Tungsten inert gas (TIG) and metal inert gas (MIG) welding applications - critical review

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Abstract. The review focused on the applications of tungsten inert gas a (TIG) metal inert gas (MIG) welding processes. Each of the welding process was critical studied to understand the operations and the need to maintain safety and reliable weld with adequate mechanical properties. In addition, the various applications in the aerospace, aeronautic, automotive and food packaging industries were critically highlighted. However, there potentials as well as problems highlighted have been critically reviewed and reported especially porosity which usually result into hole defects at the weld joint as well as plastic deformation due to the frictional heat induced have been reported in this study. Furthermore, the study further recommended friction stir processes integrated with TIG/MIG welding as an alternative method that will solve the problems associated with fatigue behaviour of welded joint. Thus, the study provided potential information to all stakeholders especially the professional welders on the need-to-know which method is applicable to aluminium alloy welding

1 Introduction

1.1 Tungsten inert gas (TIG) welding

TIG or tungsten inert gas welding is a welding technique that involved the use of non-consumable tungsten electrode to develop the weld. It is an arc welding process where the weld portion are protected from atmospheric contaminants using a shielding gas known as helium. The use of helium as an inert gas made the welding to be referred to heliarc welding in most literature. The process involves constant supply of power to obtain electrical energy and this energy passes through the arc via series of ionized gas and metal known to plasma. the welding process is mostly applied in non-ferrous metal such as magnesium, aluminium and copper.

Also, it used in welding stainless steel material. This welding process has a greater advantage over shield metal arc welding and gas metal arc welding because it gives the

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opportunity to ability to control the welding process. Thus, quality and stronger welds are always achieved using this method. However, a limiting factor to this weld is the complexity in understanding of the process and it appeared to be slower compared to the other welding process [1].

Another limitation is that the manual tungsten inert arc welding technique is difficult due to the adequate concentration required by the operator. It requires the use of both hands compared to most welding process where the welder manually engage the filler metal with one hand and use the other hand to handle the weld torch [2]. Thus, maintaining the minimum arc length as well as prevention of contact between workpiece and electrode is quite cumbersome and causes unsafe practices. In addition, striking of the welding arc will require a frequency generator to provide adequate electric spark, which is conducted for the current via the shielding gas and cause arc to be initiated, thereby, causing the separation of the electrode and the workpiece. The operator (welder) moves the welding torch in a circular pattern to form a pool of weld after striking the arc. This off course depends on the electrode required current and size of electrode. Furthermore, the welder maintains a constant separation between the workpiece and the electrode and the torch is moved again backward in a range of 10-25 degrees vertically and filler metal is further applied to the end of the weld pool as required. Filler rods are always withdrawn from the weld pool at the instance of the advancement of the electrodes; however, it must be maintained inside the gas shield to avoid the rusting of surface due to the weld [4].

An important safety factor to consider during this welding process is that welders must maintain adequate distance from the arc while in the gas shield especially in aluminium. This because filler rods have low melting point for aluminium and when it is too close to the arc, there is possibility of its melting before the actual contact is made with the weld. More so, it is important that the arc current is reduced as it approaches completion to allow the weld crater sodify and reduce cracks at the end of the process [3].

Safety is of paramount importance during this welding process and this involve the use of protective clothing which involve thin and light leather gloves and sleeve with collars to avoid exposure to the harmful ultraviolet rays. This is because smoke is absent during the welding process and the electric arc light is not protected by fumes compared to that of shield metal arc welding. Thus, causing operators to be exposed to the ultraviolet lights [4].

The potential arc light causes damages to the eyes and the skin. Hence, dark glasses are required to prevent the ultraviolet rays. In addition, welders are prone to noxious gases and particles during the process because of the brightness of the arc, which form nitric oxides in ozone layer. This constitutes some health issues with the lungs and other part of the body thus causing early death of welders [5]. Additionally, the heat emitted from the weld could poisonous fumes. A primary industry that makes use of TIG is the aerospace industry. It is also used in other industries especially those in non-ferrous metal production. TIG is also used in the manufacture of space vehicles and in the manufacture of bicycle parts. It is also used in the maintenance and repair of machine tools. The reason for its wide applications is traceable to its qualities such as adequate control of the weld region compared to the other welding processes, production of superior weld quality, because welds are free from oil, grease or solvents [5].

To maintain quality weld pool, shielding gas flow must be adequate and flow consistently so that the gas could cover the weld and prevent impurities from the weld. This is because in TIG welding, windy and dusty environment could result to increasing the gas shield needed in protecting the weld, thus leading to increase in the cost of the process. a major problem in TIG welding is the heat input. The quantity of heat either low or high depending on the current supplied could limit penetration and result in the shifting away of the weld bead from the weld surface. However, excessive heat input will cause the growth weld bead of width and possibility of molten metals in the form of droplets will ensue. More so, if the distance

between the welding torch and the workpiece is large, there will be inadequacies with the shielding gas, porosity will eventually ensue in the weld (formation of pinholes), and this will be weaker than the normal weld [4].

In addition to this, excessive current against the recommended for the electrode could result to particulate matter of tungsten present in the weld, which is known as tungsten spitting, and this can as well be eliminated by changing the diameter of the electrode. Another issue with the quality of weld is in the inadequate protection of the electrode by the gas shield from the molten metal. This can cause contamination as well as instability in the welding arc, which require additional cost to grind the electrode to remove the abrasive using diamond abrasive [6].

1.2 Metal inert gas (MIG) welding

Metal inert gas welding (MIG) otherwise known as gas metal arc welding is a process in which electric arc is created between the consumable MIG wire electrode and the work material that heat the workpiece to join (fusion). The shielding gas act as a protection from contamination via the welding gun. The welding process involve the supply of constant voltage and direct current supply of power. The transfer of metal in this welding process can be done in four distinct ways, which include short-circuiting, pulsed-spray, spray and globular method. They all have unique properties, advantages and disadvantages irrespective of the desired application [6].

It is also developed for the purpose of welding aluminium and other non-ferrous metals. It is also very fast in the welding of steel compared to the other types of welding process. Presently, it is one of the most welding technique applied in the industrial welding and fabrication process due to its speed, its adaptability to robotics application and versatility. In contrast to the TIG welding process, it does not involve the use of shielding gas; however, it makes use of electrode wire that is hollow and integrated with flux [7].

It is mostly applied in the sheet metal and fabrication industry as well as in the automobile industry. In this case, arc spot welding is mostly done to replace rivet or resistance spot welding. It is equally used in automated welding process such as in robotics [6]. However, it is difficult to use this process outdoors because of the fact that drafts dissipate the shielding gas and cause the contaminants to enter the weld. To avert this, flux arc welding is used for the outdoor especially in the construction industry. In addition, MIG welding is not also used in the underwater welding compared to the shield metal arc welding. In the case of MIG welding, the electrode for the welding process is in the form of a metallic alloy (MIG wire) and the choice of this electrode would depend on the chemical composition of the metal to be welded, variation in the process design of the joint and the surface condition of the material. Thus, selection of the electrode greatly influences the mechanical properties of the weld material and quality [8]. However, quality weld using this material should be free from contaminants, porosity and discontinuities. Thus, electrodes containing small quantity of manganese, titanium, aluminium and silicon will be the best to avoid porosity due to oxygen presence. Based on variation in the process and base material undergoing welding, the electrode diameter used in this welding must range from 0.7 to2.4 mm and sometimes 4 mm [7].

In the case of quality, there is need to control defects resulting from the presence of dross and porosity in the weld. This can cause weak and ductility in the welded material. For instance, dross is mostly associated with aluminium because of the presence of aluminium oxide or nitride in the electrode or base material. Hence, to avert these problems, continuous brushing and chemical treatment is recommended for the electrode and work material to remove the oxide present during the weld [9].

The main cause of porosity is traceable to the entrapment of gas in the weld pool and this occur during metal solidification before the escape of gas. However, the gas comes from the impurities present in the shield as well as the workpiece [8]. The quantity of gas entrapped is directly proportional to the rate of cooling of the weld pool. More so, it is worthy of note to say that aluminium has high thermal conductivity and this make the aluminium weld susceptible higher cooling rates, thus, possibility of increased porosity sets in. however, this can be controlled by adequate cleaning of the workpiece and electrode during the weld process. Also, preheating can control the cooling rate through temperature reduction between the area to be welded and base metal as well [10].

In comparison, tungsten inert gas welding has high versatility, thus, making industry professionals to have several materials joined together. It helps in the heating of a non-consumable tungsten electrode with or without a filler metal. However, it is slower in speed compared to MIG and thus, result in increased lead-time and high cost of production. In addition, operators will need special training to achieve adequate precision and accuracy. Although, control of the welding process can be achieved in this process which will produce precise and strong weld. In most cases, it provides good aesthetic weld [11].

However, metal inert gas welding process is generally deployed into thick and large materials and the consumable wire act as both filler material and electrode. In comparison to TIG welding process, it is much faster and results in minimal lead times and reduced cost of production. In addition to this, it much easier to learn and understand as well as producing weld with less cleaning compared to TIG welding process. However, in terms of quality of weld, the weld is not as strong and clean like the TIG welding process. Figure 1 and Figure 2 illustrates the tungsten inert and metal inert gas welding processes.

Conclusively, aluminium welding is quite difficult compared to welding of steel. Reason be that, aluminium does not behave like steel. For instance, steel will give response during the welding process and one can judge by what you see, however, in the case of aluminium, judgement and experience are the factors to consider in this process [7]. The understanding is that aluminium form oxide layer on its surface, which need adequate cleaning before welding. The oxide layer has a melting point of about 3700 F; however, the real aluminium beneath the oxide layer will melt at 1200 F. Thus, there is need-increased heat to melt the oxide layer and must be careful as well not to burn the aluminium layer as well. Thus, to solve this problem, it is important to deploy AC TIG since there is alternation of the current from positive to negative in the electrode.

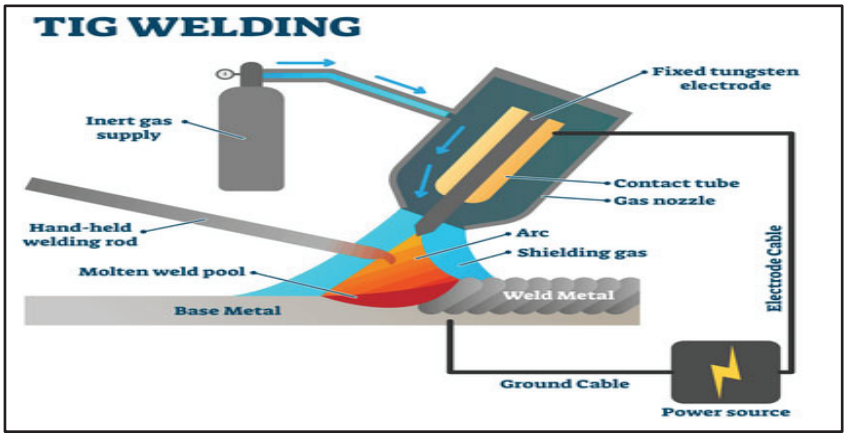

Fig. 1. TIG welding (Source: Wu *et al*., [11]).

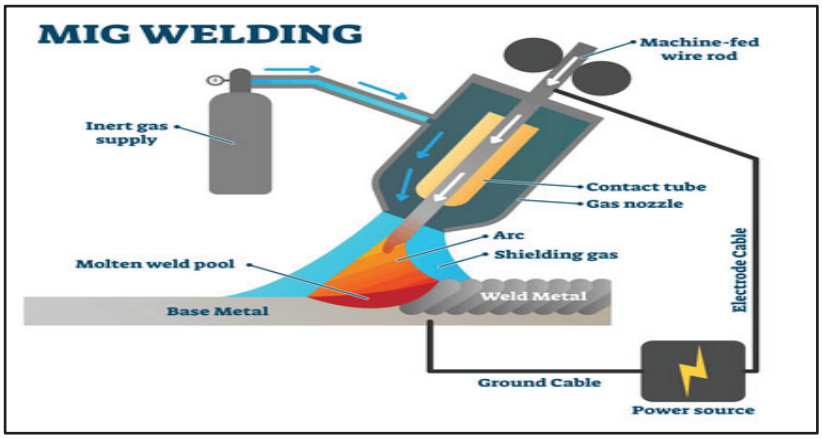

Fig. 2. MIG welding (Source: Wu et al., [11]).

2 Tungsten inert gas welding (TIG) of aluminium

Friction stir welding is suitable in the welding of aluminium metal because of its ability to prevent the solidification defect, which exist in the normal traditional fusion welding. This kind of welding provides excellent mechanical properties [7]. However, it is associated with defects such as micropores, which form at the joint of the weld. This problem is traceable to the low heat involved in friction stir welding and the high thermal conductivity of aluminium. Thus, plastic flow will result due to the low heat input, which is the reason behind the formation of holes as a defect. A great implication of the hole defect is that it represents a region for crack initiation, thus, it is important to eliminate this whole defect in order to improve the mechanical behaviour joints obtained via friction stir welding process [8]. To this end, two dissimilar joints of 2.5 mm thickness of aluminium alloy was produced via friction stir welding and TIG techniques. The result of tensile test showed an improved tensile strength with an increase 16.9% and an increase in the elongation of about 209.1% respectively. This is traceable to the introduction of the TIG arc assisted welding technique. Additionally, the result equally showed that the hole defect which usually form at the joints in conventional welding processes was eliminated and higher density of finer precipitates were formed, this constitutes the improvement in the mechanical properties [12] Magesh et al. [13] established that friction and mechanical actions processes combined to bring about plastic deformation during welding of metals and non-metals. Friction stir welding process play a major role here as it is characterized with qualities such as smooth microstructure, residual stressed induced in the weld and minimal porosity as well as less cracks on the weldment. Recently, aluminium-welding using the friction stir welding process is gaining increasing interest. This is due to the wide application of aluminium in aerospace and automotive industries. However, a major problem is the fact that in the manufacturing of cars, aluminium has not fully gained the necessary relevance and this is associated with the problem of fusion in aluminium especially in the joining of laminates [11].

Thus, Magesh et al. [13] deployed an automated approach of TIG in welding of aluminium in order to improve the quality and strength of weld in terms of width and depth of weld penetration. The study ensured certain control parameters such as speed of weld and arc length. The procedure of TIG welding involves the maintenance of the electric arc and the non-consumable tungsten as well as the workpiece. The study further examined the tensile, fracture, hardness and microstructural properties of the aluminium AA5059 alloy. The result showed that there was about 30% loss in tensile test as the base metal was 385

Mpa and the welded has 268 Mpa. Also, it was observed that there was crack at the weld due to the excessive heat of weld as shown in Figure 3. The study provided a potential information in the successful TIG welding of AA5059 aluminium alloy. It showed that that input parameters such as current, speed and gas flow rate provided the necessary improvement in the mechanical properties [13].

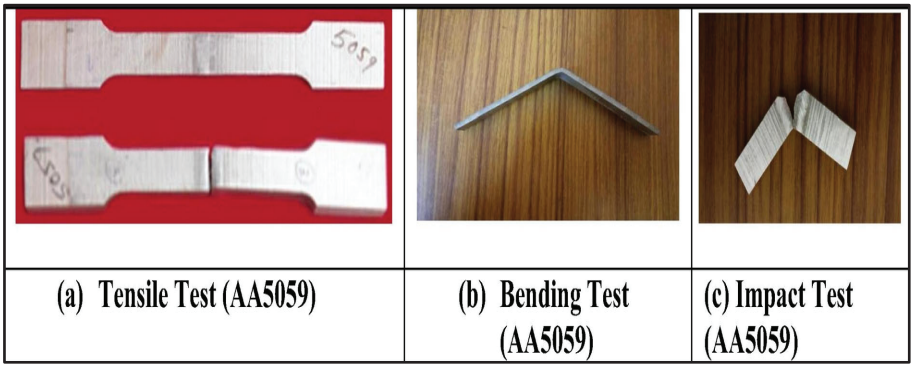

Fig. 3. image of optimized Samples. (Source: Magesh *et al*., [13])

A promising grade of aluminium alloy in the manufacture of fuel tank in aerospace industries is 2219 Al-Cu alloy. This is due to its excellent strength and weldability. TIG welding process is mostly used in the manufacturing of the rocket fuel tank because of the quality of the weld and better economy. However, there is limitation to this technique due to the initiation of tensile fracture at the partially melt zone in the weld due to uneven solidification and stress raisers at the weld region [12].

It was reported that the partially melt zone is characterized by a narrow zone outside the weld region where liquation form during weld due to the heating beyond the eutectic temperature. Thus, at this point, the partially melt zone is characterized by eutectic grain boundaries, thus there is a need to understand the content of this eutectic structures since they play a major role in the determination of the mechanical properties of the partially melt zone [10]

Based on the limitations of the alloy, Wan et al. [14] investigated the weaker region of the partially melt zone of the 2219-T8 aluminium alloy during the TIG welding process by carrying out a numerical simulation on the microstructure to examine the tensile properties of the partially melt zone. Furthermore, the study examined a constitutive characteristic and the damage behaviours of the eutectic structure as well as the aluminium matrix. In addition, the stress-strain behaviours fracture as well as the tensile properties were analysed respectively [14].

The result revealed that there exist a maximum region and clusters of eutectic particles on the weld joint. Additionally, these have significant effect elongation as well as the tensile strength. However, plastic strain dominates the matrix and there was concentration of stress at large eutectic structure [12]. More so, there was tensile cracks, which initiate into the eutectic structure, these cracks propagate into larger cracks, and this caused the eventual fracture of the eutectic structure.

Figure 4 showed the various properties of the aluminium alloy during the welding process.

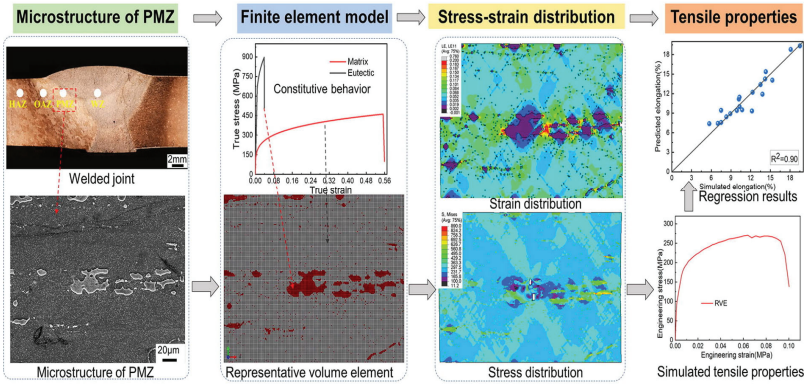

Fig. 4. Properties of 2219-T8 during TIG welding process (Source: Wan *et al*., [14]).

A study by Lu et al. [15] reported that aluminium 7055 alloy developed from spray forming technology can have up to about 600 Mpa after undergoing deformation and heat treatment. In addition, the aluminium alloy is associated with properties such as ease of machinability and adequate toughness. This one great quality distinguished the alloy as a leading component in the rail transportation and aerospace industries. However, in their welded form, the alloy is susceptible to failures such as stress corrosion and thermal fatigue cracking. Thus, defects need to be identified and restored. Additionally, multiple passes must be done during the welding process of the 7055 aluminium alloy (sprayed form) causing series of heat-affected zone (HAZ) in the alloy [13]. Also, it is understood that the HAZ is the weak region in the 7055 aluminium alloy welded joints and this traceable to the possibility of over-aging condition of softening. In the same vein, HAZ is usually affected by the secondary thermal cycle. Thus, it is important to monitor and understand the law guiding microstructural evolution and performance of HAZ when in the secondary thermal cycle to understand what actually transcend at HAZ. To this end, Lu et al. (2022) investigated the heat-affected zones of some samples subjected to single and secondary thermal cycle and this was simulated via heat treatment method. The study focused on the effect of the secondary thermal cycle softening action and the dynamics of HAZ during the TIG welded spray formed 7055 aluminium alloy [15].

The result revealed a reduction in the mechanical properties of solid solution region after the secondary thermal cycle. For instance, there was sharp decrease in the microhardness ranging from 180-to103 HV as well as the tensile strength reducing from 570 to 346 at the end of the second thermal cycle. The reason for these reductions can be attributed to the weakness in the solid solution after the second thermal cycle. However, with increase in the temperature of the thermal cycle, there was a corresponding increment in the mechanical properties at the over aging zone. At the end, there was increase in the HAZ at the end of the secondary thermal cycle [17].

Non-uniformity in temperature distribution is associated with 2219-T8 aluminium alloy. Thus, Wang et al. [16] investigated the tensile properties of two dissimilar aluminium alloy of grade 2219-T8 by considering their residual stress, size of specimen and fracture criteria using finite element approach. The results revealed that there was variation in the residual stress-releasing rate as this was observed to decrease with increased sample width [16]. In addition to this, the tensile test result revealed that the tensile strength and the elongation reduces with increasing specimen width. Thus, the variation in the tensile strength result is attributed to size distribution other than the stress releasing. Although, this understanding was obtained from Johnson-Cook fracture criterion. Thus, the study established the constitutive model for the aluminium alloy using the fracture criterion [16].

Despite the excellent the excellent weldability of 2219 aluminium alloy, it suffers from strength reduction at the joint and the weld zone at large, which always display weakness at the joint. These losses in strength at the joint is associated with segregation of the elements in the alloy, formation of coarse grains in the process of welding and dissolution of the precipitate, which supposed to strengthen the joints. This can be overcome by applying weld reinforcements are used to increase the load-bearing capacity of the joint [11].

Based on this recommendation, Wan et al. [17] restricted the tensile properties and joints of 2219-T8 aluminium alloy during TIG welding using the partially melted zone and stress concentration point. The result showed an improvement in the partially melted zone due to the refinement in the grain size and the phase particles in the base material. Also, there was increment in the tensile strength from approximately 16 to 21 Mpa and this is attributed to the high content of copper and decrease level in coarse and continuous eutectic. Additionally, there was increase in the tensile strength of approximately 318 Mpa. This occurred because of improvement at the melting zone and adequate stress distribution [16].

Similarly, the sprayed form of 7055 aluminium alloy joint is associated with low strength and high brittleness due to the conventional welding wires used in the welding of the aluminium alloy. These defects affect its widespread applications in the industry. Thus, Huang et al. (2021) investigated two different types of aluminium alloy welding wires having TiB2 and ZrB2 ceramic grains integrated into the weld joint of the aluminium alloy spray form via TIG welding process. The result revealed a microstructure, which was dominated with TiB2-7055 grains, which are equiaxed [7]. In addition, the tensile strength was observed to reach about 51.6 % of the base materials and the elongation was about 5 % showing a ductile fracture. More so, the microstructure of ZrB2-7055 joint was observed to be dominated by fine dendrites and the tensile strength which was 280 Mpa reached about 46.6 % of the base material strength and this also demonstrate s brittle fracture. Thus, these development helps in the resolution of softening and reduced plasticity associated with spray formed aluminium 7055. Lu et al. [18] investigated the softening behaviour of the spray form of 7055 aluminium alloy during TIG welding process. The result showed that the softening at the joint is attributed to the dissolution of the precipitates at the joint.

3 Metal inert gas welding (MIG) of aluminium

Light weight low-cost components are in increasing demand in the automobile industry and a promising material for this industry is the aluminium alloy because of its light weight and availability compared to other metals [17]. Also, they have good castability, high strength and corrosion resistance. However, aluminium need to be combined with other metals by joining techniques in order achieve better applications and performance. The presence of excessive hydrogen content in the die casting of aluminium, which is caused by rapid solidification during the production of aluminium via casting process, has a major consequence. This includes porosity and results in the deterioration in the mechanical properties of the aluminium alloy [11].

To resolve this problem, ultrasonic frequency pulse is introduced into the MIG welding process for the purpose of controlling the porosity of the joints via stirring and mixing thereby, increasing the tensile strength. To this end, Ye et al. [19] enhanced the joint of two dissimilar aluminium alloy joint by bonding them together using MIG welding integrated with ultrasonic frequency pulse. The result revealed a decrease in the hydrogen porosity in the joint. Thus, there was increase in the tensile strength of the joint, which reach about 185 %. Thus, the ultrasonic frequency pulse with integrated metal inert gas welding process was utilized to bond two dissimilar aluminium alloy. This revealed good microstructures and improvement in the tensile properties. Figure 5 showed the morphologies and the metallographic images of the UFC-MIG welded joints.

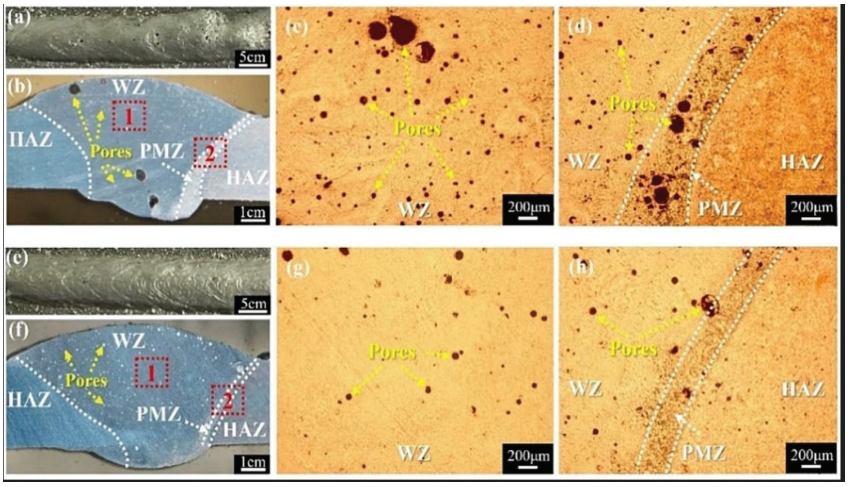

Fig. 5. Morphologies and metallographic image of Ultrasonic frequency pulse-Metal inert gas welding (UFC-MIG) (Source: Ye *et al*., [19]).

Furthermore, a major reason why aluminium is desired in the automobile manufacturing is in the energy savings and low emission due to its lightweight when compared to steel especially in the manufacture of the car body [18]. Thus, excellent and superior performance of aluminium alloy have increased its trend of application in the automotive industry. However, there are major limitation that have posed to be a challenge in the joining of aluminium and these include variation in thermal properties of dissimilar materials, low solubility and generation of brittle compounds.

To this end, Wan et al. [14] proposed a novel MIG welding and brazing process of aluminium and steel by integrating external magnetic field. This was done to enhance the arc and the droplet to move along the welding direction with an alternative electromagnetic force, which is perpendicular to the force of welding. The result showed that there was improvement in the spreadability of the molten alloy, which was occasioned by the increased current level. There was also an enhancement in the tensile strength of the weld joint because of the spreadability of the molten metal under the action of EMF. In the study of Arunakumara et al. [20], it was established that aluminium 6000 series are used several industries due to its excellent corrosion resistance, weldability and relative low cost. The use of conventional fusion welding process causes porosity, penetration of slag as well as incomplete integration of the aluminium alloy. Thus, MIG welding process is the best for the fusion welding since it will protect the joint from the impurities resulting from the welding process. Thus, the study compared the microstructural evolution and the fatigue properties of two dissimilar aluminium alloy Al 6061 T-6 and Al 6082 T-6 bonded together using MIG and friction welding processes [12]. The study examined the tensile strength of both alloys that depends on the process parameters selected during the welding process. The result showed that the MIG welding process gave a better yield compared to the friction stir welding.

It has been established that the geometry of the weld bead serves as an important factor that determines the strength, mechanical properties and performance aluminium alloy produced by metal inert gas welding especially in today's fabrication industry. Based on this assertion, Sharma et al. [21] predicted the weld bead geometry via parameter optimization in other to provide weld of high reliability.

Mathematical relationship linking the input parameters like feed rate of the wire, speed, voltage torch angle depth of penetration width of weld as well as reinforcement height was developed. The study further deployed statistical approach like central composite design and

analyses of variance as well as response surface methodology for the analyses. It was observed that the weld bead geometry influenced the mechanical properties as well as quality of the weld joint [20]. The result also indicated that the bead geometry is a function of input parameter and this parameter can be obtained from the optimal combination of the input parameters. In the case of joining aluminium and magnesium alloys, which are commonly deployed in the automotive and aerospace industries due to their lightweights and ease of casting and workability, is a complex one. The reason being that the reaction between aluminium and magnesium bring about the formation of intermetallic compounds that deteriorate the mechanical properties at the joint [21]. Friction stir welding and laser welding processes may have been used several times to join these alloys; however, these methods involve procedures, which are quite complex and expensive as well. Thus, the problem remains how to control the formation of the brittle intermetallic compound during the joining of the alloys.

Thus, Zhang and Song [22] performed MIG welding of aluminium and magnesium in the form of lap joint which is 1 mm thick using zinc foil as an interlayer material which also acted as a barrier which is capable of restraining the reaction between the alloys [23]. The result showed that the obtained lap joint was crack free while the interfacial region was composed of magnesium-zinc. The tensile strength was observed to be 64 Mpa; however, fracture was noticed at the interface of the fusion and unmelted magnesium alloy zone [24].

4 Conclusion

A critical review of tungsten inert gas (TIG) and metal inert gas (MIG) welding processes have been carried out. From the study, it was established that both welding processes have been widely deployed in the aerospace, automotive and other food production industries in the manufacturing of aluminium alloy. This is due to its lightweight castability, weldability and formability and corrosion resistance of aluminium. However, the review also established that the welding techniques are faced with several problems such as lack of wetting, reduction in strength, crack formation at the joint, porosity and formation of residual and fatigue stress at the joint. In addition, it has been established in the study that amongst several techniques adopted to increase the fatigue behaviour of the welding processes, friction stir welding have proven very effective especially in the MIG welding process. In both welding process, non-consumable tool is used to penetrate through the material and this cause frictional heat induction and eventual plastic deformation, thus, recrystallized and refined microstructures are created, hence, the objective of the friction stir process is to improve the mechanical properties of the microstructures. Friction stir welding assisted with TIG/MIG welding processes have proven successful in the refinement of microstructures as well as in the improvement of mechanical properties.

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