

# Analysis of Welding Characteristics on Stainless Steel for the Process of TIG and MIG with Dye Penetrate Testing

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*Abstract-- In this Paper we discuss about the mechanical properties of austenitic stainless steel for the process of TIG and MIG welding. As with other welding processes such as gas metal arc welding, shielding gases are necessary in GTAW or MIG welding is used to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. The gas also transfers heat from the tungsten electrode to the metal, and it helps start and maintain a stable arc. We used the TIG and MIG process to find out the characteristics of the metal after it is welded. The voltage is taken constant and various characteristics such as strength, hardness, ductility, grain structure, modulus of elasticity, tensile strength breaking point, HAZ are observed in two processes and analyzed and finally concluded.*

**Keywords-- Austenitic Stainless Steel, Embrittlement, Hardness, Tensile Strength, HAZ.**

## I. INTRODUCTION

Situations arise in industrial practice which calls for joining of materials. The materials employed are location dependent in the same structure for effective and economical utilization of the special properties of each material. Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often 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. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the work pieces to form a bond between them, without melting the work pieces. Only in this way can the designer use most suitable materials for each part of a given structure.

The growing availability of new materials and higher requirements being placed on materials and the welding processes. In general austenitic stainless steels are easily weldable. When austenitic stainless steel joints are employed in cryogenic and corrosive environment the quantity of ferrite in the welds must be minimized/controlled to avoid property degradation during service. In addition these steels are prone to sensitization of their fusion welds. These problems have been addressed by solid state welding processes, such as friction welding.

## II. SELECTION OF MATERIAL

Stainless steel is selected for Corrosion is deterioration of essential properties in a material due to reactions with its surroundings. Millions of dollars are lost each year because of corrosion. Much of this loss is due to the corrosion of iron and steel, although many other metals may corrode as well. The problem with iron as well as many other metals is that the oxide formed by oxidation does not firmly adhere to the surface of the metal and flakes off easily causing "pitting". Extensive pitting eventually causes structural weakness and disintegration of the metal.

Austenitic is the most widely used type of stainless steel. It has a nickel content of at least of 7%, which makes the steel structure fully austenitic and gives it ductility, a large scale of service temperature, non-magnetic properties and good weld ability. The range of applications of austenitic stainless steel includes house wares, containers, industrial piping and vessels, architectural facades and constructional structures.

When welding stainless steels it is advisable to follow the general welding guidelines valid for the type of steel, e.g. austenitic Stainless steels have, due to their chemical compositions, a higher thermal elongation compared to mild steels. This may increase weld deformation. Dependent of weld metal microstructure they might also be more sensitive to hot cracking and sensitive to intermetallic precipitations compared to mild steels.

Austenitic grades are those alloys which are commonly in use for stainless applications. The austenitic grades are not magnetic. The most common austenitic alloys are iron-chromium-nickel steels and are widely known as the 300 series. The austenitic stainless steels, because of their high chromium and nickel content, are the most corrosion resistant of the stainless group providing unusually fine mechanical properties. They cannot be hardened by heat treatment, but can be hardened significantly by cold-working.

Type 304: The most common of austenitic grades, containing approximately 18% chromium and 8% nickel. It is used for chemical processing equipment, for food, dairy, and beverage industries, for heat exchangers, and for the milder chemicals.

The special material properties of stainless steels affect all four machinability factors: in general, it can be said that the higher the alloy content of a stainless steel, the more difficult it is to machine. The special properties that make stainless steels difficult to machine occur to a greater or lesser extent

in all grades of stainless steels, but are most marked in the austenitic grades. They can be summarized in five points:

- Stainless steels work-harden considerably
- Stainless steels have low thermal conductivity
- Stainless steels have high toughness
- Stainless steels tend to be sticky
- Stainless steels have poor chip-breaking characteristics

As the stainless steel is classified in different categories like austenitic, ferritic, martensitic etc., from this we have chosen austenitic stainless steel (304) because of its low cost, easy availability in the market. Some Rules of Thumb for Machining Stainless Steels

There are some general rules of thumb that can be applied when machining stainless steels, to avoid (to some extent) the problems described, or at least to minimize them.

These rules are particularly important when machining austenitic stainless steels.

- Always use rigid machine tools, as the machining of stainless steels involves high cutting forces.
- Tools and work pieces must be firmly clamped, and the tool overhang must be as small as possible. (Long overhangs, or unstable machining conditions, increase the already substantial risk of vibration when machining stainless steels.)
- Do not use too great a nose radius, as this can cause vibration.
- Use tools with good edge sharpness and high edge strength.
- Use sufficient cutting depths, so that the cutting edge tip reaches below the work-hardened zone from the previous cut.

### III .METHODOLOGY

The standard specimen of austenitic stainless steel is prepared and welding processes of TIG and MIG welding are applied on the material under varied conditions of current, voltage and speed. Mechanical properties such as tensile strength, %of elongation, reduction of area and yield strength are measured with universal testing machine. The hardness of the material is also studied for the different welding processes with effect of the various welding parameters on the material. Corrosion resistance is studied. Microstructure is evaluated by electron microscope. Comparison is to be made between TIG and MIG welding processes under varied conditions and optimize the conditions so as to achieve highest efficiency and better mechanical properties..

The specimen is subjected to micro structural studies for the grain size analysis, micro hardness test, tensile test, , and corrosion studies for the stainless steel. All these tests were performed for the different welding parameters. Further, corrosion and the study of the microstructure of the material were carried out on the surfaces of the material for the knowing the grain size, grain structures as well as the grain boundaries.

Table I: Chemical Composition of Austenitic Stainless Steel (Wt. %)

Composition	C	S i	Mn	Cr	S	P	Ni
AISI 304	0.06	0.32	1.38	18.4	0.28	0.4	8.17

TIG and MIG welding process are chosen to carry out the experimental analysis on austenitic stainless steel.

### IV. EXPERIMENTAL WORK

#### A. Procedure For Carrying Out The TIG Process :

TIG: The main advantages of this process when used on stainless steels can be summarized as follows:

1. A concentrated heat source, leading to a narrow fusion zone.
2. A very stable arc and calm welding pool of small size. Spatter is absent and because no flux is required in the process, oxidation residues are eliminated so that any final cleaning operation is very much simplified.
3. An excellent metallurgical quality with a precise control of penetration and weld shape in all positions.
4. Sound and pore-free welds.
5. Very low electrode wear.
6. Easy apprenticeship

We have taken sixteen cylindrical rods of authentic stainless steels, the material specifications are as follows:

- Material : Austenitic stainless steel (304)
- Thickness : 3 mm
- Length : 150mm
- No of pieces : 6

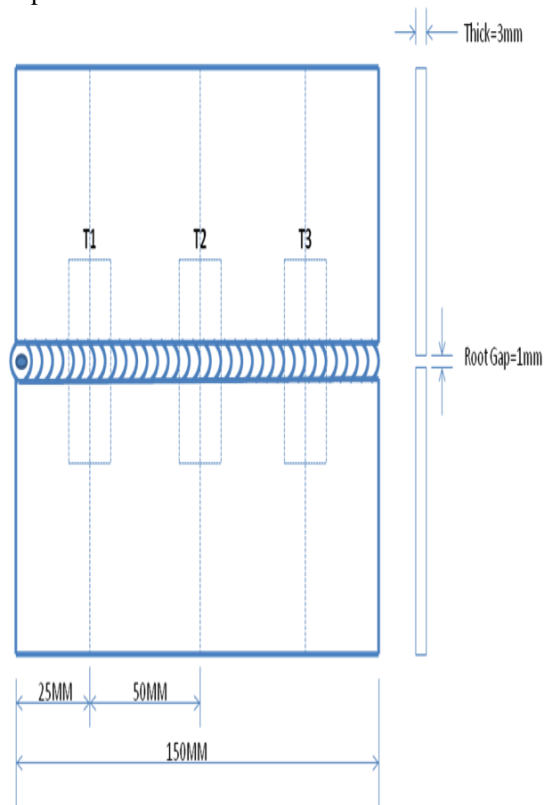


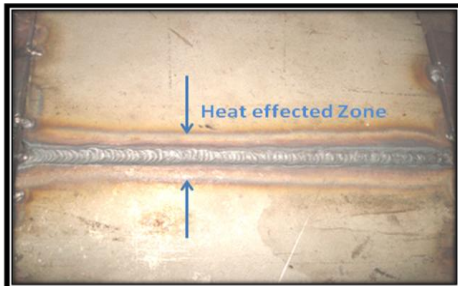
Fig.1 Specification of the Specimen of Welding Process

Irrespective of welding joints, this specimen is then tapered at 45 degree to improve the weld strength

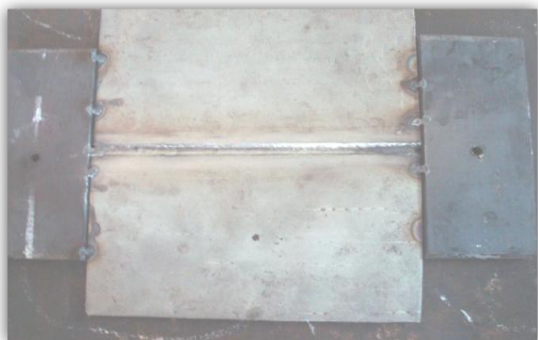


**Fig.2 Specimen Is Tapered For Weld Strength**

After tapering welding process is selected, from these 3 pieces of austenitic stainless steel 3 pieces are selected for TIG and 3 pieces for MIG process. The three pieces are welded by TIG machine. The welded pieces are shown in fig.3



**Fig. 3 .Welded pieces (TIG process)**



**Plate selected at TIG Welding**

The following weld parameters while TIG welding.



***B. Operations under MIG process:***

The three similar pieces of austenitic stainless steel which are tapered, which are shown earlier are taken for this process. The welded pieces under MIG process are represented below.

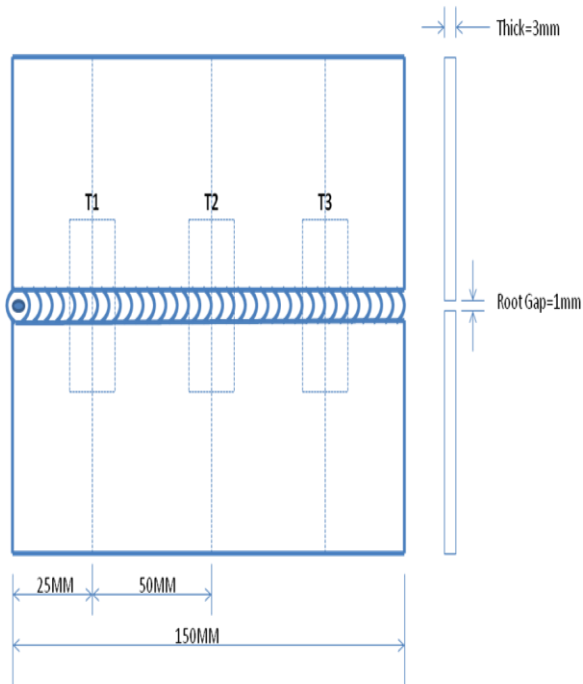


Fig. 4 Welded pieces (MIG process)

**IV. TESTS CONDUCTED ON THE WELDED PIECES**

1. Brinell's Hardness Test
2. Tension test on UTM (Universal Testing Machine).
3. Non-Destructive Testing. (Dye-Penetrant Test).

**1. Brinell's Hardness Test**

Hardness may be defined as resistance of metal to plastic deformation usually by indentation. However the term may also refer to stiffness or temper or resistance to scratching, abrasion or cutting. Indentation hardness may be measured by various hardness tests like Brinell's, Rockwell's etc. Pieces which are welded by both the process (TIG & MIG) are taken under this test.

$$BHN = \frac{2P}{\pi D [D - \sqrt{D^2 - d^2}]}$$

BHN=Brinells hardness number

P=Load on Indenter in kg.

D=Diameter of steel ball in mm.

d=Average measured diameter of indentation in mm.

Load (P) =3000 Kgs as the material belong to hard categories

Diameter (D) =10mm.

**Results under the Hardness Test (TIG)**

**1.1 The Brinell's Hardness number for the TIG welded material:**

Average diameter (d) = (5.4+4.4)/2= 4.9mm.

So,

$$BHN = \frac{2P}{\pi D [D - \sqrt{D^2 - d^2}]}$$

$$BHN = 185Kgs/mm^2$$

**Results under the Hardness Test (MIG)**

**1.2 The Brinell's Hardness number for the MIG welded material:**

Average diameter (d) = (5.1+3.6)/2=4.35mm.

So,

$$BHN = \frac{2P}{\pi D [D - \sqrt{D^2 - d^2}]}$$

$$BHN = 349Kgs/mm^2$$

Table II. The Hardness Values of AISI Obtained By Tig ANS MIG Process

PROCESS	BHN			
	TIG	185	198	220
MIG	349	354	387	394

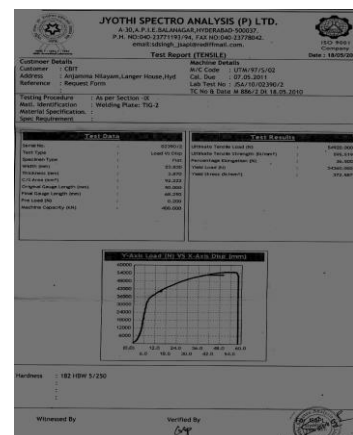
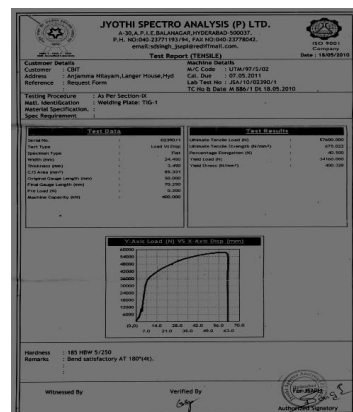
**Tension test carried on UTM (Universal Testing Machine)**

It is one of the most widely used mechanical tests. A tensile test helps determining tensile properties such as ultimate tensile strength, yield point or yield strength, % elongation, % reduction in area and modulus of elasticity. Formulas used in tension test.

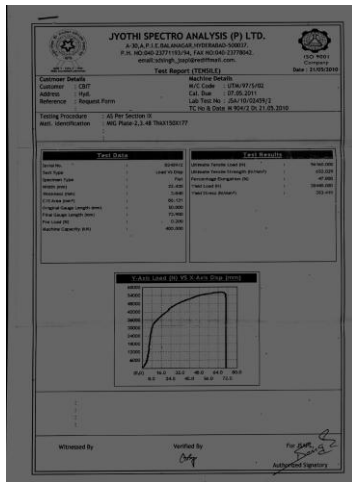
1. Yield strength = load at yield/original area (A0)
2. Ultimate tensile strength = ultimate load (Pmax)/(A0)
3. % Elongation = L<sub>f</sub> - LO/LO\*100
4. % Reduction = AO-Af/AO\*100
5. Young's modulus of Elasticity, E= stress at any point/strain at that point

Pieces which are welded by both the process (TIG & MIG) are taken under this test.

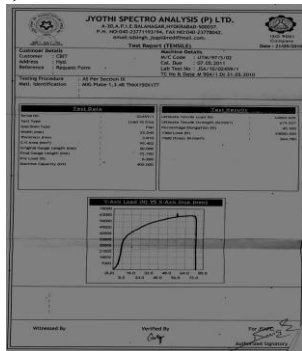
**Graph indicating for the sample1&2 (TIG Welding) Sample 1**



Sample2 (TIG) Sample 1(MIG)

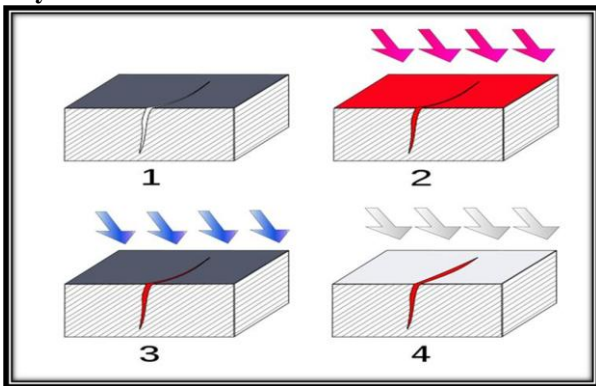


Sample2 (MIG)



Graph indicating for the samples1&2(MIGWelding)

### 3. Dye-Penetrant Test:



DPI is based upon capillary action, where surface tension fluid low penetrates into clean and dry surface-breaking discontinuities. Penetrant may be applied to the test component by dipping, spraying, or brushing. After adequate penetration time has been allowed, the excess penetrant is removed, a developer is applied. The developer helps to draw penetrant out of the flaw where an invisible indication becomes visible to the inspector. Inspection is performed under ultraviolet or white light, depending upon the type of dye used - fluorescent or nonfluorescent (visible).

Materials: Penetrants are classified into sensitivity levels. Visible penetrants are typically red in color, and represent the lowest sensitivity. Fluorescent penetrants contain two or more dyes that fluoresce when excited by ultraviolet (UV-A) radiation (also known as black light). Since Fluorescent penetrant inspection is performed in a darkened

environment, and the excited dyes emit brilliant yellow-green light that contrasts strongly against the dark background, this material is more sensitive to small defects.

When selecting a sensitivity level one must consider many factors, including the environment under which the test will be performed, the surface finish of the specimen, and the size of defects sought. One must also assure that the test chemicals are compatible with the sample so that the examination will not cause permanent staining, or degradation. This technique can be quite portable, because in its simplest form the inspection requires only 3 aerosol spray cans, some lint free cloths, and adequate visible light. Stationary systems with dedicated application, wash, and development stations, are more costly and complicated, but result in better sensitivity and higher samples through-put.



WATER TYPE PENETRANT



DEVELOPER

### Inspection steps

Below are the main steps of Liquid Penetrant Inspection:

**1. Pre-cleaning:** The test surface is cleaned to remove any dirt, paint, oil, grease or any loose scale that could either keep penetrant out of a defect, or cause irrelevant or false indications. Cleaning methods may include solvents, alkaline cleaning steps, vapor degreasing, or media blasting. The end goal of this step is a clean surface where any defects present are open to the surface, dry, and free of contamination. Note that if media blasting is used, it may "work over" small discontinuities in the part and an etching bath are recommended as a post-blasting treatment.

**2. Application of Penetrant:** The penetrant is then applied to the surface of the item being tested. The penetrant is allowed "dwell time" to soak into any flaws (generally 5 to 30 minutes). The dwell time mainly depends upon the penetrant being used, material being testing and the size of flaws sought. As expected, smaller flaws require a longer penetration time. Due to their incompatible nature one must be careful not to apply solvent-based penetrant to a surface which is to be inspected with a water-washable penetrant.



**3. Excess Penetrant Removal:** The excess penetrant is then removed from the surface. The removal method is controlled by the type of penetrant used. Water-washable, solvent-removable, lipophilic post-emulsifiable, or hydrophilic post-emulsifiable are the common choices. Emulsifiers represent the highest sensitivity level, and chemically interact with the oily penetrant to make it removable with a water spray. When using solvent remover and lint-free cloth it is important to not spray the solvent on the test surface directly, because this can remove the penetrant from the flaws. If excess penetrant is not properly removed, once the developer is applied, it may leave a background in the developed area that can mask indications or defects. In addition, this may also produce false indications severely hindering your ability to do a proper inspection.



**5. Application of Developer:** After excess penetrant has been removed a white developer is applied to the sample. Several developer types are available, including: non-aqueous wet developer, dry powder, water suspendable, and water soluble. Choice of developer is governed by penetrant

compatibility (one can't use water-soluble or suspend able developer with water-washable penetrant), and by inspection conditions. When using non-aqueous wet developer (NAWD) or dry powder, the sample must be dried prior to application, while soluble and suspend able developers are applied with the part still wet from the previous step. NAWD is commercially available in aerosol spray cans, and may employ acetone, isopropyl alcohol, or a propellant that is a combination of the two. Developer should form a semi-transparent, even coating on the surface.



The developer draws penetrant from defects out onto the surface to form a visible indication, commonly known as bleed-out. Any areas that bleed-out can indicate the location, orientation and possible types of defects on the surface. Interpreting the results and characterizing defects from the indications found may require some training and/or experience 5. Inspection: The inspector will use visible light with adequate intensity (100 foot-candles or 1100 lux is typical) for visible dye penetrant. Ultraviolet (UV-A) radiation of adequate intensity (1,000 micro-watts per centimeter squared is common), along with low ambient light levels (less than 2 foot-candles) for fluorescent penetrant examinations. Inspection of the test surface should take place after a 10 minute development time. This time delay allows the blotting action to occur. The inspector may observe the sample for indication formation when using visible dye. It is also good practice to observe indications as they form because the characteristics of the bleed out are a significant part of interpretation characterization of flaws.

**6. Post Cleaning:** The test surface is often cleaned after inspection and recording of defects, especially if post-inspection coating processes are scheduled.

**Heat Affected Zone:**

The heat-affected zone (HAZ) is the area of base material, either a metal or a thermoplastic, which has had its microstructure and properties altered by welding or heat intensive cutting operations. The heat from the welding process and subsequent re-cooling causes this change in the area surrounding the weld. The extent and magnitude of property change depends primarily on the base material, the weld filler metal, and the amount and concentration of heat input by the welding process.

The thermal diffusivity of the base material plays a large role—if the diffusivity is high, the material cooling rate is high and the HAZ is relatively small. Alternatively, a low diffusivity leads to slower cooling and a larger HAZ.

To calculate the heat input for arc welding procedures, the following formula is used:

$$Q = \left( \frac{V \times I \times 60}{S \times 1000} \right) \times \text{Efficiency}$$

Where Q = heat input (kJ/mm),

V = voltage (V),

I = current (A),

and S = welding speed (mm/min)..

Heat input rate for the sample 1:

$$Q = V \cdot I / S$$

$$15 \cdot 40 / 80 = 7.5 \text{ KJ/m}$$

Heat input rate for the sample 2:

$$Q = V \cdot I / S$$

$$10 \cdot 50 / 75 = 6.6 \text{ kJ/m.}$$

## V. CONCLUSION

1. Hardness of the austenitic stainless steel when welded with TIG process is obtained as BHN is 185 HBW 5/250, where as for the MIG welding the BHN is 349 HBW 5/250. From this we can conclude that hardness of MIG welding is greater than the hardness of TIG welding. Therefore MIG welding is suitable where the hardness is the main criterion.  
2. From the tension test conducted on the specimen we can conclude that

2.1 The ultimate load of TIG welded specimen is 57600 N where as for the MIG welded specimen is 56160N. Therefore we can say that TIG welded specimen can bear higher loads than MIG welded specimen.

2.2 The ultimate tensile strength of TIG welded specimen is 675.22 MPa where as for the MIG welded specimen is 652.029 N/mm square. Therefore we can say that TIG welded specimen has higher tensile strength.

2.3 Percentage elongation of TIG welded specimen is 40.500% where as for the MIG welded specimen is 47.8%. Therefore we can conclude that the ductility is higher in MIG welded specimen.

Note: According to the standards the percentage of reduction in area should be 40%. But we got more than the standard. So, that the weld joint is more strength.

2.4 The yield stress of the TIG welded specimen is 400.238 N/mm square whereas for the MIG welded specimen is 353.419 N/mm squared. Therefore we can conclude that TIG welded specimen can bear high yield stress.

2.5 In the corrosion resistance, the alloy material of 304 can be successfully welded by the following process.

1) TIG Welding. 2) MIG Welding.

3.0 There is no remarkable indication (Like porosity & surface cracks) and the weld surface is found "OK" The Microstructure consists of Austenite in Grain size 5 to 6 in the Matrix, No Delta Ferrite observed in TIG Welding and The Microstructure consists of Austenite in Grain size 5 to 6

in the Matrix, No IGC (Inter Granular Corrosion) Observed in MIG Welding.

Therefore the welding parameters must be optimized to obtained a controlled Ferrite level 20 to 70%. Typical recommended heat inputs are 10 to 25 KJ/cm with a 150 degree centigrade (302F) Max interpass temperature. These conditions must be optimized taking in to account the thickness of the products and welding Equipment (consult is necessary). We do not recommended pre – or post welding heat treatments. Only complete solution annealing heat treatment may be considered. Finally we have observed all the parameters good results in TIG Welding. So, TIG welding is best process for Austenitic Grade materials. As the speed decreases and the current increases the heat affected zone increases.

## VI. FUTURE RESEARCH DIRECTIONS

This work can be further extended for other stainless steel to know the comparison of the mechanical properties as well as the different parameters under the microstructure study with non destructive methods and conclude for the reduction of the cost and suggestion of suitable materials in different applications of industrial process.

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