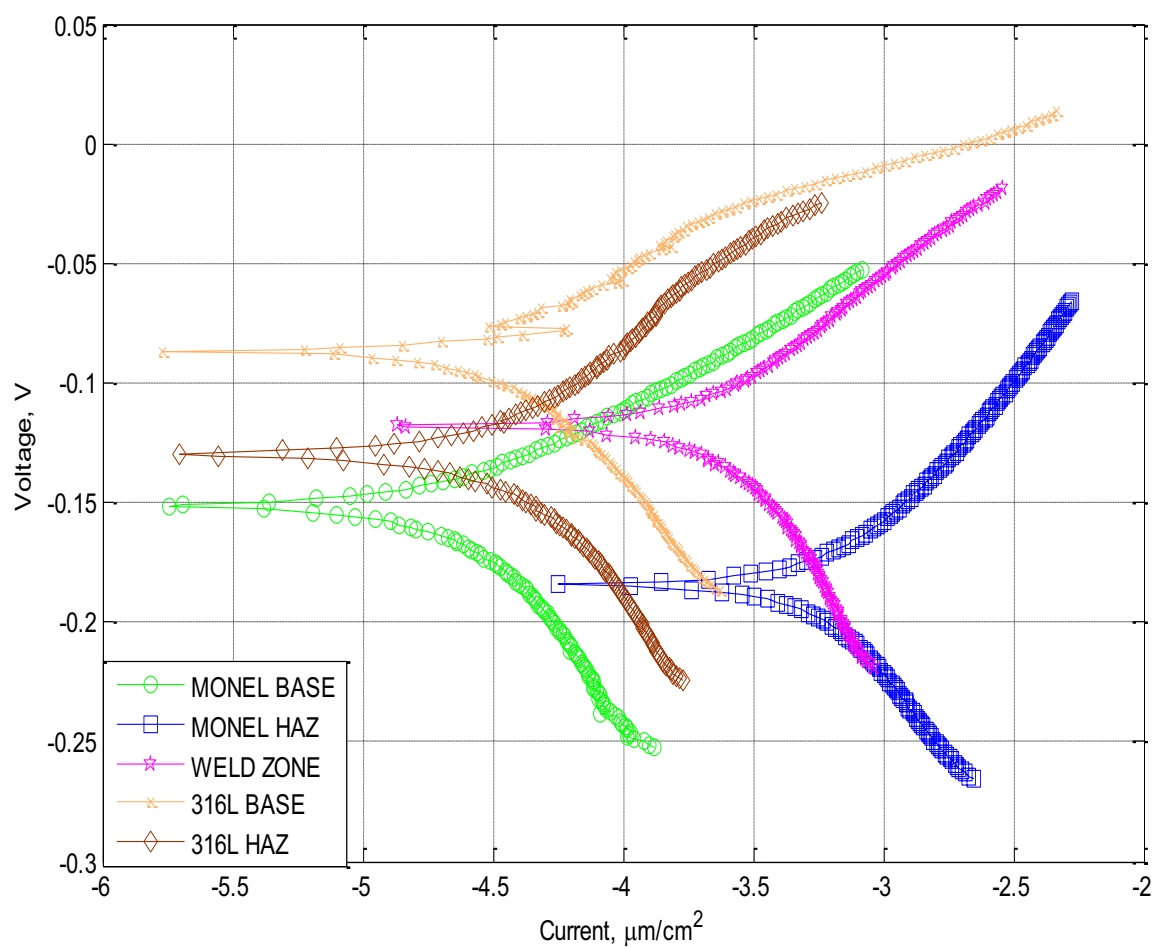


**Fig.4 Optical micrographs at different regions of welded joint**

## 6. Corrosion Study

The electrochemical test of Monel 400 and 316L austenitic stainless steel was performed with the help of Potentiodynamic method with a potentiostat coupled to PC. To carry out this process. Specimen was polarized in a 1M NaCl solution made of analytical grade NaCl and distilled water. The specimen was fixed on a copper strip mounting fixture. Fixture allowed an electrical contact to be supplied to the sample, the potential sweep rate was 0.0001670 V/S and was scanned for specimen starting from -0.1V Vs. open circuit potential ( $V_{ocp}$ ). The ends of the scans were selected after considering trans passive behavior in polarization curves. METROHM POTENTIOSTAT has been used for the study. All the measurement was performed at 298K. An initial delay of 15min for the sample to reach a steady-state condition was considered before polarization test. Similar study has been made for AISI 316L-type by Hadi Savaloni et al. [7].

The welded joint of Monel 400 and 316L austenitic stainless steel was separated into five different interface lines, and the all the five different interfaces are Monel400 base, Monel400 heat affected zone, welded zone, 316L austenitic stainless-steel heat affected zone, and 316L austenitic stainless-steel base was then tested in 1M NaCl solution. Fig 5 shows the Potentiodynamic polarization curves of all five-different zones, plotted along their self-corrosion potential ( $E_{corr}$ ), corrosion current density ( $I_{corr}$ ), corrosion rate and Polarization resistance are listed in below Figure 5



**Figure 5: Polarization curves at all zone of material.**



**Table 4 : Corrosion rate and Polarization resistance all zones of welded joint**

Material zone	E <sub>corr</sub> (obs) (mV)	J <sub>corr</sub> ( $\mu\text{A}/\text{cm}^2$ )	I <sub>corr</sub> ( $\mu\text{A}$ )	corrosion rate (mm/year)	Polarization resistance (Kohm)
SS 316L base	-86.956	1.642	2.138	0.017119	8.2367
SS316L heat affected zone	-129.96	2.9246	2.9246	0.033984	9.4322
Weld zone	-117.84	1.1922	1.8715	0.012407	8.5583
Monel400heat affected zone	-184.44	3.3586	5.6882	0.032455	3.8643
Monel 400 base	-151.33	1.5178	1.9124	0.014667	8.3561

**SS-316L Base** – From Table4, it is found that the corrosion current density of the 316L austenitic stainless-steel base material was  $2.138 \mu\text{A}/\text{cm}^2$ , self-corrosion potential ( $E_{\text{corr}}$ ) was -86.956 mv, polarization resistance of the 316L austenitic stainless-steel base was 8.2367 K-ohm and the corrosion rate of the 316L austenitic stainless-steel base was 0.017119 mm/year. The SS316L base shows a very high corrosion resistance as the oxidation forms a protective layer and stops it from corroding, as seen the polarization resistance is 9.4322(K-ohm). Cr and Ni have a good elemental corrosion resistance, in our chemical composition of Cr (18 - 20) Wt.% and Ni (8-10.5) Wt.% also contributes to the good corrosion resistance offered by SS316L.

**SS-316L HAZ** - During welding, heating of the parent material takes place in the HAZ. The material in the HAZ is heated to a variety of temperatures range from ambient temperature to the melting range of the alloy in question Et al W. Luo, [8]. In the present case between Monel 400 and 316L austenitic stainless steel the corrosion current density of the 316L austenitic stainless-steel base heat affected zone was  $2.9246 \mu\text{A}/\text{cm}^2$ , self-corrosion potential ( $E_{\text{corr}}$ ) was -129.96mv, polarization resistance of the 316L austenitic stainless-steel heat affected zone was 9.4322 K-ohm and the corrosion rate of the 316L austenitic stainless-steel base was 0.033984 mm/year. It is observed that Corrosion rate was increased 98% than the 316L austenitic stainless-steel base.

**Weld Zone** – This zone is having the best corrosion resistance, this is observed because of the filler material used which is - **3ERNiCrFe-3**, having a substantial amount of Cr and Ni by wt.% as (13.0-17.0) & (59.05) respectively. The corrosion current density of the welded zone was  $1.8715 \mu\text{A}/\text{cm}^2$ , self-corrosion potential ( $E_{\text{corr}}$ ) was -117.84mv, polarization resistance of the 316L austenitic stainless-steel heat affected zone was 8.5583 K-ohm and the corrosion rate of the 316L austenitic stainless-steel base was 0.012407 mm/year. It is observed that Corrosion rate was decreased 27.52% then the 316L austenitic stainless-steel base. and 63.49 % decreased than the 316L austenitic stainless-steel heat affected zone and 61.77% decreased than the Monel400 heat affected zone, and 15.40% decreased from Monel base.

**Monel 400 HAZ** - The corrosion current density of Monel400 heat affected zone was  $5.6882 \mu\text{A}/\text{cm}^2$ , self-corrosion potential ( $E_{\text{corr}}$ ) was -189.6mv, polarization resistance of the 316L austenitic stainless-

steel heat affected zone was 3.8643 K-ohm and the corrosion rate of the 316L austenitic stainless-steel base was 0.032455 mm/year. It is observed that Corrosion rate was increased 121.27% because of the grain distortions than the Monel400 base.

**MONEL 400 Base** - The corrosion current density of Monel400 base was 1.9124 uA, self-corrosion potential ( $E_{corr}$ ) was -151.33mv, polarization resistance of Monel400 base was 8.3561 K-ohm, Polarization is different in different mediums thus resisting the corrosion rate and demanding more current. et al Int. J. [9]. The corrosion rate of the Monel400 base was 0.032455 mm/year.

## 7. Conclusion

Bi metal welding of 316L stainless steel and Monel 400 alloy was performed using ERNiCrFe-3 and gas tungsten arc welding process. Post weld heat treatment along with cryogenic treatment has been done on the welded specimen. Corrosion rate, optical microscopy was studied in base metal, HAZ and weld metal separately. The Monel 400 HAZ seems to have lower corrosion rate since the chromium content is less when compared to stainless steel base metal and HAZ due to lesser chromium content and smaller grains formed due to annealing.

## References

- [1] Sherazi S and Ahmad H (2014), Volatility of Stock Market and Capital Flow. *Middle-East Journal of Scientific Research*, 19(5): 688-692.
- [2] Alber S A, Abass M, Zaghloul B and Elrefaey A (2000), Masao Ushio Investigation of dissimilar Joints between Low Carbon steel and Monel 400. *Trans, JWRI*; 29(1): 21-28.
- [3] Devendranath R K, Arivazhagan N and Narayanan S (2012). Effect of filler materials on the performance of Gas Tungsten arc welded AISI 304 and Monel 400. *Materials & Design*. 40:70-79.
- [4] Tated R G and Patil P I (2012), Comparison of Effects of Cryogenic Treatment on Different Types of Steels: A Review, *International Conference in Computational Intelligence*.
- [5] Sendooran S and Raja P (2011), Metallurgical Investigation on Cryogenic Treated HSS Tool, *International Journal of Engineering Science and Technology (IJEST)*, Vol. 3 (5), pp.3992
- [6] SMC (2005), MONEL Alloy 400, Special Metal Corporation, Available at <http://www.specialmetals.com/assets/documents/alloys/monel/monel-alloy-400.pdf>, accessed on 8th October 2015
- [7] Hadi S, Ensieh A-T, Fateme A: On the corrosion resistance of AISI 316L-type stainless steel coated with manganese and annealed with flow of oxygen.
- [8] Luo W, The corrosion resistance of 0Cr19Ni9 stainless steel arc welding joints with and without arc surface melting.
- [9] *Int. J. Electrochem. Sci.*, Vol. 7, 2012, Corrosion Polarization Behavior of Type 316 Stainless Steel in Strong Acids and Acid Chlorides.