TIG Welding

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Research Paper

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Abstract

Tungsten Inert Gas welding is a common technique that uses arcs and non-consumable tungsten electrodes to create aesthetically befitting products. This research aims to explore the efficiency of TIG welding using the Taguchi design that focuses on input, constant, and output parameters. Furthermore, the analysis compares TIG welding and metal inert gas welding to determine which is better in terms of efficiency, time, labor, and output.

Introduction

The welding industry has for eons now reported changes in its modus operandi and techniques, with new strategies being coined to improve efficiency levels. One of the topmost welding techniques is the tungsten inert gas (TIG), also referred to as gas tungsten arc welding (GTAW). TIG welding was introduced in the 1940s by Russell Meredith to reduce the challenges faced by welders when creating aluminum and magnesium alloy welds (Weld Guru, 2022). The technique gained widespread attention due to its two-pronged nature, which uses tungsten electrodes and inert gases that shield the weld pool from contamination. A prescriptive review of the technique reveals four basic components: the power source, welding torch, inert shielding gas, and controls, as shown in Figure 1 below. The welding torch can be cooled with water or air, containing a tungsten electrode and gas nozzle (Weld Guru, 2022; Yajvinder & Das, 2018). The controls, on the other hand, allow the welder to manage the welding process manually or automatically. The welding process uses heat generated by the electric arc between the workpiece and the non-consumable tungsten electrode. The heat melts the surfaces, with the arc zone and weld pool being protected from atmospheric gases by the inert gas.

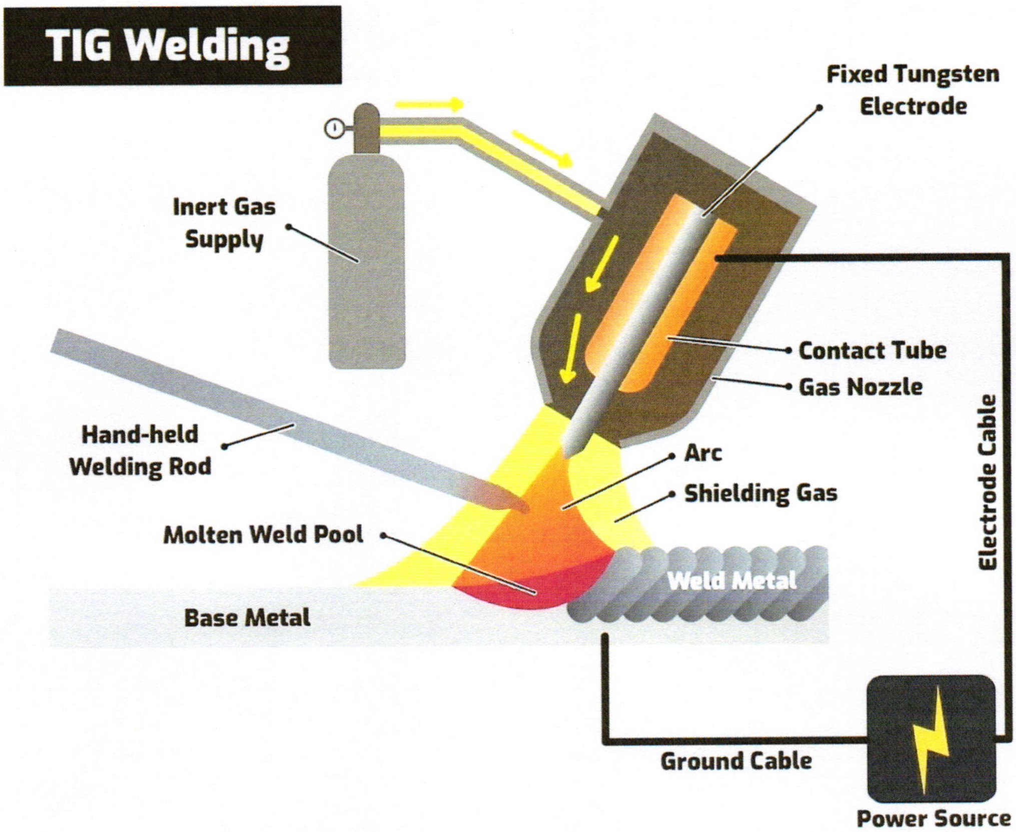

Figure 1: TIG Welding Technique

Source: Weld Guru (2022)

Despite the rise in interest in TIG welding, scholars and practitioners alike concur that it is a relatively slow process. Conversely, the technique is lauded for its versatility, as it can be used to weld more than one material in a single process. It is applicable for heavy or exotic alloyed materials and can be used to weld thin materials due to its ability to generate low heat input. The subsequent essay presents an expository analysis of the efficiency of TIG welding. The analysis is guided by the thesis that the technique is highly efficient because it uses cleaner processes, improves flexibility, and gives welders control over the heat produced.

Analysis of Efficiency

The Taguchi design presented by Rakesh and Patel (2022) is seminal in determining the efficiency of TIG welding. The model helps organize the key parameters that affect the welding process, thus allowing for data collection. The data is then used to determine which factors can affect the product quality and efficiency of the technique. The first parameter in the Taguchi design is the input parameter which places primal emphasis on the welding current and gas flow rate (Rakesh & S.Patel, 2022). The welding current coincides with the amount of heat applied to the weld. Furthermore, it relies on the type of material welded, thickness, speed of welding, and shield gas. Maintaining a viable welding current helps minimize the occurrence of defects with the requisite penetration. An in-depth analysis of the welding current used in TIG welding reveals that it relies on the red region of the current. The welding currents of the process are set at rates lower than 300 A, which reduces the risk of surface instability (French, Merin-Reyes, & Yeadon, 2019). The welding technique ensures no vigorous or oscillating fluctuations on the weld pool surface, which minimizes the prevalence of competing forces. In most instances, the arc pressure in TIG welding pushes the weld pool downwards, which increases its arc efficiency (French, Merin-Reyes, & Yeadon, 2019). The arc pressure is maintained by a voltage of between 10 and 50 volts, reducing flux consumption that can undermine the welding process (Weld Guru, 2022; French, Merin-Reyes, & Yeadon, 2019). The voltage aligns with the heat input, which determines the formation of an arc and an input. The below calculation shows that the heat input levels for the traditional TIG are set at 19.3 kj/in or 0.76 kj/mm. The preferred voltage is set at 13 volts with a welding current of 200 A.

Heat input [kj/in.]= (voltage*amperage*60)/ travel speed [in/min]*1000

Q= (13 v* 200 A*60)/ 8 in/min*1000

=19.3 kj/in.

=0.76 kj/mm

Most TIG machines come intact with control features that allow for manual, semi-automatic, and automatic current management. The moderated welding current is correlated with a rise in arc efficiency, which focuses on the amount of energy given by the process to melt the welding rod (Arcraft Plasma Equipment, 2022). TIG is known for having the lowest arc energy since it requires less heat when breaking down the gas and producing prolonged electrical discharge. The low arc efficiency ensures that TIG welding is used when bonding copper, magnesium, aluminum, and stainless steel alloys, creating high-quality and pure welds. The technique creates an arc between the work (base metal) and the non-consumable electrodes, which creates a coalescence between 2 or more metals. The electrodes serve at the core of the technique's advantages as they are made of tungsten which has the melting point of any metal at 3410 degrees Celsius. (Weld Guru, 2022). Additionally, the TIG welding process relies on the Direct Current Electrode Negative (DCEN) polarity, which manages its arc efficiency. The polarity occurs when the tungsten electrodes are connected to the negative terminal of the power source, thus contributing to the liberation of electrons (TWI Global, 2022). The base metals are connected with the positive terminal with the liberated electrons flowing towards the plates; the existence of a sufficient potential difference accelerates the electrons at high velocity. The reliance on the DCEN polarity ensures that the requisite heat is generated in the vicinity of the base plate surface. A comparative analysis reveals that TIG welding conforms to the rule of thumb, which dictates that 66% of the total arc heat should be generated on the base metal surface. The remaining 44% is generated at the electrode surface, increasing the base plates' melting rate and accentuating deep penetration (IDC Technologies, 2022). In Layman's terms, the base metal surface is referred to as the node, while the electrode surface is the cathode. The electrons flow out of the cathode into the anode, with the shield gas helping create a plasma that combines the ions. A prime example of the process' arc efficiency is shown in the below calculation involving a TIG welding process using a welding current of 120 A and an arc voltage of 30 volts. The welding process relies on the DCEN polarity to weld a 2 mm thin plate with voltage drops of 4 volts, 10 volts, and 16 volts. Additionally, at least 20% of heat is generated in the base metal surface while the rest is derived from the electrode surface. To calculate the arc efficiency, one has to add the heat generated in the base metal zone and the electrode surface, then divide the outcome by the amount of heat produced by the welding arc. Therefore:

(16 0.2 X 4)/30~ 16.8/30

Arc efficiency: 0.56~56%

Based on the above calculation, the arc efficiency levels are seminal in influencing the operations of TIG welding. Scholars concur that the combination of low arc voltage and moderated welding current reduces the occurrence of the Lorentz Force (French, Reyes, and Yeadon, 2019). The force is associated with arc pinching, which increases the energy density and distorts the surface of the weld pool. Furthermore, the two input variables work in tandem to reduce the aerodynamic drag force caused by the flow of the cathode plasma jet that contributes to the weld pool surface being pushed radially outwards. The gas flow rate additionally influences the efficiency of TIG welding. In most instances, welders have to choose between three shielding gases, namely 100% helium, argon, or a combination of both (French, Merin-Reyes, & Yeadon, 2019; Weld Guru, 2022). The flexibility in options is an added advantage to welders as they can tailor their processes based on the requirements. For example, using 100% argon reduces the cost and improves availability. The gas produces high-frequency arc starts because it contains a low ionization potential. Furthermore, it is preferred due to its ability to create a stable arc compared to helium. Helium, on the other hand, is notable because it has high thermal conductivity and can be used to produce high heat inputs in the cathode and anode. The high heat inputs facilitate the movement of ions between the two areas at faster speeds while increasing the depth-to-width ratios (IDC Technologies, 2022). Helium is preferred when welding thick materials, although its high ionization rates can contribute to inconsistent arc starts. The combination of argon and helium offers many benefits, the topmost being the provision of high heat inputs from helium. Furthermore, the combination ensures that the welding process maintains a superior arc derived from the inclusion of argon. The optimal gas flow rate for TIG welding is set between 10 and 35 cubic feet per hour (IDC Technologies, 2022). The moderate gas flow rate is seminal as it reduces the occurrence of turbulent flows while increasing laminar flows. Furthermore, the gas flow rate minimizes the introduction of atmospheric gases into the shielding gas column that can contaminate the weld and tungsten. The automatic control features in the TIG welding machine ensure that the laminar flow column remains stable. This is because a decrease in the flow rate can lead to the shielding gas column breaking (IDC Technologies, 2022). In order to compensate for heat buildup, most TIG welders are trained to use a downslope at the end of the weld. The second stricture is the constant parameter which focuses on the state of the materials involved in the welding process. There are two states notable in welding, which include thin and thick materials. Welders prefer TIG welding due to its ability to weld thin and stainless steel, thus creating neat welds devoid of discoloration and distortion. On the contrary, the technique is inefficient in thick materials as they require more heat and can lead to distortion, especially when helium is used. The third parameter is the output which focuses on the final product derived from TIG welding. The output efficiency of TIG welding is quite high as it allows for deep penetration welding. Most welders are taught how to ensure that the welding arc heat penetrates far into the workpiece, thus creating a deep weld pool (IDC Technologies, 2022). Specifically, the technique involves using the keyhole TIG, which focuses on creating a keyhole through the workpiece. The keyhole enables the formation of a narrow cavity in the welding process, thereby increasing the heat distribution deep into the workspace. On the other hand, the standard TIG welding technique increases deep penetration by maintaining energy densities between 1010 and 1013 wm^{-2} (French, Reyes, and Yeadon, 2019). The densities allow for the formation of a keyhole with the use of argon gases, increasing stability via recoil pressure. The recoil pressure ascertains that the keyhole remains open during the welding process. The automatic controls in TIG welding machines reduce the risk of increasing the energy densities to above 1013 wm^{-2} which undermines welding and contributes to the dissipation of energy (French, Merin-Reyes, & Yeadon, 2019). Additionally, the keyhole TIG maintains the energy levels through the creation of a cooling shoulder surrounding the tungsten electrode. The shoulder passes water around the electrode, thus restricting high-temperature levels. The keyhole technique reduces the magnetic pinching effect, whereby the charged particles create a magnetic field that might constrict their flow. The magnetic field is associated with the restriction of the arc jet diameter and an increase in the arc density to above 1013 wm^{-2}. Compared to other methods, the standard and keyhole TIG techniques are efficient when exposed to high-frequency axial magnetic fields. The inclusion of the cooling shoulder minimizes the probability of the magnetic field frequency reaching 1500 Hz. The cooling shoulder further maintains the arc temperature and pressure, thus minimizing the arc from changing into a compressed cylinder that dissipates energy. Another output efficiency prevalent in TIG welding is deposition or welding efficiency. Deposition efficiency focuses on the ratio between the weight of the welding electrode melted and the electrode deposited in the weld joint. The efficiency is oft measured in terms of percentage. Schmidt (2022) alludes that the best deposition efficiency falls between 60 and 80%. Since TIG uses filler wire agitation to enhance molten weld pool dynamics, one can note that it has a high deposition efficiency of between 90 and 97% (Schmidt, 2022). The filler wire agitation enhances the fluidity of the weld puddle, thus releasing evolving gases. Furthermore, it reduces the chances of porosity and inclusion, which improves the deposition efficiency of the technique. Moving further from the Taguchi design, one can note that the TIG welding technique boasts high accuracy due to the use of inverter power sources. The power sources facilitate the initiation and maintenance of a stable arc of 0.5 amps, allowing for a 0.5% accuracy (Arcraft Plasma Equipment, 2022). Furthermore, arc accuracy is enabled through small-diameter electrodes, which determine the amount of amperage used in the welding process. TIG welding does not require large-diameter electrodes since they are quite challenging to start compared to smaller ones. Furthermore, the large-diameter electrodes are replaced with smaller ones since they introduce the risk of arc instability. The inverter power sources cause arc pulsing, which involves using the power supply when alternating the current from the peak current to the current background value. The current creates a seam of overlapping spot welds, reducing the base material's overall heat input (Arcraft Plasma Equipment, 2022). Furthermore, it allows for an influx in the welding speed. The arc pulsing is lauded for its ability to increase weld quality and repeatability levels. TIG welding permits welders to weld materials and joints with poor fit-up effectively via arc pulsing. The pulsing improves the weld quality and output by regulating the width, frequency, background, and peak currents (TIP TIG, 2022; Arcraft Plasma Equipment, 2022). Cumulatively, TIG welding is highly efficient and accurate as it permits the welder to choose the precise amperage for their work. The welding does not produce the same minute flaws similar to other techniques due to the use of automatic, semi-automatic, and manual control features. The flexibility allows the welders to make the cleanest cuts possible while creating excellent lines with robust strength. Furthermore, TIG welding can meld more metals and alloys with precise bead control allowing for its application in areas that merit aesthetics and cosmetic welding, such as automobile factories.

Comparison

TIG welding compares and contrasts heavily with metal inert gas welding (MIG). MIG is a technique that involves using fully or semi-automatic arcs to create welds with consumable wire electrodes (Ogundimu, Akinlabi, & Erinosho, 2019). The electrodes act as the filler material, with gases like argon and carbon dioxide used to protect the weld from contamination. The shielding gases further promote weld penetration while reducing the bead porosity of the weld. A comparative analysis reveals that TIG welding produces stronger welded joints than MIG welding. This is because the TIG welding creates narrow, focused arcs that offer better penetration. Furthermore, the precision levels in TIG welding are quite high, which reduces the occurrence of holes and defects weakening the weld (Ogundimu, Akinlabi, & Erinosho, 2019).

MIG welding requires one to cut v-shaped grooves into joints or grind the metal prior to commencing wielding. Such processes are time and cost-intensive, which undermines the productivity of the welders. Subsequently, TIG welding is quite slow compared to MIG welding. The latter uses air-cooled features which automatically feed the filler material into the weld pool. Furthermore, MIG welding provides a broader arc that dissipates heat compared to TIG welding (Ogundimu, Akinlabi, & Erinosho, 2019). The broader arc allows the practitioners to move the puddle faster and engage in long-term welding without worrying about overheating. In TIG welding, the practitioners must manually feed filler material into the pool, which increases the workload. Furthermore, using air-cooled torches in TIG welding causes a spike in the risk of overheating, especially when applied over lengthy runs. As mentioned, TIG and MIG rely on shielding gases to protect the weld pool from contamination. Conversely, TIG uses helium, argon, or a combination of both, while MIG relies on argon and carbon dioxide. The efficiency of MIG hinges on the combination of argon and carbon dioxide at a rate of 75% and 25%, respectively (Ogundimu, Akinlabi, & Erinosho, 2019). The carbon dioxide levels are seminal in stabilizing the arc and improving penetration. Furthermore, the gas flow rates contrast heavily with TIG using a rate of 10 and 35 cubic feet per hour compared to the 35 and 50 cubic feet per hour for MIG. Finally, TIG welding is preferred over MIG due to its aesthetic qualities. The technique is devoid of any impurities, which contributes to zero spatter. Furthermore, TIG welding requires light polishing after completion, with MIG welds having a less desirable appearance due to the prevalence of deformities. The MIG welds are used in settings where appearance is less important.

Conclusion

In due summation, tungsten inert gas (TIG) welding is an efficient technique in terms of input, constant, and output parameters. The preceding analysis shows that the technique offers greater weld strength and automatically allows for regulating welding current and gas flow rates, thereby improving the dissipation efficiency and deposition efficiency. Furthermore, the comparative analysis between TIG welding and metal inert gas welding reveals that the former is devoid of any defects and can be applied in settings where appearance is seminal.

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