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# Influence of Process Parameter on Lack of Fusion in TIG Welding of SS 304: A Review

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***Abstract***

*TheTIG welding or gas tungsten arc welding (GTAW) process is widely used in many appliances because of its versatility in industry. For GTAW process, metals like carbon steel, stainless steel, aluminium, copper, low-alloy steel and non-metal also are widely used in all positions. Butt joint, lap joint, T-joint, edge joint and corner joint are the common types of joints used in welding. The incompletely fused spots like porosity,which occurs after welding is known as lack of fusion that leads to undesirable results; and to overcome this, it requires change in welding techniques and parameters within the limits. A large number of resources are used nowadays for reworking the welds. But it causes higher cost of production and delay for completing the work. Higher amount of rejection of product may generate if the lack of fusion is not to be controlled physically during welding. This work is aimed to predict and reduce lack of fusion with TIG welding process parameters. Using various design of experiment methods, straight and indirect effects of the process parameters can be determined and process parameters can be optimized.*

***Keywords:****TIG welding, SS 304, lack of fusion, process parameter, design of experiment*

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## INTRODUCTION

Tungsten Inert Gas welding (TIG) process is most commonly used in industry. TIG welding or GTAW (Gas Tungsten Arc Welding) uses a non-consumable tungsten electrode. It is protected by inert gas like argon gas or helium gas. Inert gas is used for arc shielding in order to prevent air from contaminating the weld. This shielding gas prevents oxidation of the tungsten electrode, the molten weld puddle, and the heat affected zone adjacent to the weld bead. Mostly, argon gas is used as inert gas by industry because it is less costly than helium gas. TIG welding is very useful to weld thin plate of metallic and non-metallic material. Since the process uses a non-consumable tungsten electrode, extra filler material is usually added [1].

TIG is used very commonly in areas, such as rail, car manufacturing, automotive and chemical industries. Stainless steel is extensively used in industries as an important material, because of its excellent corrosion resistance. TIG welding is one of the welding processes, often used to weld similar and dissimilar metals. Figure 1 shows the tungsten inert gas or GTAW welding process.

Stainless steel graded 304 (SS 304) is used because the SS 304 possesses high strength and toughness as well as corrosion resistance. One of the typical applications of SS 304 includes storing and transportation of liquefied natural gas (LNG), whose boiling point is –162°C under 1 atm [3].

The most crucial part is welding process in any thin sheet product manufacturing because the rejection of product most commonly occurs due to welding defects. During TIG welding of thin section (approximately 1 mm thick plate), cavities are formed because of lack of fusion in SS 304 and also there is decrease in mechanical properties like tensile strength and hardness. Therefore, control of lack of fusion is important to avoid service failures and ensure the dimensional compliance, especially while welding thin walled sections. Figure 2 shows a specimen SS-304 with TIG welding.

In order to control the lack of fusion, a thorough understanding the mechanism of development and the influence of welding parameters on the generation of lack of fusion are required. The main parameters are current, voltage, gas flow rate and welding speed. Since voltage is mostly kept constant, by varying other parameters, we can overcome the problem.

## LACK OF FUSION IN WELDING

Among various types of defects in welding, lack of fusion is very challengeable type of defect. Lack of fusion is a very dangerous weld defect in a welded structure. Because of the notch effect, a crack may further propagate under the smallest load applied [5].

Lack of fusion is defined as in welding, incompletely fused spots, called lack of fusion. A weld can lack union with the parent metal or with a previous weld bead. Lack of fusion can be classified into two groups: The one in which lack of fusion includes voids or non-metallic inclusions which can be detected by non-destructive methods like radiographic test; and the one in which the lack of fusion shows no discontinuity in the material since it is a structural defect and thus cannot be detected by non-destructive methods. The lack of fusion is a planar defect. It may appear at the edge of the parent metal or between runs. The defect is usually to be found at the weld inside and it rarely reaches the final runs or the root run (Figures 3–5). Lack of fusion occurs due to poor welding technique.

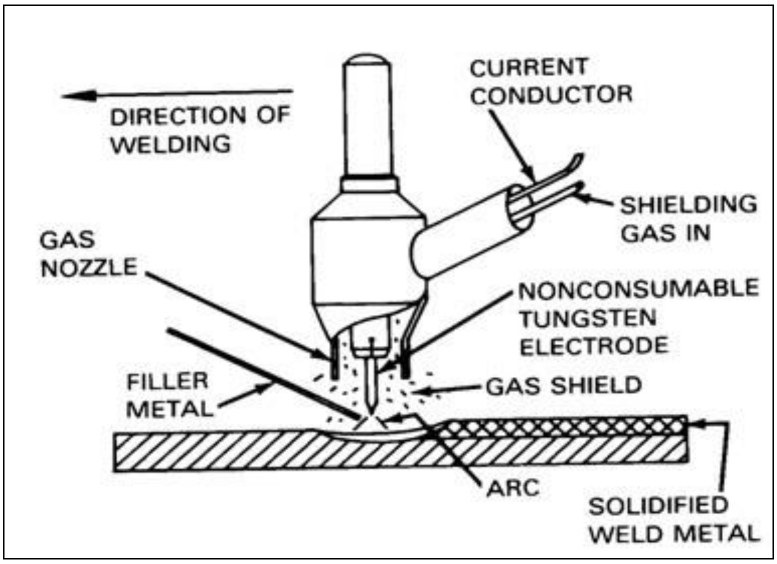


***Fig. 1:*** *Tungsten Inert Gas or GTAW Welding Process [2].*

***Fig. 2:****Specimen SS-304 with TIG Welding [4].*

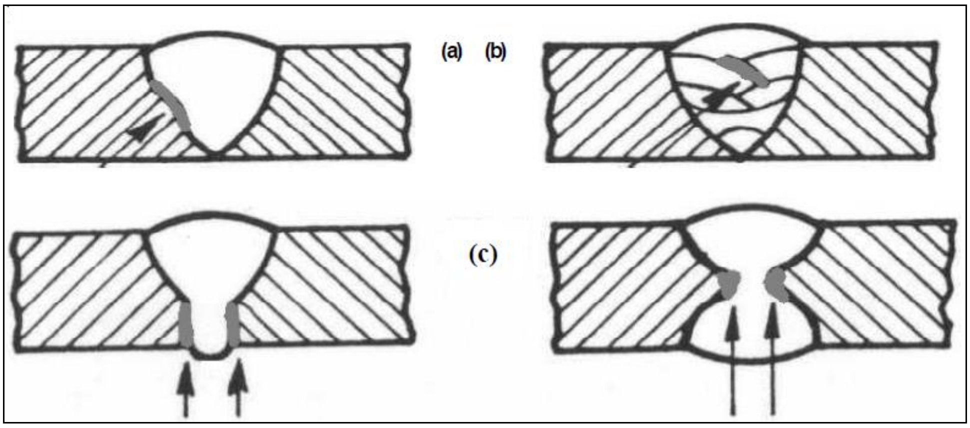


***Fig. 3:****Possible Location of Lack of Fusion:* ***(a)****At Side Wall;****(b)****Among Runs;****(c)****In Root [5].*

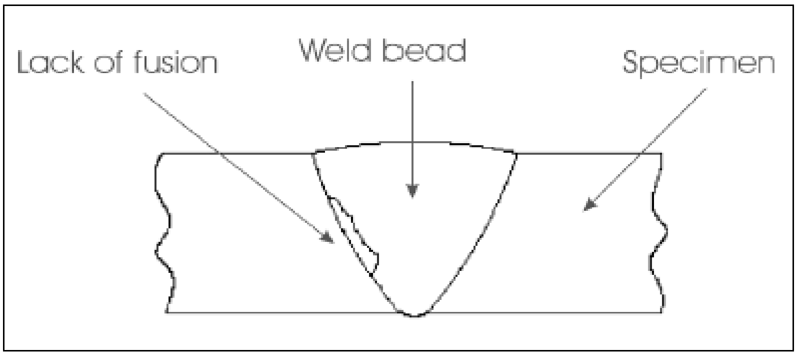


***Fig. 4:****Welded Bead with a Lack of Fusion Defect [6].*

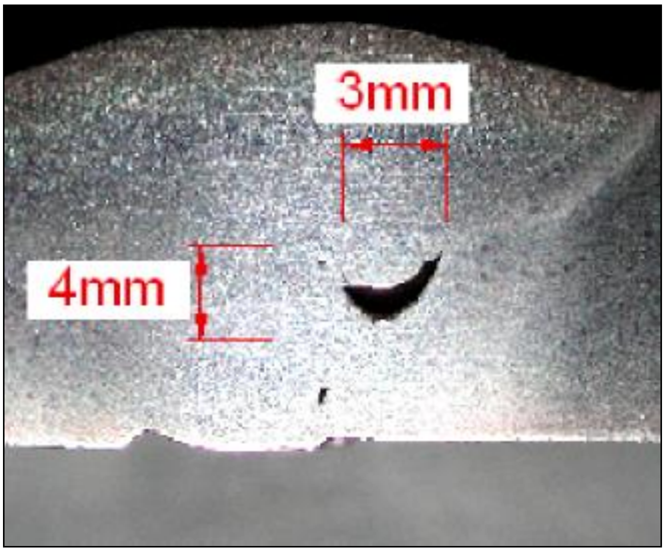


***Fig. 5:****Welded Bead Section Containing a Lack of Fusion [6].*

## FACTORS AFFECTING LACK OF FUSION IN TIG WELDING

### Current

The primary source of heating the base plate is current that flows through the arc. The steam of electrons across the arc is termed as the current. Potential, kinetic and thermal energy are carried out by the current. When the electrons strike to the base plate, these three types of energy are released as heat. Current is the most affecting parameter in welding, and this is because, it is the main source of heat, very low current will increase the lack of fusion.This means that lack of fusion may occur at a side wall where the parent material has not melted to a sufficient degree. A similar situation may occur between passes when a previous pass has not re-melted so that no weld dilution occurs. A third case may be with the root passing when, due to too narrow a gap, the root does not melt through. The weld pool will simply flow through.

**Voltage**
The voltage in arc welding is the amount of drop of the voltage occurring at the electrode and the arc. This voltage drop v in welding is known as the "arc voltage". The value of lack of fusion increases with increase in voltage.

**TravelSpeed**
Base plate is heated by the amount of heat transferred from heat source. The heat source velocity is known as the travel speed. If the heat input from the arc is kept constant, the heat energy to be delivered to the base plate will increase as the travel speed decreases. Lack of fusion will reduce if the travel speed is increased.

**Gas Flow Rate**
The amount of gas flowing per unit time is known as the gas flow rate. Gases like inert or active gas are used for providing shield to the weld pool in order to protect it from atmospheric gases. The gas flow rate will determine the amount of depth of melting and thus it will affect the dilution. Gas flow rate has very less effect on lack of fusion.

## EFFECT OF PROCESS PARAMETERS

Zuhailawati *et al.* have considered current, filler size and flow rate of shielding as process parameters. From experiments, it was concluded that the weld current used should be suitable with filler size in order to achieve good joint [7]. High welding current with smallest filler and low flow rate is beneficial for high strength joint since weld microstructure becomes finer without crack.

The above Table 1 reviles that the larger filler gave lower value of tensile test because during welding, extra heat required to melt the larger filler was much more than to melt the smaller size of filler metal. As a result, this high heat input will reduce the strength of the welding[7].

Ravisankar *et al.* have considered power, weld speed, and heat input as process parameters. From experiments, it was concluded that a considerable increase in temperature distribution was observed with the increase in the weld speed and power. When weld speed and power increase the tensile stress and compressive stress. The radial residualstresses were found to be negligible and were not influenced bythe variation in the weld speed and power [8].

Gadewar *et al.* have considered weld current, gas flow and work piece thickness as process parameters [1]. From the experimental analysis it is found that the process parameters considered (welding current, shielding gas flow and work piece thickness) have great influence on the considered weld characteristics (Front width and Back width) [9].

Devendran *et al.* have analyzed the parameters of SS 304 using TIG welding [2]. The parameters like Young’s modulus, factor of safety, stress, strain, hardness, toughness etc.,and from the experimental analysis, they concluded thatthe TIG welded specimen can hold onto a force of 0.5 times more than the calculated force. Hence its factor of safety is 1.48 which is excellent for any machine.

***Table 1:*** *Process Parameters [7].*

| Sample | Current (A) | Filler (mm) | Flow Rate (C fh) | Mean Tensile Strength (Model) (MPa) | Mean Tensile Strength (Experimental) (MPa) | Percent of Error (%) |
|---|---|---|---|---|---|---|
| 1 | 35 | 2.4 | 13 | 720.9 | 725.34 | 0.69 |
| 2 | 35 | 1.6 | 13 | 745.96 | 746.680 | 0.13 |
| 3 | 46 | 2.0 | 12 | 724.84 | 729.22 | 0.69 |
| 4 | 40 | 2.0 | 12 | 718.33 | 796.500 | 9.79 |
| 5 | 40 | 1.6 | 14 | 738.49 | 734.00 | 0.54 |
| 6 | 40 | 1.6 | 10 | 756.75 | 819.67 | 8.33 |

Kumar and Shashi have considered heat inputs like low, medium, high and base metal as process parameters. From the experimental analysis it is found that maximum tensile strength and ductility is possessed in SS 304 by the weld joints made using low heat input. As heat input increases, the fusion zone and HAZ area also increases [10].

Mousavi and Miresmaeili have considered current, voltage, tungsten electrode diameter, filler diameter, welding velocity and gas flow rate as process parameters and material is SS 304L [11]. From the experimental analysis it is found that magnitudes of the transverse residual stresses increased about threefold and also they reviled that constrained weld structures had less distortion than non-constrained weld structures.

***Table 2:*** *Range of Process Parameters [11].*

| **Parameters** | **Range** |
|---|---|
| Current (A) | 250–275 |
| Voltage (V) | 15 |
| Tungsten electrode diameter (mm) | 3.2 |
| Filler diameter (mm) | 3.2 |
| Welding velocity (mm/s) | 3.5 |
| Gas flow rate (l/min) | 11 |

The Table 2 shows the list of welding parameters used in analyses of residual stress distributions in TIG welding process for 304L stainless steel [11].

Juang and Tarng have considered arc gap, gas flow rate, welding current and welding speed as process parameters [12]. The optimization is to be used to analyze weld pool geometry. Taguchi method is adopted to solve the optimal weld pool geometry. From the experimental analysis they reviled that the optimal weld pool geometry has four smaller-the-better qualities characteristics like front height, front width, back height and back width of the weld pool in TIG welding of stainless steel which are greatly improved.

***Table 3:*** *Selected Process Parameters in Taguchi Method [12].*

| **Symbol** | **Process Parameters** | **Level-1** | **Level-2** | **Level-3** | **Level-4** |
|---|---|---|---|---|---|
| A | Arc gap (Mm) | 1.7 | 2.0 | 2.3[a] | 2.6 |
| B | Flow rate (l/min) | 8[a] | 9 | 10 | 11 |
| C | Welding Current (A) | 40 | 45 | 50[a] | 55 |
| D | Welding Speed (cm/min) | 13.5 | 14.0 | 14.5 | 15.0[a] |

The Table 3 shows that Taguchi method has been used for optimization and in the study, an$L_{16}$ ($4^5$) orthogonal array which has 15 degrees of freedom was used.

The experimental layout for the welding process parameters using the $L_{16}$ orthogonal array is shown in above Table 4 [12].

***Table 4:*** *$L_{16}$ Orthogonal Array [12].*

| **Experiment Numbers** | **Process Parameters Level** | | | |
|---|---|---|---|---|
| | **Arc Gap** | **Flow Rate** | **Welding Current** | **Welding Speed** |
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 1 | 4 | 4 | 4 |
| 5 | 2 | 1 | 2 | 3 |
| 6 | 2 | 2 | 1 | 4 |
| 7 | 2 | 3 | 4 | 1 |
| 8 | 2 | 4 | 3 | 2 |
| 9 | 3 | 1 | 3 | 4 |
| 10 | 3 | 2 | 4 | 3 |
| 11 | 3 | 3 | 1 | 1 |
| 12 | 3 | 4 | 2 | 2 |
| 13 | 4 | 1 | 4 | 2 |
| 14 | 4 | 2 | 3 | 1 |
| 15 | 4 | 3 | 2 | 4 |
| 16 | 4 | 4 | 1 | 3 |

Souza *et al*. have considered radiography test as NDT for detecting the lack of fusion defect in welding. They have used computational simulation with XRSIM software to establish the optimal radiographic parameters to reach the lower limit for detection for lack of fusion [6].

## CONCLUSION

From the comprehensive study of TIG welding on SS 304, it emphasised that factors like welding current, voltage, gas flow rate and travel speed are identified as process parameters which affect the major welding defects. These defects can be optimized by using optimized process parameters with appropriate optimizing techniques like design of experiment, FE simulation, ANOVA method, 3D computer simulation, XRSIM software, and Taguchi method.

At the end it has been observed that welding current, travel speed and gas flow rate are the most influencing parameters in TIG welding and they affect the defects like lack of fusion, lack of penetration, distortions, reduction of tensile strength and reduction of hardness.

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