TIG & MIG Hybrid Welded Steel Joint: A Review

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Abstract

The objective of this article is to review the TIG/MIG welding technology and its application in improving the microstructural, mechanical and metallurgical properties of engineering materials. It is shown that the TIG/MIG hybrid process is very effective in improving the mechanical and metallurgical properties of welded structures compared to independent welding processes. Combining the positive properties of individual welding process in the same weld pool is a novel technology. However, more studies reveal that Hybrid MIG-TIG process has not been extensively researched despite its promising benefits. The optimization of its process parameter is not fully understood. Its processes and applications are still limited. Most studies either focus on experimental investigation limited to the geometric properties like tensile and hardness properties. The TIG/MIG hybrid welding method has not been used to solve fatigue and its related problems of steel components in the structural industries. Just a few numerical analyses are done. Extensive work has not been done on the mechanical, metallurgical and corrosion properties of the hybrid. Information on the thermal behaviours and temperature distribution is also lacking. Hence, there is a need to research the TIG/MIG hybrid welds and perform numerical modelling to validate the results using experimental data.

Keywords: Hybrid Welds, TIG/MIG Welding Process, Stainless Steel

1.0 Experimental method and procedure

Welding is one of the oldest and most common joining techniques for metallic structure. It is a general term used to describe a wide variety of bonding techniques. The American Welding Society (AWS) defines welding as a material joining process used in making welds. A weld is defined as a "localized coalescence of metals or non-metals produced by heating the materials to their melting temperatures, with or without the application of pressure, and /or filler materials" (Jain 2008). Welding technology is categories into two broad types. The solid-state welding and fusion welding (Jain 2008). In recent times, metals have been welded by the combination of more than one welding process, generally referred to as a hybrid welding process. Among other hybrid processes, Tungsten Inert Gas and Metal Inert Gas (TIG/MIG) hybrid welding process is a novel welding technique. TIG/MIG hybrid welding is the welding of metals by the combination of the TIG and the MIG arc welding process in a single weld seam. This is done by setting a leading a TIG arc while the MIG arc is trailing (called TIG/MIG hybrid) or by a leading MIG arc while the TIG arc is trailing (called MIG/TIG hybrid).

1.1 Experimental method and procedure

Solid-state welding is the joining of materials achieved by the application of pressure or by the combined effect of heat and pressure. In case where heat is required in this form of welding, the heating temperature is usually set below the melting temperatures of the materials to be joint. Solid-state welding processes include Friction Stir Welding (FSW), Explosive Welding (EW), Friction Welding (FW), and Diffusion Welding (DW). Solid-state welding processes produce joints that are free from solidification defects as often the case with fusion welding processes (Guo 2014). Solid-state welding processes are efficient in joining dissimilar materials and do not require shielding gases, filler metal addition and flux.

1.2 Experimental method and procedure

Fusion welding requires the application of heat for coalescence to take place. The metals to be joint are heated to their melting temperatures and then allowed to solidify producing a strong joint. Often, a filler metal is added to the weld pool to increase the strength of the joint. Inert gas is used to protect the molten pool. Fusion welding is further sub-divided into three categories (Kumanan et al. 2007).

- **Oxyfuel Gas Welding:** In this form of welding, oxyfuel gas is used to produce flame to melt the materials. This form of welding includes Oxyacetylene Welding (OAW), Oxyfuel Gas Welding (OFGW), and Pressure Gas Welding (PGW).
- **Arc Welding** An electric arc is employed in these welding processes. These include Shielded Metal Arc Welding (SMAW), Submerged Arc Welding (SAW), Tungsten Arc Welding (GTAW), Gas Metal Arc Welding (GMAW) also called Metal Inert Gas Welding (MIG) welding, Gas Plasma Arc Welding (PAW), and Stud Welding.
- **Resistance Welding:** In resistance welding, a strong electric current is conducted through the metal plates over a limited area, which causes localised heating to plastic state; the weld is then completed by the application of pressure for a given period of time (Jain 2008).
  Other types of fusion welding are electronic beam welding (EBW), and laser beam welding (LBW).

Fusion welding has many benefits; it requires simple equipment components, which are quite affordable and available. A wide range of material types and thickness can be welded with the fusion welding process. It also has some disadvantages, which are majorly related to the heating and the cooling process. These include porosity of welds, slack inclusion, undercut, and hot cracking, which in turn weakens of the mechanical properties such as the tensile strength, the fatigue strength and the ductility of the welded joint. This process also puts a limitation to variety of metal combinations due to the differences in the melting temperature, coefficient of expansion and conductivity of the different metals to be joint.
Among the arc welding process of the fusion welding technique, Tungsten Arc Welding (GTAW), Gas Metal Arc Welding (GMAW) also called Metal Inert Gas Welding (MIG) welding, have gained great assistance and applications in many industries such as marine, aerospace, automobile, construction and a lot more due to their excellent capabilities and mechanical properties of the finished welds.

2.0 Tungsten Insert Gas Welding

Tungsten inert gas (TIG) welding is an arc welding technique where coalescence is produced by the application of heat (Khotiyan and Kumar 2014) [4]. The TIG welding schematics in given in Figure 1.

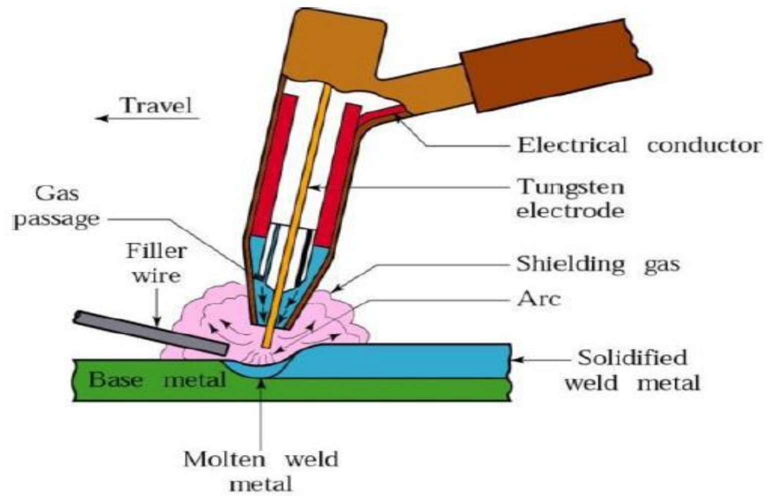

Figure 1: The TIG welding Process (Kumar and Mharathi 2015)

In this process, an electric arc is being maintained between a fixed non-consumable tungsten electrode and the workpiece (metal) being welded. The ignited electric arc produces the required heat to melt the metals. Usually, shielding gas is fed through the torch to protect the weld pool and the hot tungsten from atmospheric contamination. A separate filler rod can be fed into the arc stream where filler metals are necessary. The fact that no flux is required in tungsten inert gas welding gives it an advantage over other types of welding as it produces clean weld joints, free of voids. Tungsten Inert Gas has thus become one of the most extensively used techniques for joining ferrous and nonferrous metals (Susmitha et al. 2016).

TIG welding technique offers numerous advantages like, joining a wide range of metals, joining of dissimilar metals, the possibility of joining metals with thinner diameter up to 0.5 mm thickness, narrower HAZ (heat affected zone), absence of slag higher quality welds the possibility of controlling the welding current as low as possible so that the welds are not damaged during the welding process among others (Susmitha et al. 2016). Arivazhagan et al. (2011), reported welds void of cracks, which exhibited good compact toughness and high hardness value. Mishra et al. (2014), reported better mechanical properties of TIG-welded joint as compared to MIG welds. However, the TIG welding process has the disadvantages of shallow penetration and low productivity.

On the other hand, Metal Inert Gas (MIG) Welding, generally called Gas Metal Arc Welding (GMAW) was developed in the 1940s (Bahman and Alialhosseini 2010). It is an arc welding method of joining metals by heating them with an electric arc between a continuously fed wire electrodes, shielding gas is employed to shield the molten weld pool from environmental contamination. The shielding gas is fed continuously throughout the welding process through a welding gun (Jeffus 1997). Several metals and alloys can be MIG welded, these include; Aluminium, Stainless Steel, Magnesium, Nickel, Carbon Steel, Silicon, Bronze, Copper and tubular metal-cored surfacing alloys. MIG welding process variables are welding current, welding voltage, travel speed, type of shielding gas, electrode size, electrodeposition, and electrode extension. Abbasi et al. (2012), investigated the effect of MIG Welding parameters on the weld bead shape characteristics and reported that 'increase welding speed lead to increase penetration depth up to the speed of 1450mm/min which is the optimum value to obtain maximum penetration, beyond which the penetration decreases'. Mishra et al. (2014), stated that current and voltage parameters for MIG welding process are the major process parameters affecting the weld characteristics and that the penetration of the weld is directly proportional to the welding current.

This welding method is widely used in many engineering applications owing to its numerous advantages such as good and high-quality welds (Nadzam 1997); (Anders 2003), (Khanna and Maheshwari 2016) high production and deposition rate, spatter free welds with exceptional physical and metallurgical characteristics, the ability to weld dissimilar metals, the capability to weld a wide range of metal thickness, ability to weld varieties of materials, high-quality welds, less operator requirement skills, ease of all position welding, it guarantees higher electrode efficiency.

Beautiful weld bead appearance. It has been labelled as a multi-factor and a multi-objective technique (Srivastava 2010), (Sonasale 2014). According to Arun and Ramachandran (2015) the joint of AA6061 plates in lap joint configuration produced by GMAW welding process had superior mechanical properties when compared to GTAW and FWS joints. MIG welding process has virtually replaced the Shielded Metal Arc Welding (SMAW) and the Gas Tungsten Arc Welding (GTAW or TIG) in many industrial applications. MIG welding is mostly used in automotive, construction and high production manufacturing industries to repair cars, to assemble parts, in pipes welding and a lot more. MIG welding produces very strong joints, even for a very tiny piece of metals. Aluminium and steel are commonly welded using MIG welding (Shah et al. 2013), (Shakhashir 2008). The MIG process is shown in Figure 2.

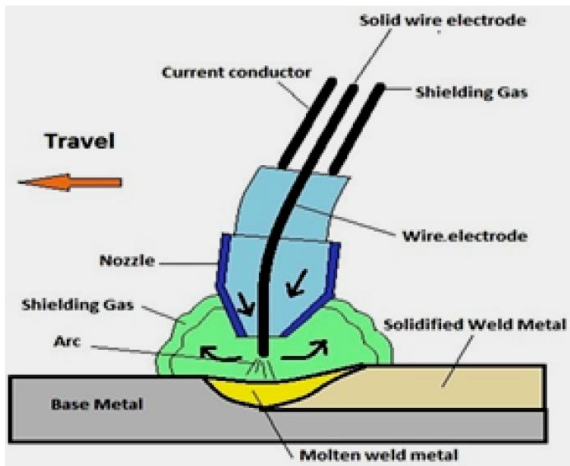

Figure 2: The MIG welding Process (Chavda et al. 2014**)**

Despite the numerous advantages of the MIG welding process, it is not without mini drawbacks. The short-circuiting mode of metal transfer is of low heat input characteristics, limiting its use to thin materials. The axial spray mode of transfers heat at a higher rate, limiting its use to thicker materials, flat or horizontal welding positions.

3.0 Tungsten Insert Gas Welding

Hybrid welding is a field in welding technology in which several welding procedures are combined to operate in one weld bead (Schneider et al. 2017). Hybrid welding was invented in the late 1970s (Steen et al. 1978), (Steen 1980) with the combination of a high power laser and an electric arc either with MIG or TIG welding. The need for greater capacity energy source, which will invariably increase productivity, give rise to the introduction and practice of hybrid welding (Messler 2004). An attempt is being made to combine the positive properties of different welding processes in a way that the synergy effect takes place and can be taken advantage of. Many combinations of welding processes have been employed since the introduction of hybrid welding technology. Corresponding technology developments are motivated by the enhanced capability of the combined process, compensating the respective disadvantages encountered by the different welding processes is a major reason for the development of the hybrid technique (Emmelmann et al. 2011), by the fact that the other welding process can compensate deficiencies of the individual welding process.

Hybrid welding processes are demonstrating more effective in improving the weld quality, with increased welding speed, as these processes combine the merits of the various heat sources employed. Hybrid welding processes such as Laser-TIG (Moradi et al. 2014), (Lui et al. 2006), (Zhang and Kong 2012), Laser–MIG (Yan et al. 2014). TIG-MIG (Miao 2015), (Meng 2014), FSW-MIG hybrid welding, tandem-GMAW, tandem-TIG welding, and other combinations have been in increase, in the pursuit of better weld quality, improved microstructural and mechanical properties and better service performance. Hybrid welding processes seeks to eliminate the defects faced with single welding process and comes along with its own unique benefits such as the ability to weld highly reflective metals, the capacity to bridge fairly large gaps and the enhancement of arc stability (Moradi et al. 2014), narrower HAZ with stable welding velocity of about 4 m/mm.

4.0 Tungsten Insert Gas Welding

MIG and TIG hybrid technique is a novel approach of improving the welding output and quality owing to the merit of the two methods. High welding speed and high quality can be achieved due to stable cathode spots. The combination of the MIG and TIG arc produces the desired joint property on the workpiece. The schematics of the welding process is shown in Figure 3.

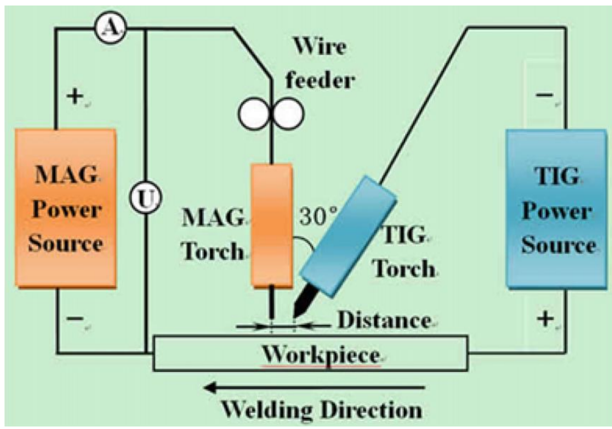

Figure 3The MIG welding Process (Zhou et al. 2017)

Meng et al. (2014), discovered that the tensile strength and microhardness of the MIG-TIG process were higher than those of the traditional MIG and TIG process carried out independently. The HAZ of the hybrid process was also seen to be narrower. They also reported that productivity could be increased by the TIG-MIG hybrid welding compared to conventional welding processes, because it increases the depth of penetration of the weld, increases the speed of welding and is capable of controlling the width of the heat-affected zone largely. Dykhno and Davis (2017) also observed this**.**

Ismail et al. (2017), [35] conducted an experiment to analyze the mechanical integrity of TIG-MIG hybrid welding of 304 stainless steel and mild steel. For the hybrid process, half the circular specimen was welded with TIG and the remaining half was welded with MIG. The properties considered for the analyses were percentage reduction, percentage elongation, tensile and yield strength. The outcome of the experiment was compared with those of TIG and MIG welded joint respectively. The results revealed that the TIG-MIG hybrid method proved to be a prospective alternative for TIG and MIG methods. In addition, on most occasion, for the set parameters, the hybrid process was found to result in better mechanical properties.

Li, et al. (2010) studied the impact of hybrid welding on the welding speed, MIG welding was merged with a fibre laser, and they observed that the fibre laser-metal inert gas hybrid welding was approximately seven times more efficient than the conventional MIG welding process. TIG-MIG hybrid welding has been used to eliminate the production of spatter, which is a major problem associated with MIG arc ignition. This is indeed a unique arc ignition method of welding.

According to Tang et al. (2018), in TIG-MIG hybrid process of 304 stainless steel, the first ignited TIG arc (with Direct Current Electrode Negative, (DCEN)) enabled the trailing performed MIG welding (with Direct Current Electrode Positive (DCEP)) to realize a non-contact arc ignition between the MIG wire end and the surface of the work piece, no spatter was produce during the ignition-to-stabilization process of the MIG arc.

Chen et al. (2017), investigated the influence of low current auxiliary TIG arc on high-speed TIG-MIG hybrid welding. The hybrid welds were compared with the conventional MIG welds, results showed a destabilized MIG arc by a trailing TIG arc, which then stabilizes by a leading TIG arc. The hybrid process causes a decentralization of the MIG arc force and reduces the impingement of molten droplet, this is seen to be true irrespective of the TIG arc leading or trailing. They observed a slower backward fluid flow in the hybrid process, which was of great advantage, as it impeded the accumulation of high-temperature filler metals at the end of the weld pool, and provided more time for the molten metal to fill the weld toe, resulting in suppression of the undercut defect. This was not so for the MIG welding process carried out. The surface temperature gradient at the tail and middle of the hybrid weld pool was lower than that of the MIG weld pool. Microstructure analysis of TIG-MIG hybrid weld joint revealed that at a higher welding speed, they were evidence of noticeable dendrite formation with no obvious grain coarsening in the weld zone. The HAZ of the hybrid process also became narrower.

MIG-TIG DSA welding-brazing has also been used to obtain high-quality 5A06/Ti6Al4V butt joints, having brilliant front and back appearance (Zhang et al. 2018). Schneider et al. (2017), used the Taguchi method to optimize the parameters for TIG-MIG Hybrid Welding of AISI 1045 steel on the weld bead geometry. These geometric properties were analyzed using macrography. They stated that the parameters that most influenced and affected the penetration of the welds were, the wire feed speed, the voltage, the welding speed and the type of shielding gas of the MIG process, in their respective order. It was also seen that using CO_2 as the shielding gas gave the highest penetration values. The HAZ decreases as the welding speed was increased. The voltage, the type of shielding gas and the welding speed of the MIG, the gas flow rate, shielding gas and the electric current of the TIG process respectively, mostly influenced the bead width. The intensity of the electric current (TIG) and the feed velocity of the wire (MIG) had a significant influence on the bead height.

TIG–MIG hybrid welding has also been used in joining stainless steel and magnesium alloys. It has shown great displayed potentials of high productivity and low cost. The work of Ogundimu et al. (2018), also demonstrates that the MIG/TIG process can achieve high ultimate tensile strength and increase the strain-hardening effect. They compared the process with individual MIG and TIG process. The microstructures of the HAZs revealed a coarse columnar dendritic of ferrite for the MIG process and a thin fine pattern of dendritic ferrite for the TIG welded samples and equiaxed pattern for the MIG/TIG process. The microstructures of the HAZs for the three welding process are presented in Figure 4.

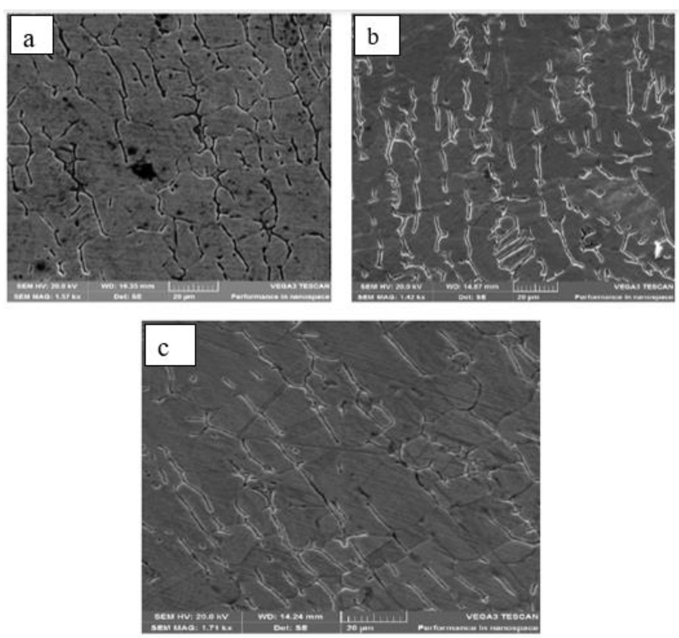

Figure 4: The Microstructure presentation of the HAZs of the MIG, TIG and hybrid TIG/MIG (Ogundimu et al. 2018)

The application of TIG–MIG hybrid welding on AZ31B Mg and 430 ferritic stainless steels with Cu interlayer of different thickness (Ding 2015), revealed excellent weld bead appearance having no pore nor spatter. MIG-TIG

double-sided arc welding–brazing has also been described as a novel technique (Zhang et al. 2018). It was used to achieve excellent weld appearance and average tensile strength of two and a half time that of the conventional MIG welded joint, and most importantly, the interfacial intermetallic compound formation was effectively controlled (Ye et al. 2017).
Zhou et al. (2017), stated that sound and uniform bead geometry of the bottom plates could be achieved without the use of backing plates for welding thinner materials by the MIG-TIG welding process. Moreover, it was observed that the tensile strength of the hybrid process was higher than that of the parent metal. They also stated that the TIG arc poses a repelling force on the MIG arc, which consequently controlled the heating position of the MIG arc, thus affecting the energy distribution of the MIG arc. During MIG-TIG double-arc hybrid process of root welding of thick plates, at optimum condition, about one-third of the arc energy generated acts on the root face, while the rest of the heat energy influences the weld pool. The lower temperature was obtained during hybrid welding, which is favourable for controlling the formation of the weld bead of the backside of the welded joint (Zhou et al. 2017),.
More research on TIG-MIG hybrid welding process (Ding et al. 2015), (Zhang et al. 2016) also revealed excellent results. To analyze the arc phenomena of the hybrid process, a numerical model was developed by Mishima et al. (2013), for the TIG-MIG hybrid welding process. They stated that the heat generated by the electric arcs could be optimized by adjusting the set angle between the welding torches of the MIG and TIG machine.

Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes as studied by Mishra, Tiwari and Rajesha (2014) welded stainless steel of grades 202, 304, 310 and 316 with mild steel. The joints dilution percentage was calculated and tensile strength of dissimilar metal joints was examined. The results were compared for different joints made by TIG and MIG welding processes and it was observed that TIG-welded dissimilar metal joints have better physical properties than MIG welded joints.

Table 1: Total dilution in TIG welded Stainless steel and mild steel samples [Mishra et al. 2014]

Test Samples	**Welded length (mm)**			**Diameter (mm)**	**Percentage Dilution**		
	Weld Zone	**in SS**	**in MS**		**of SS**	**of MS**	**in weld zone**
TS 1	13	3.0	2.0	10	23.070	15.38	38.45
TS 2	13	2.5	2.5	10	19.23	19.23	38.46
TS 3	15	3.0	4.0	10	20.00	26.60	46.60
TS 4	14	3.5	2.0	10	25.00	14.28	39.20

Table 2: Total dilution in MIG welded Stainless steel and mild steel samples [Mishra et al. 2014].

Test Samples	**Welded length (mm)**			**Diameter (mm)**	**Percentage Dilution**		
	Welded Zone	**in SS**	**in MS**		**of SS**	**of MS**	**in weld zone**
TS 1	15	4.0	2.0	10	26.60	13.33	39.90
TS 2	12	3.5	1.5	10	29.16	12.50	41.66
TS 3	16	4.0	5.0	10	26.60	13.33	39.90
TS 4	15	3.5	4.0	10	25.00	28.57	53.57

5.0 Conclusions

Review relates that Hybrid TIG/MIG process has not been extensively researched despite its promising benefits. The optimization of its process parameter is not fully understood. Its processes and applications are still limited. Most studies either focus on experimental investigation limited to the geometric properties like tensile and hardness properties. This welding method has not been used to solve fatigue and its related problems in the structural industries. Just a few numerical analysis is done. Extensive work has not been done on the mechanical, metallurgical and corrosion properties of the hybrid. Sufficient information on the thermal behaviours and temperature distribution is also lacking. Hence, there is a need to research the TIG/MIG hybrid welds and perform numerical modelling to validate the results using experimental data.

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