

Microstructural and Strengthening properties of TIG and MIG welding- An Overview

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Abstract. The study focused on the standalone TIG and MIG welding and the combined effect, emphasizing the microstructural properties and strength of the welded joint, especially the heat-affected zone. The literature study revealed that both welding techniques and their combination have full penetration in terms of the weld, and the HAZ for TIG-MIG has a larger width in comparison with TIG and MIG. TIG-MIG joints usually demonstrate ductile fracture compared with standalone MIG or TIG welded joints. However, it is characterized by adequate properties like tensile strength compared with the TIG and MIG welding processes. In addition, a comparison between the TIG-MIG techniques and the traditional MIG welding revealed a refined appearance in the joint, as revealed by several microstructures of the joints.

1. Introduction

Metallic structures can hardly be assembled from just a single alloys or spare part. In production/manufacturing, structures are produced via fabrication using different engineering materials and technique depending on the intended application [1]. However, the engineering materials are made with varying compositions as well as specific properties. Thus, from the science of engineering materials, the use of appropriate technique and material for their processing is key to the development of a sustainable product [2].

Welding is defined as a means of joining two or more components to achieve a robust integral structure. The process of welding would always have effect on the material microstructure and properties as these changes based on the parameters involved [3]. For instance, there is an increasing demand for the development of high entropy alloys (HEA) in the research and development of most institute, especially in the academic world. Thus, the new trend of the HEA development has brought a paradigm shift to material experts from the traditional alloys to a more multi-faceted alloy involving several elements which may be more than four [4]. Hence, combination of these several elements having different crystal structures would result to compounds having complex microstructures and phases [5].

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Although, use of casting technique for an existing HEA causes a general solidification with simple microstructures compared to the complex one. Consequently, microstructures of most HEAs are characterized by single-phase solid solutions having face centered cubic or body-centered-cubic crystal lattice structure. They are associated with properties like excellent strength, ductility and corrosion resistance as well as wear [6].

Tungsten inert gas welding (TIG) usually involve the use of arc and electrode as well as the workpieces that required joining in the presence of a shielding gas. It is a very important technique especially in the welding of metals and alloys. It requires high-quality weld [7]. However, it is associated with limited thickness of a material that requires welding in a single pass, inadequate tolerance to some materials behaviour as well as reduction in the overall productivity. Also, increase in the current used in welding causes expansion of the weld without actual weld showing [8]. Thus, causing structural defects. However, the problem can be minimized using activated tungsten inert welding method where the penetration can be increased by applying a flux on the joint to be welded before the actual welding. Hence, this would improve the penetration in TIG welding [9]. Furthermore, ZnO was established to be a capable flux in activated tungsten inert gas welding. It has been established that it can improve the tensile strength even better than use of TiO. Thus, activated tungsten inert gas welding is useful in joining two dissimilar metal having a thickness ranging from 8 mm – 10 mm in a single pass. Thus, making it possible to have full penetration of weld without edge penetration [10].

In the case of MIG welding, it basically involves an arc welding process where two metals are joined together via the heating of the metal using the arc. The arc is formed between the two surfaces of the metal to be welded and a filler electrode is continuously fed into it [11]. Also, shielding gas is needed to protect the molten pool of metal from reaching the atmosphere as well as the operator. For instance, MIG welding of aluminium 7005 was carried out using ER5356 filler rod. The result of the mechanical properties carried out showed a significant improvement in the tensile test, yield strength as well as elongation respectively [12].

The weld zone showed the structure of a cast material, while the tensile fracture morphology demonstrated a ductile rupture. However, it was also observed that a columnar crystal existed along the direction of radiation and as well characterized by the grain in the fusion region. Additionally, fibrous microstructure occurred as recrystallization occur at the HEA [13]. Figure 1 showed the microstructure of the weld zone, heat affected zone and base metal as well. From the microstructure, it was observed that that figure 1 a revealed as-cast structure with equiaxed grain dominating the weld zone. Also, columnar grain boundaries were found around Figure 1b as well as equiaxed crystals at the lower region. In fact, the majority of the heat affected zone was observed to have retained original structural properties of the base metal [14].

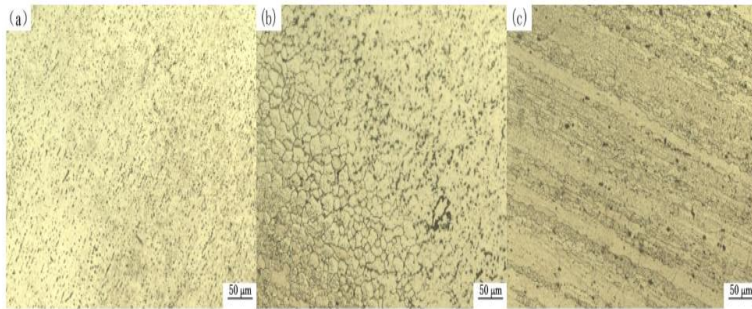


Figure 1: Optical morphology of weld metal, fusion zone and base metal Source: [14]

2. Microstructural Properties Mechanical Strength of TIG Welding

Several industries preferred fusion welding of Al-Mg alloys such as TIG welding and MIG welding techniques. This is due to their comparative advantages and ease of application. Some of the numerous reasons for using TIG welding include low cost, accessories, ease of maintenance. TIG welding of aluminium is established to always demonstrate high strength and ductility than MIG weld joint and this is due to use of elevated temperature of heating at controlled level [15]. For instance, Liyakat and Veeman [15] investigated the influence of friction stir welding on the weld bead of TIG welded aluminium 5052-H32 alloy and serious attention was dedicated to the mechanical and microstructural characteristics. Comparison between the friction stir process and untreated TIG-welded aluminium was done using the optical and scanning electron microscope. It was established from the study that the result of the yield strength of the unprocessed TIG improved from 79.5 MPa to about 129.5 MPa. However, it later jump to 201 MPa after process [16]. Brittle and ductile fracture were observed in the TIG weld joints and the friction stir process in TIG joint. Thus, the result revealed that the friction stirs treated weldment gave a better result than the unprocessed TIG welded joints. Figure 2 showed the TIG welding experimental set-up with V-butt joint. Also, friction stir process was attached on the TIG weld (AS is advancing side and RS implies retreating side). Similarly, Figure 3 showed the TIG weld and TIG-FSP welded joint of the aluminium alloy. The Image that the weld bead of the TIG sample demonstrated the behavior of a weave bead while that of the FSP zone displayed a smooth surface [17].

Thus, there was adequate fusion in the weld bead and plate as observed from the smooth trend of material flow under the TIG current of about 180A. This gave an acceptable appearance without macro defect. However, the thick weld structure observed due to the filler metal was traceable high-quality joint with adequate strength [18]. In addition to this, the microstructure behavior at different zone of the weld in shown in Figures 4 and 5 where different optical images were used to differentiate the different heat affected zones during the welding process. From the Figures, it was observed that there were no macro defects during the passes to achieve perfect penetration, thus, fusion was observed on the weld as well as on the FSP-TIG weld specimen. However, it was observed that the base metal was seen to comprise of fragments which are uniform due to the existence of strain hardening conditions [19]. Thus, the weld samples demonstrate gradual trend of cast microstructure from fusion zone to the base metal grain structure within the fusion zone/heat affected zone regions. Thus, elongated grains were observed from the weld.

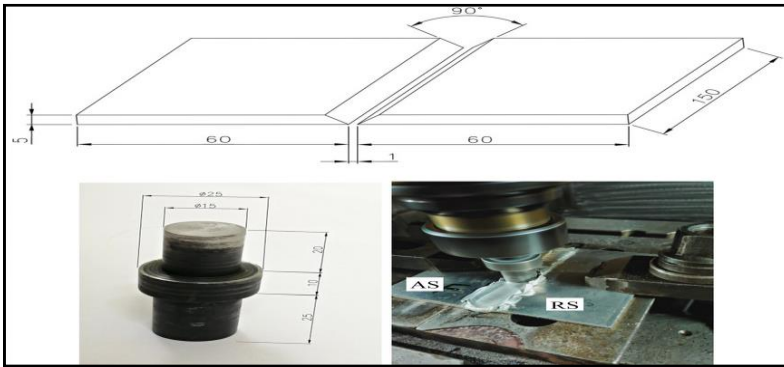


Figure 2: FSP-TIG experimental set-up for Aluminium 5052-H32 alloy. Source: [15].

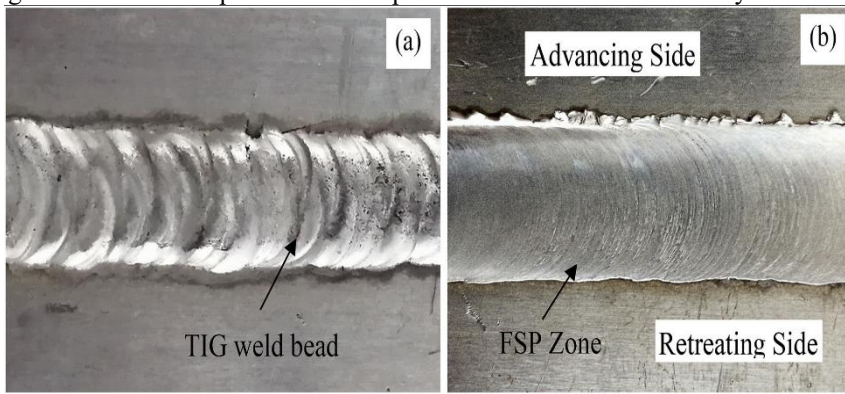


Figure 3: (a) Weld bead of TIG specimen and (b) FSPed surface on weld bead of TIG specimen. Source: [15]

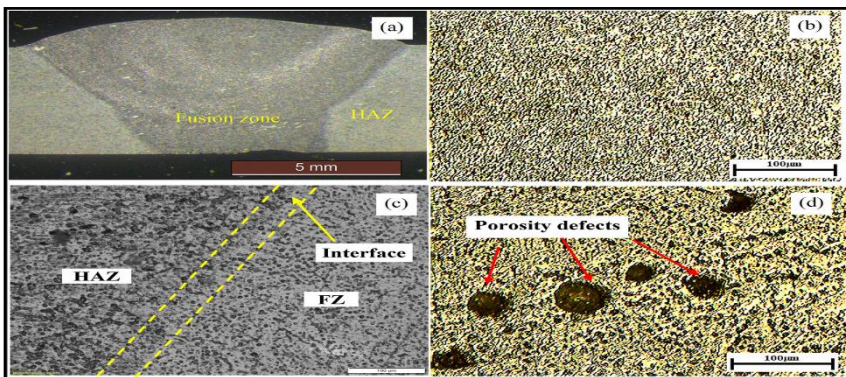


Figure 4: (a) Image of TIG weld sample, (b) base material (c) HAZ/FZ interface and (d) weld FZ. Source: [15]

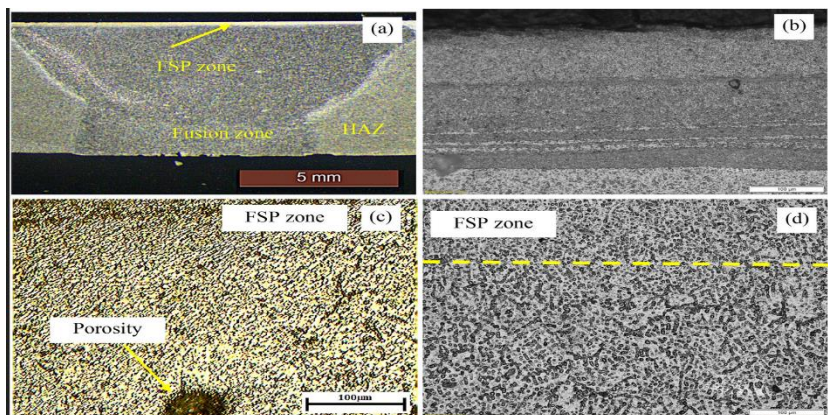


Fig. 5. (a) Image of FSP + TIG sample, (b) Optical microstructure on FSP zone of weld region, (c) defect below FSP zone and (d) Fusion zone. Source: [15]

Mandal *et al.* [20] reported that Inconel 617 has the capacity to strengthen other alloys for application in high-temperature zones. This is due to superior mechanical properties and creep-rupture strength. It is known to exhibit equiaxed grain, although its trend of microstructure is a combination of fine and coarse structure. Microstructure of this alloy is known to exhibit an intergranular and trans granular precipitate which always occur after heat treatment conditions.

Furthermore, Msomi *et al.* [21] studied the relationship between microstructures and the properties of AA6082/AA8011 joint which was subjected multi-pass friction stir welding process. The were joined via TIG technique and later subjected to underwater by keeping the water at room temperature. It was reported that the microstructural analyses demonstrated the passes made which caused the grain refinement. This increase in passes resulted in an improvement in strength, however, it influenced the strain rate and micro-hardness of the stir zone. According to Fu *et al.* [22] alloys of titanium are usually deployed in several applications because of their excellent strength, temperature resistance as well as corrosion resistance. TIG welding technique is the most preferred for joining titanium alloys because of reduction in cost, portability of the equipment and the ease of automation. However, it was reported that complex microstructures are associated with TIG welding as well as the mechanical properties.

Thus, investigating the TIG welding is critical to the welding and the subsequent microstructural evolution as well as the mechanical properties. To this end, Fu *et al.* [22] investigated the behaviour of a TIG welded joint of Ti-4Al-2V alloy. The result showed that both the heat affected and fusion zones were characterized by martensitic and acicular microstructure and this appeared more complex than the base metal. Also, different microstructure evolved with some showing equiaxed grain pattern.

According to Zhang *et al.* [23], direct current TIG and polarity tungsten inert welding on large fuel tanks usually result to the solidification segregation at the weld zone as well as microstructural change in the nanosized precipitates in other parts of the joints. This implies that a softening phenomenon exist which is attributable to the inhomogeneity in joints. Thus, reducing the tensile strength of the joint. Based on this, the study examined the microstructural evolution of 2219-C10S aluminium alloy via TIG process. It was observed that eutectic grain boundaries formed at the weld zone while symbiotic eutectic formed at the grain boundaries with no evidence of precipitates inside the grains [24]. Additionally, it was

observed that a dendritic structure was observed at the various weld zone especially at the capping and backing zone of weld as observed in Figure 6.

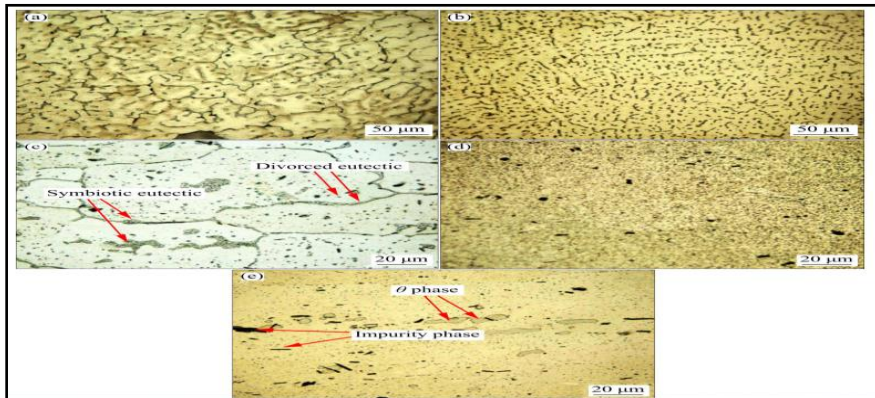


Figure 6: Metallographic structure showing the regions of weld Source: [23]

3. Microstructural Properties and Mechanical Strength of MIG Welding

MIG welding is a versatile welding technique which is widely used for materials of thin and thick sections. It involves the striking of arc between the end of a wire electrode and the workpiece which eventually melt both into a pool of metal. The wire represents the source of heat as well as the filler metal for the welding joint [24]. The pool (weld) is usually shielded from the environment using shielding gas which is fed through the nozzle around the wire. Thus, the selection of shielded gas depends on the material that need to be welded. Thus, MIG is widely used in the industry for about 50% of weld metal deposited. It is flexible and easily automated [25].

Kumar et al.[26] carried out the microstructural behaviour of two weldment using MIG process. The alloys were labelled P11 and P22 steel using CO₂ as the shielding gas. Impact test, microhardness as well as microstructures were determined using the impact tester, Vicker hardness tester and optical microscope respectively. The result revealed that the impact test for the welded sample is 49J while the P11 and P22 was 48 and 64 J respectively. Also, there was increase in hardness at the HAZ and lower at the base metal.

In addition to this, Madavi et al. [27] investigated the impact of fluxes in activated metal inert gas welding of SS316 having 5 mm thickness. It was established that the microstructural results showed a well-ordered grain boundary with evidence of flux presence compared to those without flux. Also, it was observed that the produced weld has smooth and orderly crystalline structure as shown in Figure 7.

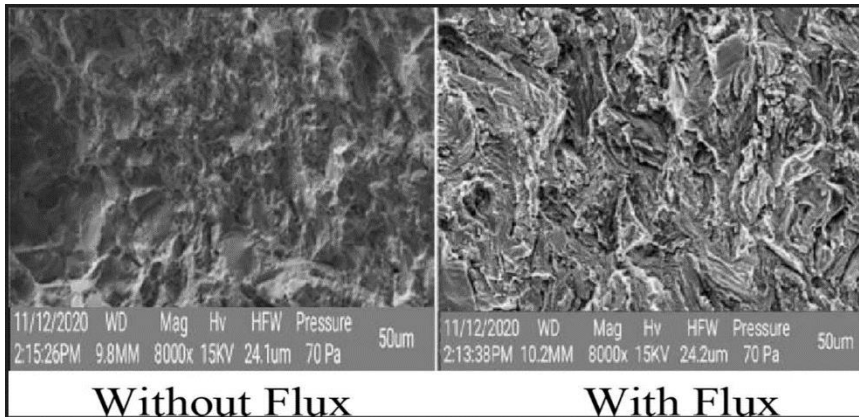


Figure 7: Comparison of MIG weldment with flux and without flux. Source: [27]

From the Figure, it could also be observed that light colors were deposited which is attributable to the excellent hardness and value of the tensile strength. In addition to this, it was observed that the microstructure was dominated by martensite structure which is attributed to high temperature from the welding process. Lastly, the without flux was characterized by tempered martensite with carbide precipitate [28]. According to Singh, Kumar, Kumar and Kumar, (2022) [29], high regions of heat and weld pool constituted the major regions affected during the welding of the base metal using MIG welding technique. Input parameters like change in current changes the grain and the behavior of the heat affected zone. Thus, affecting the entire microstructure of both zones. This is one reason why various research concentrate on the parameters during the MIG welding process. For instance, the process parameter on the microstructure of the stainless-steel plate was observed to affect size of grain in the weld zone of parent metal as well. Even the pearlite content in the high heat zone was observed to be high [30].

Pan et al. [31] reported that aluminium 6005A was welded ER5087 filler rod using metal inert gas welding technique. The results revealed a refined grain size because of Al₃(Sc, Zr) which accelerated the grain nucleation at the welded zone. The result also showed that the microstructure of the welded joint was smooth with evidence of refined grain boundaries. Also, high density of pores was observed at the weld zone due to the high solidification rate. There was no escape of gas bubbles from the melt causing the formation of pores at the weld zone.

To resolve the cold cracks associated with high strength steel especially those of large thickness, austenitic stainless-steel welding materials are used. However, only few researches of austenitic welding material especially nickel-based is considered [31]. Thus, Sun et al. [32] investigated the use of MIG gas welding technique to weld two alloys of nickel which are ERNiCrMo-3 and ERNiCrMo-4 having varying content of solid solution. The results revealed that the welded joints were observed to form excellently without defect.

Zhou et al. [33] investigated the impact of energy ratio on microstructure and mechanical behavior in the transition zone of a hybrid laser-MIG welded 316L/AH36 joints. In this study, transition zone was observed to be the region between the laser and the hybrid zones. While the ratio of laser to arc, energy is known to be energy ratio. Additionally, ferrites, austenites and martensites were observed on the microstructure. Also, there was obvious difference in the distribution and the crystallographic behavior of the microstructure of the transition zone as observed in the energy ratio.

Yang et al. [34] investigated the impact of using alternating magnetic field on the mechanical and microstructural behavior during the welding of HG785D steel using laser-MIG welding technique. The result of the experiment showed that there was significant improvement in the appearance of the welded joint and the weld depth was significantly improved as well. This is attributed to the use of the magnetic field. Furthermore, the microstructure was observed to show a lath martensite at the arc zone and laser zone as well. More so, the grains were refined at the arc zone and the effect of the alternating magnetic field was felt with the evidence of increased high ratio of mis-orientation [34].

To overcome the problem of porosity, coarse grains as well as inadequate mechanical properties of aluminium alloy welded joints, ultrasonic vibration was used during the laser assisted MIG welding. The results showed that increases in the power of ultrasonic vibration resulted to reduction in the porosity of the welded joint and resulted into refinement in the microstructure of the joint. Additionally, ultrasonic vibration was established to improve the strength as well as homogeneity in the microhardness of the welded joint [35].

Li et al. [36] investigated effect of repair welding on the microstructural and mechanical behavior of a welded joint using MIG welding technique. The results revealed different microstructures in different regions of the weld which can be attributed the production process. Equiaxed grain size characteristics as well as long grain characteristics were observed at the AT5 and AT4 zones respectively. Also, the microstructure of the AT5 region showed no obvious change after welding process. Also, the welded zone was observed to display cast dendritic structure. More so, the elongated grain displayed by AT4 can be attributed to the rolling process during production [37].

4. Comparative Performance of TIG and MIG Welding Processes

Inconel 617 is a superalloy with adequate strength and carbide hardened nickel used in elevated temperature application areas in power plants. This is due to its excellent stability, strength and high-temperature as well as corrosion resistance. It is widely deployed in the fabrication of the major tubes in boiler plants such as superheater and the reheater tubes. The traditional fusion welding methods is what is usually applied in the joining of these large section tubes in the boiler plants [38].

However, they associated with several problems which include distortion of components, excessive consumption of filler materials as well as high stress induction during the process. In addition to this, during the welding of Nickel based alloy, there is possibility of weld imperfections and defects using this conventional fusion method and these associated failures are generally difficult to control for thick section welding due to susceptibility of cracking [38].

Deploying of several methods to improve the traditional fusion welding process have been done especially in the welding of thick-sectioned superalloy materials. For instance, reduction of input heat during dip arc welding showed significant improvement in the production time as compared to the conventional fusion welding. In the case of nickel and cobalt, localized failure is always associated with the fusion zone under the solidification grain boundaries [39]. Recently, laser-based welding techniques have gained a tremendous importance over the traditional welding techniques for thick-sections. This is due to their capacity in producing quality welds having deeper penetrations and minimum residual stress, narrow weld bead and heat affected zone as well. Thus, Aqeel et al. [38] did a comparison of the welding performance of laser-TIG welding and laser-MIG welding process of Inconel 617 which is of 10 mm thick. The result revealed that the weld produced by the MIG and TIG

welding showed a wine-cup and shaped structure respectively with reduction in fusion and heat affected zone.

In the study of Wu et al. [40], it was established that TIG-MIG hybrid welding produces excellent weld formation compared to the conventional MIG welding at an increased welding speed. Thus, the study focused on improving the adaptive source of heat as well as arc pressure of TIG-MIG using the flat surface distribution. Also, 3-D transient model was utilized to model the heat and mass transfer in order to analyze the welding parameters of the TIG-MIG welding process at high speed. The quantitative relationship between the process matters, molten pool behavior as well as the weld beam formation were simulated under TIG current, speed and distance between electrons [41].

Ding et al. [42] deployed the TIG-MIG hybrid welding process to join the ferritic stainless steel and magnesium alloy together. The melted magnesium weldment wets the ferritic steel to form a brazed magnesium-copper. The result showed that the microstructure the welded joint was strengthened with evidence of refined and smooth grains. Ye et al. (2017) established weld appearance and presence of interfacial compounds on welds are associated with aluminium and steel butt joint. Also, a comparison between the TIG-MIG welding and the traditional MIG welding revealed a refined appearance in the joint of the produced microstructure [43].

5.0 Conclusion.

In the present study, microstructural evolution and the strengthening mechanisms of tungsten inert gas and metal inert gas weld joint of metals/alloys was carried out. Comparative review on their microstructure and mechanical properties of TIG-MIG welding processes was carried out by studying the optimal parameters needed in enhancing the structural integrity of the welded joints. From the study, the following conclusions can be drawn:

- (i) It was established in literature study that TIG-MIG weld joints usually have excellent tensile properties when compared standalone TIG or MIG weld joints
- (ii) Also, TIG-MIG joints usually demonstrate ductile fracture compared with standalone MIG or TIG welded joints.
- (iii) In the case of the joints formed using the three methods that is TIG, MIG and TIG-MIG, full penetration is always possible
- (iv) In terms of the HAZ, the width is larger than the heat affected zone of the TIG and MIG

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