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A Comparative Study of the Mechanical Properties of Welded Aluminum Alloy 5052 Using Different Parameters in the TIG and MIG Welding Processes

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Abstract: This study investigates how the welding process parameters affect the mechanical properties of aluminum alloy 5052 using metal inert gas (MIG) welding and tungsten inert gas (TIG) welding. The experimental results showed that the mechanical properties of the alloy are significantly influenced by the welding process parameters used in MIG welding. In addition, verified that a welding voltage of 29 volts, a wire speed of 24 mm per minute, and a gas flow rate of 21 liters per minute are the optimal welding parameters to improve the tensile strength of the welded parts. The successful accomplishment of TIG welding butt joints with a thickness of 6 mm has been documented in the study. An in-depth analysis was conducted on the hardness profiles and tensile characteristics of the TIG welding joints. The optimal parameters identified for achieving a deep penetration of 5.93 mm include a welding current of 150A, a gas flow rate of 12L/min, a welding speed of 126 mm/min, and a heat input of 1428.57 J/mm.

Keywords: (TIG Welding, MIG Welding, Hardness, UTS, Mechanical characteristics)

Introduction

Metal Inert Gas Welding is a commonly operated welding process that provides substantial advantages in terms of welding properties and efficiency. It involves electrical energy passed through highly ionized gas and metal vapors to generate a plasma arc for welding a variety of materials, including stainless steel and non-ferrous metals like aluminum, magnesium, and copper alloys [3]. This type of welding process uses a constant electrode made of consumable wire. With a welding gun, the shielding gas is usually blasted with argon, but sometimes a mixture of argon and carbon dioxide is blasted into the weld area. Figure 1 illustrates more details about components of MIG welding [1].

Tungsten Inert Gas (TIG) welding, also referred to as Gas Tungsten Arc Welding (GTAW), is a commonly employed welding technique because of its capacity to produce strong welds, narrow fusion zones, precise manipulation of weld shape, and minimal electrode wear [4].

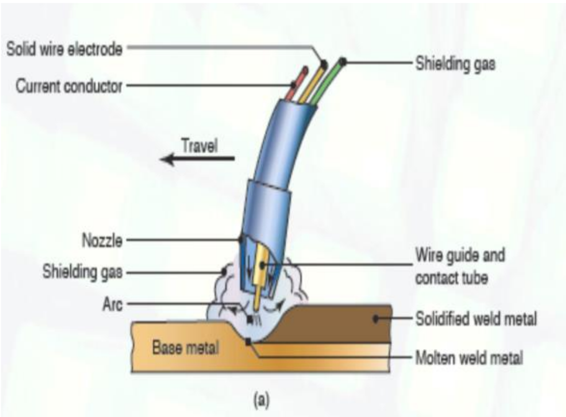

Fig. 1: Gas Metal Arc Welding

This method proves especially advantageous in the aviation industry for welding stainless steel, where the ability to accurately control arc voltage and length is vital for ensuring welding stability and enhancing quality [5]. In Figure 2: TIG welding (Tungsten Inert Gas). The filler metal, which is similar to the metals to be welded, is obtained from a filler wire. In this procedure, the tungsten electrode is not used, and the shielding gas is often argon, helium, or a combination of the two. As with close-fit joint welding, GTAW welding can also be performed without the use of filler metals [2]. However, this study aims to investigate the effect of welding parameters such as speeds, current, gas flow rate on the mechanical properties; and make comparative analysis between TIG and MIG welding processes for aluminum alloy 5052 weld joints.

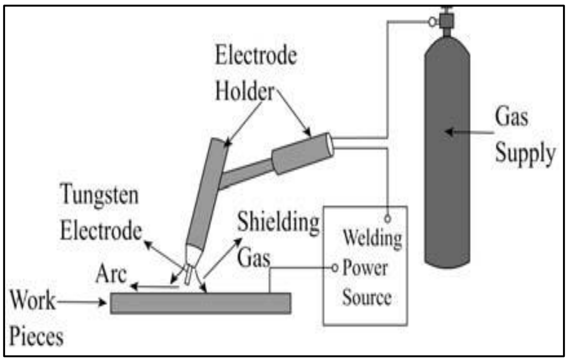

Fig. 2: Schematic of tungsten inert gas welding process

Related Studies

Variations in welding parameters significantly affect the mechanical properties of welded aluminum alloy 5052 in TIG and MIG welding processes. Studies emphasize the importance of parameter optimization, including welding speed, current, voltage, and gas flow rate, in achieving high-quality welds with desirable mechanical and microstructural properties [6,7]. For aluminum alloys like AA 5052, the welding current, speed, and gas flow rate play crucial roles in determining the weldment's hardness, tensile strength, and impact strength [7]. Additionally, the use of pulsed TIG welding can affect mechanical qualities such as impact toughness and notch tensile strength, with optimized process parameters leading to improved mechanical properties in heat-treatable aluminum alloys [8]. Furthermore, the correlation between welding parameters like current, voltage, and speed with micro-hardness and impact strength highlights the importance of parameter selection for enhancing mechanical properties in TIG welding of aluminum alloys [9]. In addition, Ancona et al. [12] performed laser butt welding of AA5083 aluminum alloy. They used the design of the experimental technique to study the effects of the variables on the mechanical properties and porosity degree. The results illustrated the high powers and high welding speeds provided the best results in terms of tensile stress.

Ogundimu [11] studied the material characterization of type 304 austenitic stainless steel weld produced by TIG and MIG welding processes, found that TIG welding process is more appropriate for welding type 304 austenitic stainless steel than the MIG welding process. Mohammed & Pachchinavar [1] studied the material characterization of stainless steel weld produced by Tungsten inert gas welding (TIG) and metal inert gas welding (MIG). The researchers investigated the impact of different process parameters on the weldability of stainless steel. Through mechanical testing and non-destructive testing (NDT), they examined the effects of varying major process parameters, such as current, type of joint, and weld time, on impact strength and hardness in this process. Incidentally, this work focuses on welding AA 5052 plates using TIG and MIG processes to examine the process parameters and compare the two processes for the joints produced.

Materials and Experimental Procedure

TIG and MIG welding processes were used in this study to join two 5052 AA plates at different welding parameters. With the use of 4043 graded filler for TIG welding because of its good, similar physical, mechanical properties and chemical compositions for obtaining the best weld joint and 5356 filler wire for MIG welding, this technique is used to weld 5052 aluminum alloy. The chemical composition of aluminum alloy 5052 is shown in Table 1. The chemical composition of 4043 and 5356 filler wire is shown in table 2 and table 3 respectively.

Table1: The chemical composition of 5052 aluminum alloy

Chemical composition %wt									
Materials	Fe	Si	Mn	Cu	Mg	Ti	Zn	Cr	Al
Al alloy 5052	0.5	0.6	0.5	0.1	2.6	0.1	0.2	0.25	balance

Table 2: Chemical Composition of 4043 Filler Wire

Chemical composition %wt							
Material	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Ti**
ER4043	64.5-	0.8	0.3	0.05	0.05	0.1	0.2

Table 3: Chemical Composition of 5356 Filler Wire

Chemical composition %wt							
Material	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Ti**
ER5356	0.25	0.40	0.10	0.05-.20	4.5-5.5	0.1	0.06-0.20

This study makes use of Miller XMT 400 series MIG welding technology. This technique uses 5356 filler wire to join 5052 aluminium alloy. After preparing eighteen samples with dimensions of 250 mm x 50 mm x 6 mm, each pair of specimens is welded together. The edges of the work components are appropriately prepped before welding. A wire brush is used to remove any dust from the edges. Gas cylinder: In MIG welding, a precise amount of argon gas is supplied to the welding flame to create a protective atmosphere and ensure a steady welding arc. The flow of gas is controlled by valves and regulators. The electrodes used in this process have a diameter of 0.8 mm and are referred to as ER 5356 electrodes, are the filler material employed in this experiment. The work components that needed to be welded were then placed in relation to one another, and the welding operation was carried out. The welded sample is displayed in Figure 3 below.

Fig. 3: MIG Welded specimens

This experimental project makes use of TIG welding. This technique is used to weld 5052 aluminium alloy using graded filler wire 4043. After the completion of the preparation process, a total of eighteen samples were obtained, each measuring 500 mm in length, 50 mm in width, and 6 mm in thickness, each pair of specimens is welded together. The edges of the work components are appropriately prepped before welding. Wire brushes and cloths are used to remove any dust from the edges. The welding procedure was then carried out after the work items that were to be welded were positioned in relation to one another as indicated in figure 4. The welded sample is displayed in Figure 5 below.

Fig. 4: Welding fixture

For every welded specimen in this investigation has own parameters used for MIG and TIG welding processes as appears in Tables 4 and

5; in addition, the following mathematical method is used to determine the heat input: Energy or heat input is computed using the following mathematical formula:

Fig. 5: TIG Welded specimens

Heat input (joule/mm) =60 VI/S, where:

V = Arc voltage in volt

I = welding current in ampere

S =Welding speed in mm/min

Table 4: Input Parameters of MIG welding

Specimen ID	Arc Voltage (V)	Welding Speed (mm/Min.)	Gas Flow Rate (Lt/Min)
1	20	24	16
2	20	29.5	19
3	20	35	21
4	24.5	29.5	21
5	24.5	35	16
6	24.5	24	19
7	29	35	19
8	29	24	21
9	29	29.5	16

Table 5: Input Parameters of TIG welding

Specimen ID	Welding Current (Amps)	Arc Voltage (V)	Welding Speed (Mm/Min.)	Gas Flow Rate (Lt/Min)
1	120	20	66	10
2	120	20	78	11
3	120	20	90	12
4	140	20	96	11
5	140	20	102	12
6	140	20	120	10
7	160	20	144	12
8	160	20	144	10
9	160	20	156	11

Tensile testing is often used to determine basic design details, identify the strength of materials, and serve as a resource for material specifications. The SP1000 testing machine from Zwick/Roell was used to carry out the tensile test and eighteen samples were tested. Three samples of each regime were tested as shown in (Figures 6 and 7) to ensure repeatability from which the average is calculated. In addition, hardness is another indicator of metal strength, while local metal has high hardness and is susceptible to environmental corrosion and cracking. In addition, layers with different degrees of hardness prevailing in an alloy can influence the course of crack propagation. The hardness in the heat affected zone (HAZ) of a weld is critical to the performance of the weld in the field. If the weld is too hard, it loses ductility and is prone to cracking. If the weld is too soft, there is a risk of collapse or tensile failure. Therefore, the hardness of the material is closely correlated with the strength. This means that any change in heat level during the welding process can lead to a change in the hardness and therefore the strength of the weld. The hardness of aluminum alloys was measured using Vickers hardness, which usually indicates metal strength. Therefore, all data and results obtained in the experiment were subject to some human errors and efficiency of handling and use by machines. For the test results, Figure 8 shows the machine used for the hardness test.

Fig. 8: The hardening test machine

Results and Discussion

Micro – hardness of MIG welding process

Following the samples' cutting and processing, the micro hardness test was carried out. The micro-hardness test results were obtained from three different positions on every sample subjected to MIG welding: the base metal, the heat-affected zone (HAZ), and the welding pool region. Higher hardness levels are seen to be ideal since the welding pool's micro-hardness value is a larger-is-better sort of quality feature. Figure 9 makes it evident that increasing the welding voltage from 20 to 29 volts causes the hardness to increase from 74 to 95 volts.

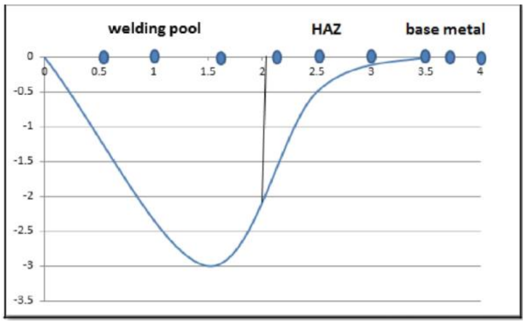

Fig. 9: Three areas of Measured Microhardness.

The hardness value is higher at the initial welding wire speed (24 mm/min) and lower at the third welding voltage level (29 v). It increases from 75 HV to 90 HV and then decreases to 80 HV as the gas flow increases from 16 l/min to 19 l/min. Consequently, the hardness value is higher at the second level of gas flow rate (19 l/min). In Figure 10, the hardness values are shown versus the rate of argon flow. The graphs showing that welding voltage (20 v) and argon gas flow rates (16 l/min) were used to generate a reduced hardness (74 HV). Too little heat can be produced by the decreased AGFR, the rise in temperature of particles primarily contributed to the increase. The most effective process parameters have been determined in the (HAZ) region. According to Figure 11, it can be inferred that the best Hardness at HAZ is achieved with the third level of welding voltage (29 V), the first level of welding wire speed (24 mm/min), and the third level of gas flow rate (21 l/min).

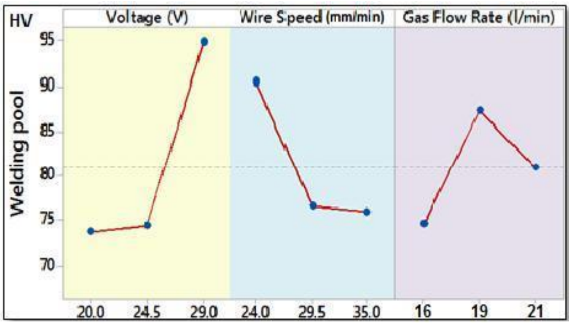

Fig. 10: Taguchi analysis for process parameters impacts on the hardness at welding pool.

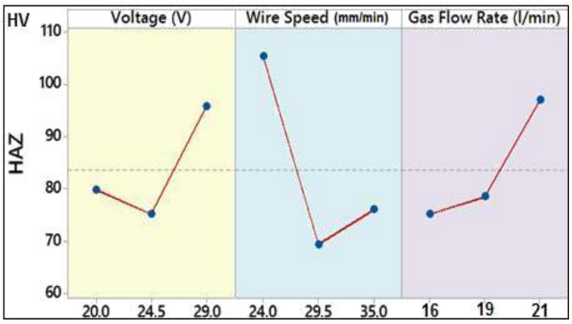

Fig. 11: Process parameters effects on hardness at (HAZ)

The optimal hardness for the base metal is attained when using a welding voltage of (29 V), a welding wire speed of (24 mm/min), and a gas flow rate of (21 l/min) see (Figure 12).

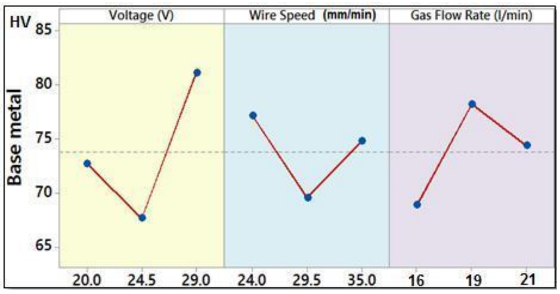

Fig. 12: Process parameters Effects on Hardness at base metal

Tensile Strength Test of MIG welding process

The impact of three separate process parameters on the tensile strength of the welded connections is depicted in Figure 13. The increase in welding voltage leads to a rise in tensile strength, reaching 231.72 (N/mm2). On the other hand, the impact of an increase in shielding gas flow rate on tensile strength results in only a slight increase. Conversely, an increase in wire speed causes a decrease in tensile strength.

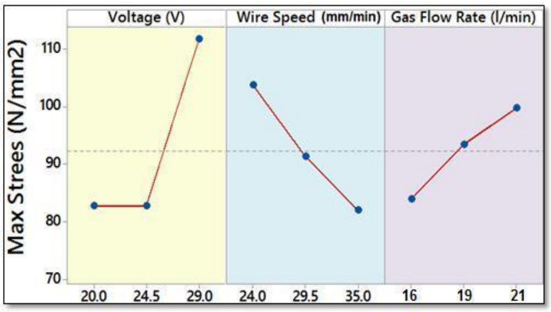

Fig.13: Taguchi Analysis for Tensile Strength

The welded junction's tensile strength decreases as the wire speed rises from 24 mm/min to 35 mm/min at 20 v to 29 v, about from 101.84 N/mm2 to 92.27 N/mm2. However, when wire speed increases, the total amount of heat input for the welding drops, as does the corresponding welding penetration, and as a result, the welded joint's tensile strength diminishes. Additionally, it is noted that the tensile strength is greatest at the first level, or third level, of welding voltage (29 V).

Micro – Hardness OF TIG Welding Process

The micro-hardness value of the welded zone was measured at the cross-section for each welded specimen to assess the changes in its mechanical properties. Figure 14 illustrates the micro-hardness values at the welded zone, is measured from the center of the welding zone towards the base material, for different samples that were executed with varying welding currents and speeds. The graph indicates that nearly all of the sample's microhardness values, which range from 50 to 70 HV in the welded area, it is located there compared to the base material. These values, after a certain distance, are slightly larger than the hardness of the base material of the specimen processed at different welding speeds.

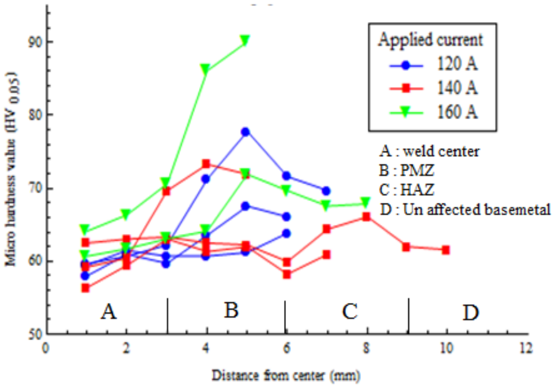

Fig. 14: Micro-hardness value from the center of the weld zone towards the base material for different welding speeds and current values

Tensile Strength Test of TIG welding process

Table 3 presents the recorded values of tensile strength for each welded joint, which were produced at various welding speeds and current settings; these values significantly fall below the tensile strength of pure aluminum. Additionally, Figure 15 illustrates the relationship between the tensile strength of the welded joints and the welding speed, specifically at a welding current of 120 A.

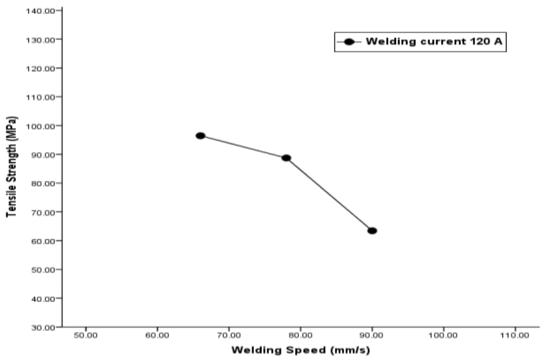

Fig. 15: Tensile strength of the welded joint against various welding speeds for applied current of 120 A

This chart demonstrates how the tensile strength value nearly drops as welding speed increases. Similarly, figure 16 plots the tensile strength of the welded joints vs welding speed at a welding current of 140 A. This graph demonstrates that the tensile strength change as a function of speed does not follow any obvious pattern. Furthermore, figure 17 shows that the tensile strength values range from 66.

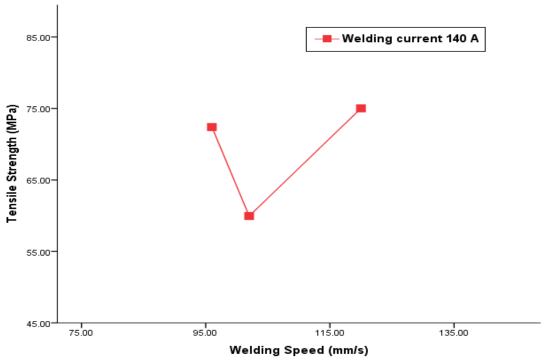

Fig. 16: Tensile strength of the welded joint vs various welding speeds for used current of 140A

Figures 15, 16, and 17 make it evident that, under nearly all welding speed conditions (90 mm/Min welding speed excluded), The tensile strength values of the welded joint, achieved with a welding current of 120 A, surpass the tensile stress values of the welded junction completed using a welding current of 140 A and 160 A.

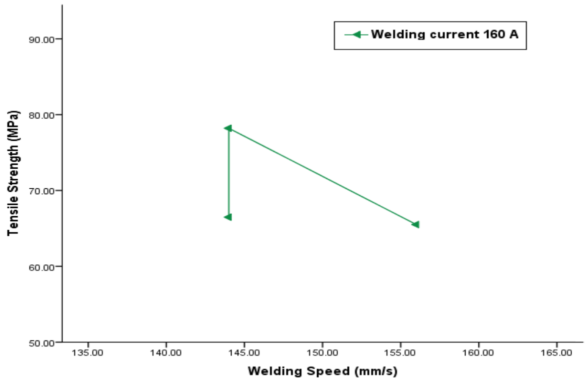

Fig. 17: Tensile strength of the welded joint against various welding speeds for applied current of 160A

Conclusion

This study used the Taguchi method to examine the effects of voltage, wire speed, and gas flow rate on the mechanical properties, or microhardness and tensile strength, of aluminium alloy 5052 that had been welded by wire electrodes ER5356 and ER4043, respectively. The results of this investigation showed that the tensile and microhardness of the welded AA5052 are significantly impacted by every MIG process parameter. However, the following summarizes the key findings concerning the MIG welding process:

- The most important factor influencing the welded AA5052's microhardness and tensile strength was voltage. Micrographs also provided proof of this.
- The optimal welding conditions for achieving maximum tensile strength and hardness are a welding voltage of 29, wire speed of 24, and gas flow rate of 21. In summary, the key conclusions regarding TIG welding procedures can be stated as follows:
- When welding with low current, gas flow rate has little impact; nevertheless, when welding current increases, welding speed has some impact.
- As welding speed increases, less heat is used throughout the process, which also results in less welding penetration.
- Gas flow rate and welding current have effect together on welding penetration.
- Optimum parameters setting for deep penetration of 5.93 mm is obtained at welding current of 150A, gas flow rate of 12L/min, welding speed of 126 mm/min and heat input of 1428.57 J/mm.

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