Experimental investigation and characterization of Inconel 625 and Inconel 718 alloy using tungsten inert gas welding process.

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Abstract: The Nickel alloys of Inconel 625 and Inconel 718 are welded using the Inconel 625 filler wire. For welding these metal inert gas welding, plasma arc welding and tungsten inert gas welding are chosen. from these process welding Inconel 625 and 718 TIG is the most preferred process by considering the weld penetration, arc stability, clean weld bead, strength of the weld, easier availability, all positional welding etc.for Tungsten inert gas welding the shielding gas plays a major role for obtaining the proper bead so shielding gas selection and the shielding gas compositions are taken as the major factor next to the welding speed, filler metal selection, electrode dia. this paper deals with the suitable method for welding Inconel 625 and Inconel 718.The various tests are performed in destructive and non destructive testing to find the quality of the weld. The destructive tests include the tensile test and in non destructive testing visual inspection, liquid penetrant testing are performed in order to find any cracks or defects in the weld. Charecterization like micro hardness, micro structural analyses are also performed to find the changes occur in the weld. From the obtained results the Inconel 718 has good weld strength.

Keywords — Nickel alloys, TIG welding, shielding gas, characterization, NDT, Inconel.

I. INTRODUCTION

TIG welding works on same principle of arc welding. In a TIG welding process, a high intense arc is produced between tungsten electrode and work piece. In this welding mostly work piece is connected to the positive terminal and electrode is connected to negative terminal (DCEN). This arc produces heat energy which is further used to join metal plate by fusion welding. A shielding gas is also used which protect the weld surface from oxidization.

The electrode is connected to the negative terminal of power source and work piece to positive terminal. This current supplied form a spark between tungsten electrode and work piece. Tungsten is a non –consumable electrode, which give a highly intense arc. This arc produced heat which melts the base metals to form welding joint [16].

The shielded gases like argon, helium is supplied through pressure valve and regulating valve to the welding torch. These gases form a shield which does not allow any oxygen and other reactive gases into the weld zone. These gases also create plasma which increases heat capacity of electric arc thus increases welding ability [13].

For welding thin material no filler metal is required but for making thick joint some filler material used in form of rods which fed manually by the welder into welding zone[17].

II. LITERATURE REVIEW

K Tsuchiya et.al [1] carried out preliminary research for further development of some plasma arc welding methods for thick plate above 10mm.Large plasma torch and the control equipment designed to be proof against up to 1000A with straight polarity connection have been fabricated. In plasma arc welding of 16mm thick mild steel plates, weld beads were produced as burn through or incomplete penetration beads. When the plates were backed up with copper plates, unstable plasma arc and sometimes series arcing occurred and resulted in a defective bead [1].

Kunio Narita investigated the effect of different welding parameters of plasma arc welding process on the shape of welds and consistency of defects in the flat, vertical and overhead positions of mild steel pipes of thickness 6.4mm and outer diameter 406.4mm [2].

Bharathi et al explains that Plasma Arc Welding (PAW) is an ancient art dating back to the Bronze Age. The paper

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states that PAW produces a stable, inherently strong joint that cannot be matched by other welding methods. The PAW process is quite similar to the Tungsten Inert Gas (TIG) welding process, but PAW has a number of critical advantages over TIG welding. In PAW, the arc is constricted by a cooled gas nozzle. In turn, increases the welding speed by around 20% in soft-plasma welding. PAW also saves time and costs at the same time as ensuring deeper penetration [14]. The tungsten electrode has a much longer service life because it is enveloped in the protective plasma gas [3].

G Shanmugavelayutham et.al evaluated the electro thermal efficiency of a DC arc plasma torch and temperature and thermal conductivity of plasma jet in the torch. The effect of nitrogen in combination with argon as plasma gas on the above properties were investigated [4].

G. Ravichandran carried out thermal analysis of molten pool formation and solidification for keyhole welding using Plasma Arc Welding has been done using Finite Element Method [5].

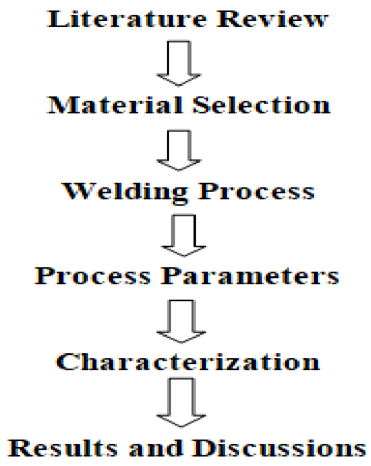
Yaowen Wang et.al addressed the problems involved in the automatic monitoring of the weld quality produced by plasma arc keyhole welding. The acoustic signal of plasma arc welding was acquired by using a condenser microphone at high speed and analyzed with the aid of computers. It is shown that the overall AC power of the acoustic analysis, especially the low frequency part (0±100 Hz) of the acoustic signal power spectra, greatly varies with the variation of status of the weld pool [6].

Y. F. Hsiao et.al studied the optimal parameters process of plasma arc welding (PAW) by the Taguchi method with Grey relational analysis was studied. SUS316 stainless steel plate of thickness 4mm and the test piece of 250mm x 220mm without groove was used for welding. Torch stand-off, welding current, welding speed, and plasma gas flow rate (Argon) were chosen as input variables and Welding groove root penetration, Welding groove width, Front-side undercut were measured as output parameters [7].

Jukka Martihainen investigated the possibilities and the technological conditions for welding structural steels, especially high strength steels, reproducibly and with high quality [8]. The investigation comprises butt welding with an I-groove in the flat, horizontal – vertical and vertical positions and root welding of thick plates in the flat position. It was shown that mechanized plasma keyhole welding is a very useful method for structural steels [10].

A. Dudek et.al proposed a research method for diagnostics and determination of temperature and shape of plasma arc used for surface treatment of 40Cr4 steel with TiO2 coating. The surface of samples, previously coated with ceramic coating was re-melted with plasma arc. For investigations of arc shape the high-resolution modern visible light camera and thermo vision camera was used [11]. The temperature distribution in plasma arc with percentage quantity of temperature fields was determined. The arc limiting profiles with isotherms was also determined [9].

III. Methodology



Material Selection

- Inconel 625
- Inconel 718

Table 3.1 Chemical Composition of Inconel 625 and 718.

% of elements	Weight %	
	Inconel 625	**Inconel 718**
Chromium	20-23	17-21
Nickel	58.0	50-55
Molybdenum	8.00-10.00	2.8-3.3
Cobalt	1.00	1.0
Niobium + Tantalum	3.15-4.15	4.75-5.5
Aluminium	0.40	0.60
Titanium	0.40	0.90
Carbon	0.10	0.08
Iron	5.00	17.0
Manganese	0.50	0.35
Silicon	0.50	0.35
Phosphorus	0.015	0.015
Sulphur	0.015	0.015

Table 3.2 Physical Constants of Inconel 625 &718.

Physical constants	Inconel 625	Inconel 718
Density (g/cm^3)	8.44 g/cm^3	8.19 g/cm^3
Melting range (°C)	1290-1350 °C	1260-1336 °C

Inconel 625 filler wire with 1.6 mm thickness is chosen as the filler wire for welding of Inconel 625 and the Inconel 718 because it match the requirements for welding.

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3.1. Design of Welding:

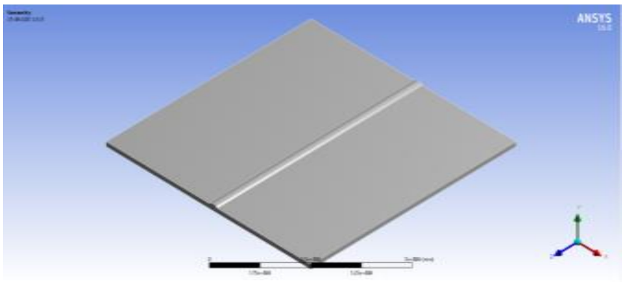


Fig 4.2 Design of welding plate.

3.2 Welding Parameters:

Table 3.3 Welding Process Parameters.

Dimensions for Joining 2 Plates	**50*25*2 (Similar)**
Weld Type	Butt Joint
Groove Type	Single V Groove
Current Range	35 A
Voltage	60-70 Volts
Shielding Gas	Argon
Shielding Gas Flow Rate	21.5 Psi
Polarity	DCEN
Mode of Operation	Manual
Electrode	2%Thoriated tungsten Electrode
Electrode Dia	1mm
Torch Position	Vertical
Welding Speed	68.9 mm/min

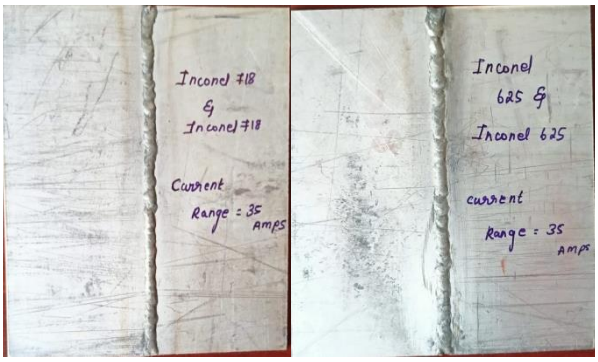
From the table 3.3 the welding process parameters chosen in order to obtain the good weld and having the optimum welding strength and defect free welds [12].

IV. Results and Discussion

For welding Inconel 625 and Inconel 718 plate using the filler wire of Inconel 625 the bead on plate welding using the different current ranges varying from 25 amps to 45 amps. From the fig 4.1 bead on plate I choose the correct current range of 35 amps and we characterized it by bead width, penetration, melting rate of filler wire etc

Fig 4.1 Bead on plate on Inconel 625 and Inconel 718.

4.3 Welded Sample:



A **B**

Fig 4.3 Welded sample of A. Inconel 625 & B. Inconel 718

The welding is done properly as per the specifications and the welded materials are taken to the various testing processes.

4.4 Visual Inspection

Visual inspection (VT) visual inspection is a non destructive testing (NDT) weld quality testing process where a weld is examined with the eye to determine surface discontinuities. It is the most common method of weld quality testing. The magnification range has 10X

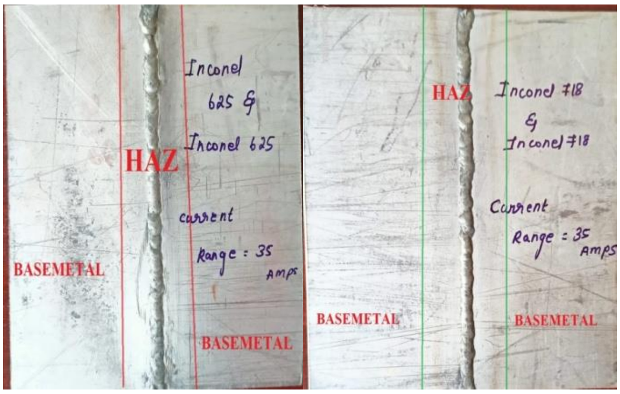


Fig 4.4 Visual inspection of Welded Plates of Inconel 625 and Inconel 718

Inspection:

- Angular Distortion - Due to application of heat.
- Lack of Side wall Fusion - Due to improper feeding of filler wire
- Mechanical damage
- Grinding marks & Chisel marks.

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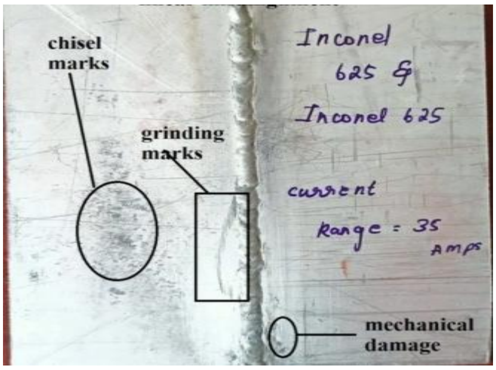

Fig 4.5 Visual inspection of welding plate

4.5 Liquid penetrant Inspection:

- Pre cleaned using Cleaner CL -96
- Applied Penetrant of Penetrant PT -97
- Developer applied DV-98

Fig 4.6 Liquid Penetrant Testing.

From the penetrant testing it's observed that there is no defect in the volumetric flaws or cracks detected.

4.6 Micro hardness:

The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation. When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kg f force.

Table 4.2 Vickers hardness values for load of 500 kgf for Inconel 625

Inconel 62	Base metal	HAZ	Weld metal	HAZ	Base metal
1	252	238	262	243	253
2	244	224	264	237	252
3	238	232	268	247	256

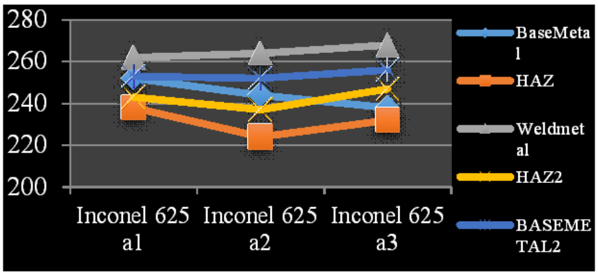

Chart 4.1 Vickers hardness values for load of 500 kgf for Inconel 625

Table 4.3 Vickers hardness values for load of 500 kgf for Inconel 718

Inconel 718	Base Metal	HAZ	Weld Metal	HAZ	Base Metal
1	262	258	272	241	264
2	258	251	269	236	267
3	253	248	265	245	262

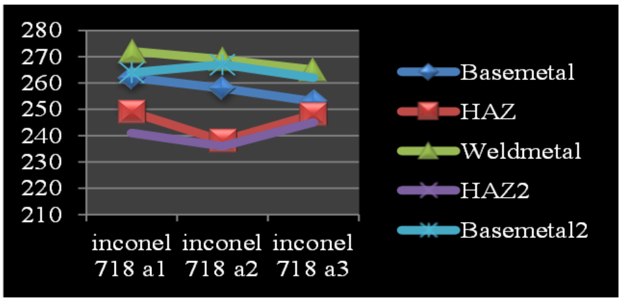

Chart 4.2 Vickers hardness values for load of 500 kgf for Inconel 718.

4.7 Optical Microscopy

Here we have used the equipment optical microscope with a magnification of 100X.The microstructure was taken only for the sample which is welded using the optimized parameter. The specimen cut across transverse to the welding direction has been polished in the subsequent emery papers such as 220, 400, 600, 800 emery sheet and followed by cloth polishing. After that the welded specimen was etched to reveal the micro structures. The etchant used for this purpose is HNO_3, Hcl and Acetic acid etched for few seconds.

Table 4.4 Constituents of Etchant.

S.No	Chemical Name	Amount in ml
1	Hcl	15 ml
2	Acetic Acid	10 ml
3	Nitric Acid	10 ml

Inconel 625 microstructure

Inconel 625 is a solid-solution matrix-stiffened face-centered-cubic alloy.

Fig 4.7 Micro structure of base metal Inconel 625.

Precipitates rich in niobium located along the surface of metal which were identified as the alpha phases (100x).

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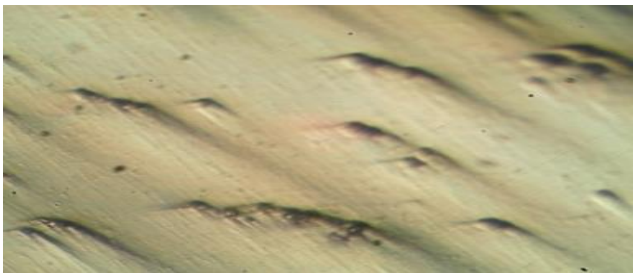
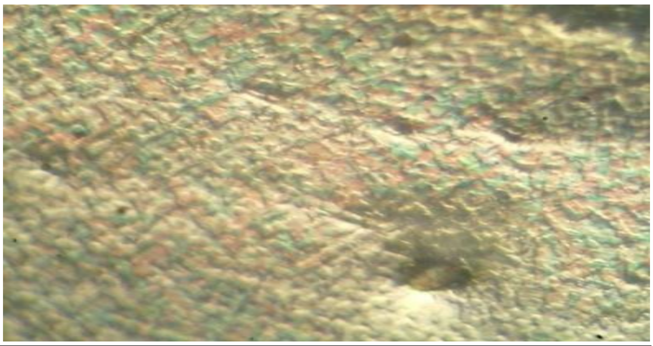


Fig 4.8 HAZ of Inconel 625 (Un etched condition).

Precipitates Rich in Nb Which May Nb Rich Carbides Segregation of Heavy Metal Such As Nb and Mo (100x)



Specimen	Ultimate tensile strength (Mpa)	Yield strength (Mpa)	% Elongation	Remarks
Inconel 625	648.24	597.42	4.8	Broken At Weld
Inconel 718	711.59	623.57	5.2	Broken At Weld

Fig 4.9 Weld Metal of Inconel 625 (etched condition).

Segregation of nickel and chromium dentric cores as well enrichment of inter dentric regions in Nb and Mo (100X).

Inconel 718 Microstructure:

Inconel 718 is an age-hardenable austenitic material. Strength is largely dependent on the precipitation of a gamma prime phase during heat treatment.

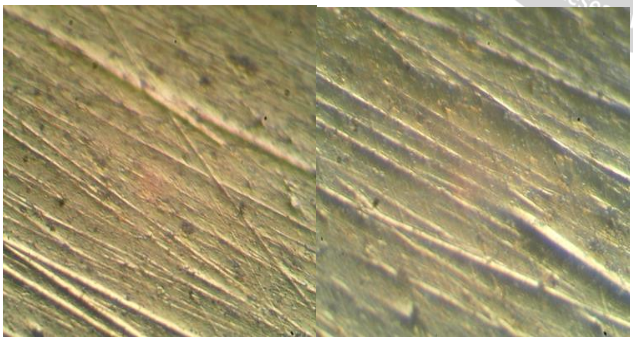


Fig 4.10 Microstructure of Weld Metal of Inconel 718.

Precipitates rich in Nb and Ti are located along the surface of the metal which was identified through (100X).

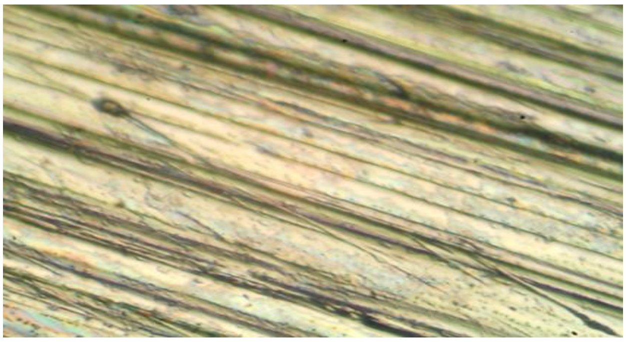


Fig 4.11 Microstructure of HAZ on Inconel 718

Nb and Ti rich precipitates along the inter dendritic regions and fusion boundary layer Nb and Ti rich precipitates along the inter-dendritic regions and fusion boundary layer Precipitates rich in Nb and Ti are rich in inter dentric region and the fusion boundary layer.

4.8 Tensile test:

Tensile test are performed on the Inconel 625 and Inconel 718 weldments for testing the strength of the weldments [18].

Table 4.5 Tensile test of Inconel 625 & Inconel 718

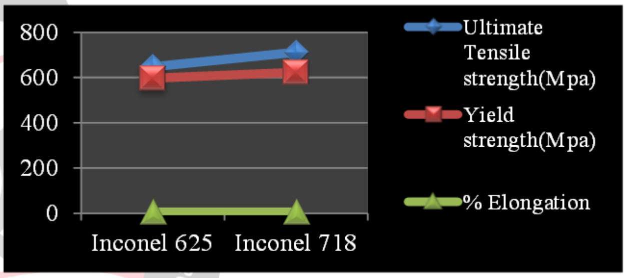


Chart 4.3 Tensile test results

Chart 4.3 Results in Inconel 718 has the better tensile properties than that Inconel 625and the % elongation also maximum in 718 material.

V. CONCLUSION

Inconel 625 and Inconel 718 are welded using the filler wire of Inconel 625 filler wire of 1.6 mm thickness using the gas tungsten arc welding (TIG Welding).

By conducting the various tests to check the properties of the Inconel 625 and Inconel 718, Excellent properties has been achieved such as good surface finish, deeper penetration of metal into the gaps on less time, very good strength, toughness and hardness.

From the various literatures it's observed that Tungsten inert gas welding is the more feasible welding process for joining Inconel 625 and Inconel 718 which results in good quality of weld in both productively and economically [17].

Inconel 718 has higher tensile strength than Inconel 625 and the specimens are prepared by the ASTM E8 Standard for tensile test. The Inconel 718 has the tensile strength of 711.59 Mpa and Inconel 625 has the tensile strength of 648.24 Mpa.

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From the visual inspection it is observed that there is a defect in the weld like porosity, spatter etc. from the inspection it is observed that there is a linear misallignment in the weld due to the high heat input.

From the penetrant testing, which is a non destructive testing it gives the results that there is no cracks, volumetric flaws or defects in the weld.

From the Vickers micro hardness test the hardness values in the HAZ are lower and the Weld metal has greater hardness value than the base metal.

From the micro structural analysis in Inconel 625 it is observed that Precipitates rich in niobium located along the surface of metal which were identified in the alpha phases and in Inconel 718 Precipitates rich in Nb and Ti are located along the surface of the metal.

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REFERENCES

[1]K.Tsuchiya, K.Kishimot, Matsunaga, E.Nakano, (1973), "Plasma Arc Welding for thick plate (part-1)", Japan welding society, pp 554-566.

[2] Kunio Narita,(1975),"Plasma arc welding of pipelines-A study to optimize welding conditions for horizontal fixed joints of mild steel pipes", Int. J. Pres. Ves. & Piping 3: pp 233-266.

[3] SelvaBharathi,S.M.Sadham Javidur rahman, P.Rajdev ,M.syed Mohamed," Experimental Method Of Heat Penetration Using Plasma Arc Welding", International Journal of Innovative Research in Science, Engineering and Technology, Volume 3, Special Issue 3, March 2014.

[4] G Shanmugavelayutham and V Selvarajan, (2003),"Electro thermal efficiency, temperature and thermal conductivity of plasma jet in a DC plasma spray torch", PRAMANA journal of physics, Indian Academy of Sciences Vol. 61, No. 6, pp 1109–1119.

[5] G. Ravichandran, (2001), "Solidification behavior in Plasma Arc Welding", Sadana, Vol. 26, parts I & II.

[6] Yaowen Wang, Qiang Chen, (2002), "On-line quality monitoring in Plasma arc welding", Journal of Materials Processing Technology, 120 pp:270-274.

[7] Y. F. Hsiao, Y. S. Tarng, and W. J. Huang, (2008),"Optimization of Plasma Arc Welding Parameters by Using the Taguchi Method with the Grey Relational Analysis", Journal of Materials and Manufacturing Processes, 23: pp 51–58.

[8] Jukka Martihainen, (1995), "Conditions for achieving high quality welds in the plasma keyhole welding of structural steels", Journal of Materials Processing Technology pp 68-75

[9] A. Dudek, Z. Nitkiewicz, (2007) "Diagnostics of plasma arc during the process of remelting of surface layer in 40Cr4 steel", International Scientific Journal, Volume 28,Issue 6,pp 369-372.

[10] Y. M. Zhang & B. Zhang, (1999), "Observation of the Keyhole during Plasma Arc Welding", AWS Welding Research Supplement, pp 53-58.

[11] Swap nil S. Ingle, Dr. Rajendra S. Dalu (2013), Thermo-Mechanical Analysis in TIG Welding of Aluminium Alloy 6082, International Journal of Science and Research (IJSR), Index Copernicus Value: 6.14

[12]R. Ramachandran**,** analysis and experimental investigations of weld characteristics for a Tig welding with ss316l, International Journal of Advances in Engineering Research, 2015, Vol. No. 10, Issue No. II, August.

[13] Sivaprasad, K., & Raman, S. (2007). Influence of magnetic arc oscillation and current pulsing on fatigue behavior of alloy 718 TIG weldments. *Materials Science and Engineering: A*, *448*(1), 120-127.

[14] Mohammed Naghiyan (2018) "Evaluation of the hot corrosion behavior of Inconel 625 coatings on the Inconel 738 substrate by laser and TIG cladding techniques, *optics and laser technology*.

[15] Choon man lee (2018),"A Study on the machining characteristics using Plasma assisted machining of AISI 1045 Steel and Inconel 718", *International Journal of mechanical Science* 142-143, Pg. 595-602.

[16] O'Brien, Annette (2004) *"Welding Handbook",* Volume 2 Welding Processes, Part 1, *American Welding Society (AWS)*

[17] Prakash Mohan, "Study the Effects of Welding Parameters on Tig Welding Of Aluminium Plate" *Nit Rourkela*.

[18] https://www.twi-global.com/ tensiletesting.pdf.

 DOI : 10.35291/2454-9150.2021.0258