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Welding Defects Analysis with Various Alloys using TIG and MIG Welding Process

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ABSTRACT

This paper aims to analyze the process of tungsten inert gas and metal inert gas welding and the defects of welding. Metal inert gas and Tungsten inert gas welding are the most popular gas-shielded arc welding processes used in many industrial fields. MIG welding is more highly efficient than TIG welding. This research has focused on welding defects with various types of welding joints for various metal alloys by using tungsten inert gas and metal inert gas welding processes. In this work, mechanical properties such as yield stress, elastic stress, and breaking stress have also been found for both TIG and MIG welding processes.

Keywords: Welding Defect, Welding Using Various Alloys, Aluminum, Magnesium, TIG and MIG.

NOMENCLATURE

Abbreviation/Symbol	Meaning
TIG	Tungsten Inert Gas
MIG	Metal Inert Gas
LOP	Lack of Penetration
AlMg	Aluminum Magnesium Alloys
Si	Silicon
N	Newton (unit of force)
mm	Millimeter (unit of length)
kN	Kilonewton
amps	Ampere or A (unit of electric current)
%	Percent
N/mm^2	Newtons Per Square Millimeter

INTRODUCTION

In the manufacturing process, Welding is a process of joining two metals (similar or dissimilar) pieces by the application of heating them to a molten state to form a formidable bond upon solidification. Welding is the least expensive process and is widely used nowadays in fabrication [1-5]. There are many types of welding processes such as Arc welding, Metal inert Gas welding (MIG welding), Oxyacetylene welding, Tungsten inert Gas welding (TIG welding), Laser welding, and Friction welding [6]. According to the American Welding Society, the common application includes construction, pipelines, machinery structures, shipbuilding, job shop fabrication, and repair work. Tungsten inert gas and Metal inert gas welding are the most popular gas-shielded arc welding processes [7]. TIG and MIG welding processes are used for metal joining in many industries. Tungsten inert gas welding is a high-quality welding process that has less spatter and better weld bead surfaces than Metal inert gas welding with pure argon (Ar) [8]. To improve the efficiency of Tungsten inert gas welding is needed because of its slow speed and the small amount of deposited metal. Metal inert gas welding is a high-efficiency process with high rates of metal deposition [9]. In the MIG welding process consumable electrode is used but not in the TIG welding process. In the MIG welding process high deposition rate but not in TIG welding. It needs to improve in quality, spatter production, oxidation of the bead surface, and weld metal toughness [10]. For Metal inert gas welding, pure argon shielding gas is desirable for weld-metal toughness. The Metal inert gas arc is unstable in pure argon because of instabilities in the cathode spots on the base metal surface [11, 12]. For this weld defects and irregularities of the weld, a bead is created. If a small amount of an oxidizing gas such as oxygen or carbon dioxide is included with shielding gas, arc stability will improve and suitable welding execution will be possible. For this mixed gas of $Ar+O_2$ or $Ar+CO_2$ is used for conventional Metal inert gas welding. By using these gases, it is possible to avoid the oxidation of the weld bead surface and increased oxygen content in the weld metal, which causes a decrease in weld metal toughness.

Tungsten Inert Gas (TIG) Welding Procedure

TIG welding is a method that fuses metals by generating an arc between a non-consumable tungsten electrode and the workpiece. This process employs argon shielding gas and additional filler metal (MS-1020). Key TIG welding factors include arc voltage (18v), welding current (130A), and travel speed (165mm/min). The arc created between the tungsten electrode tip and the workpiece generates heat for melting the base metal. Filler metal is typically added to the front of the weld pool to complete the joint [13-16].

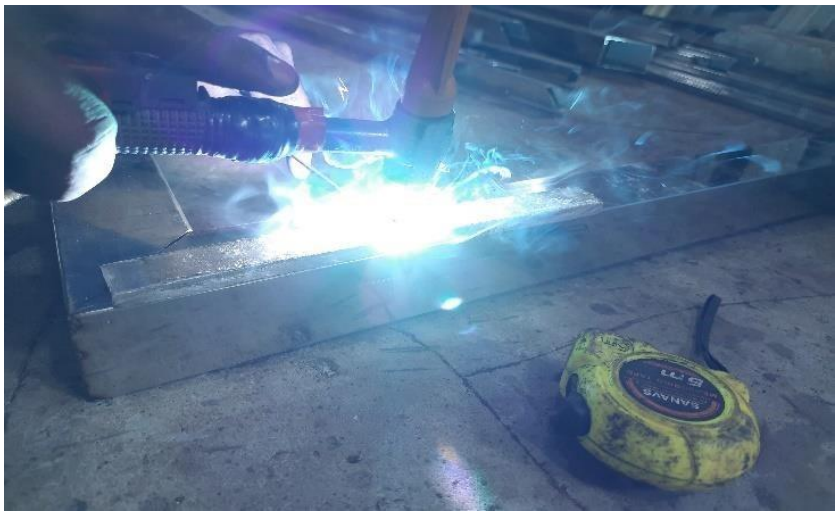


Figure 1: TIG welding process.

Metal Inert Gas (MIG) Welding Procedure

MIG welding, at its core, is a technique that connects metals by heating them through an arc formed between a consumable electrode and the workpiece. This method employs shielding gas (argon) and an electrode (MS-1020). Crucial MIG welding variables encompass arc voltage (16v), welding current (120A), and travel speed (169mm/min). The arc formed between the MS-1020 electrode tip and the workpiece generates the necessary heat to melt the base metal and complete the joint [17-20].



Figure 2: MIG welding process.

METHODS

There are two types of existing testing methods such as:

1. Non-destructive testing method
   a) Ultrasonic testing method
   b) X-ray testing method
   c) Liquid penetration test
   d) Magnetic particle test
   e) Visual inspection

2. Destructive testing method
   a) Tensile test
   b) Bending test
   c) Impact test
   d) Pressure and fracture test

The following testing methods are used in this research.

Nondestructive Method

Liquid Penetrant Test

The liquid penetrant examination is one of the most popular Nondestructive Examination (NDE) methods in the industry. It is economical, versatile, and requires minimal training when compared to other NDE methods. Liquid penetrant exams check for material flaws open to the surface by flowing very thin liquid into the flaw and then drawing the liquid out with a chalk-like developer [21, 22].



Figure 3: ORION 115D Developer.

Steps of Liquid Penetrant Test

The exact procedure for liquid penetrant testing can vary from case to case depending on several factors such as the penetrant system being used the size and the material of the components being inspected. However, the general step can be summarized as follows:

Surface Preparation

The surface must be free of oil, grease, water, and other contaminants that may prevent penetrant from entering flaws. The surface had been prepared by the application of ORION 115D Developer [21].



Figure 4: Surface cleaning after use of developer.

Penetrant Application

Once the surface has been thoroughly cleaned and dried the penetrant material ORION 115P Red Dye Penetrant is applied by spraying on the welding area. The penetrant is left on the surface for a sufficient time to allow as much as possible to be drawn or to sleep into a defect [23].



Figure 5: ORION 115P Red Dye Penetrant.



Figure 6: Application of penetrant.

Developer Application

A thin layer of developer is then applied to the sample to draw the penetrant trapped in flaws back to the surface where it will be visible. The developer is allowed to stand on the part surface for a period of time sufficient to permit the extraction of the trapped penetrant out on any surface flaws. This developer time is usually a minimum of 10 minutes [23].



Figure 7: MAGNAVIS 7HF Preparation bath.

Ultrasonic Test

Ultrasonic testing is a nondestructive testing method that allows for a full volumetric examination of the materials and is designed to detect surface, subsurface, internal, and dimensional flows. This type of testing uses high-frequency sound waves that are transmitted throughout the material being tested in order to conduct a thorough inspection. Ultrasonic inspection can be used to detect surface flaws such as cracks seams and internal flaws such as voids, and the inclusion of slugs [24].

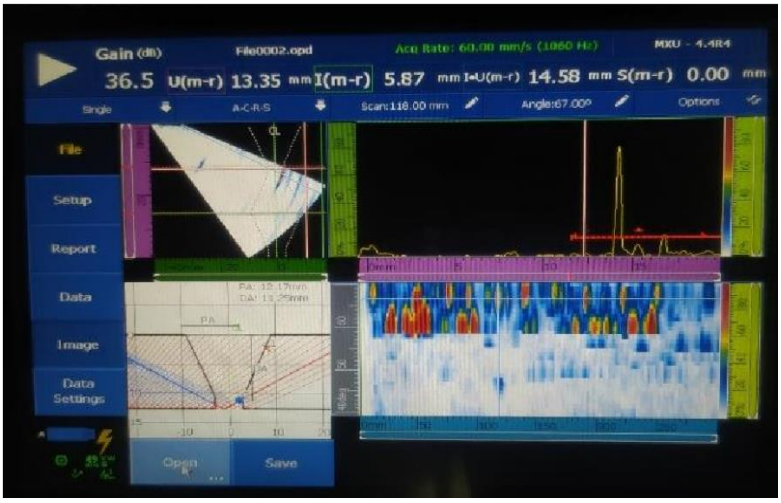


Figure 8: Lack of penetration in MIG welding, echo indicating at a distance of 12mm from the edge of the workpiece.

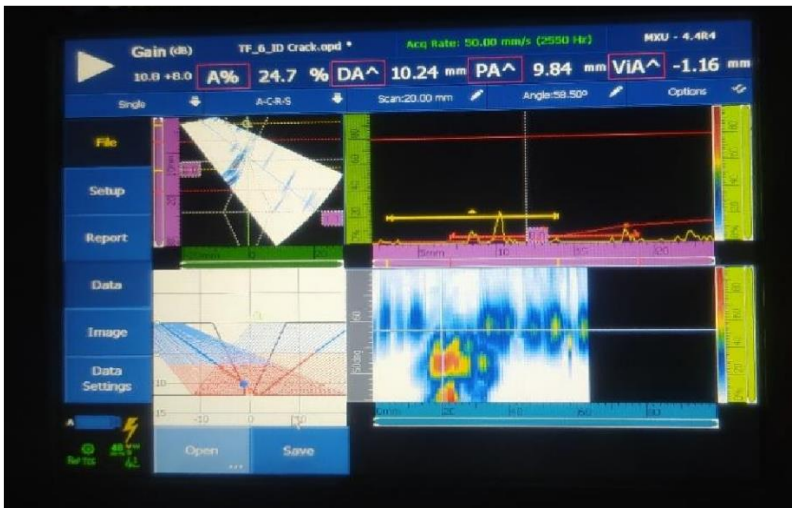


Figure 9: Lack of penetration in TIG welding, echo indicating at a distance of 11 mm from the edge of the workpiece.

Tensile Test

Tensile testing is a destructive test process that provides information about the tensile strength, yield strength, and ductility of the metallic material. The tensile tests were performed using the universal testing machine [17].

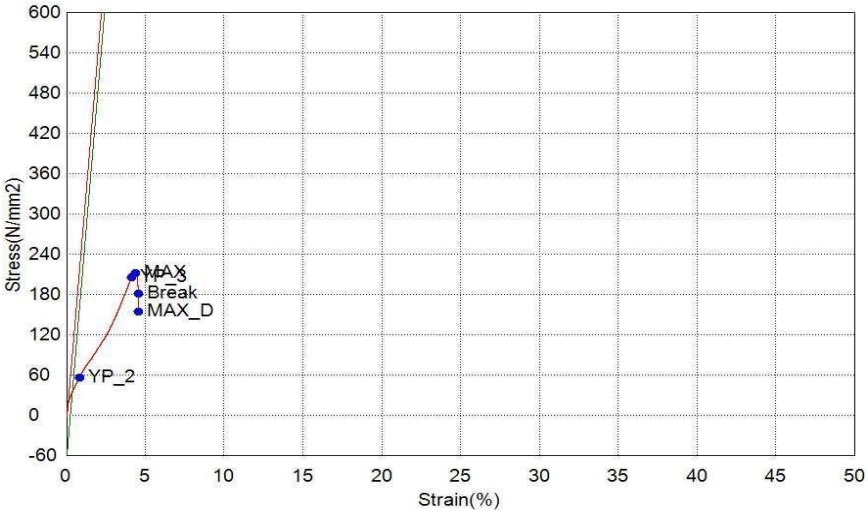


Figure 10: Tensile testing result for MIG welding.

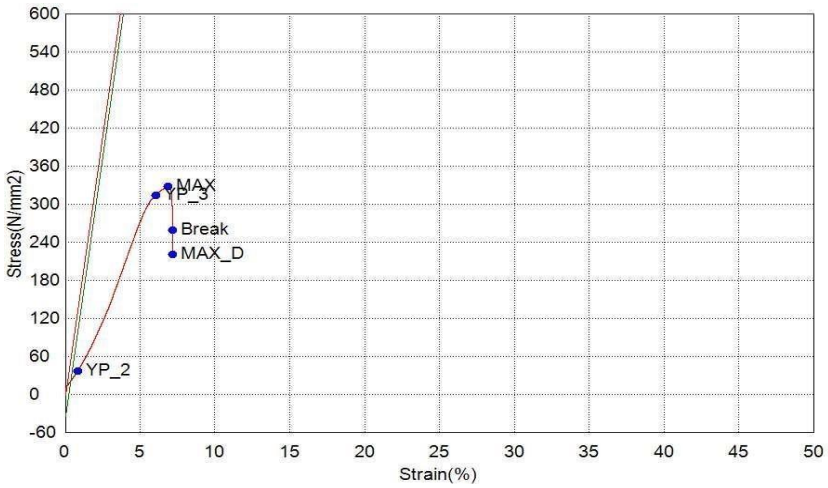


Figure 11: Tensile test curve for TIG welding.

RESULTS

Liquid Penetration Test

The liquid penetration test has been performed. This test helped to find out some defects such as blow holes and lack of penetration as shown in the above figure. In the above figure, it is seen that the defects of TIG welding are more than the MIG welding sample [21].



Figure 12: Liquid penetration test for TIG and MIG welding.

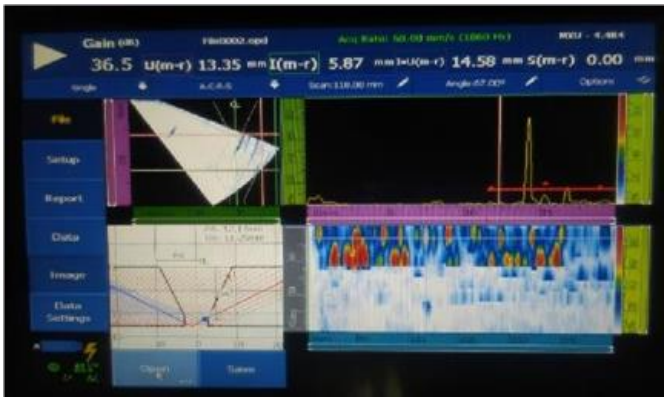


Figure 13: Lack of penetration in MIG welding, echo indicating at a distance of 12mm from the edge of the workpiece.

Ultrasonic Test

The ultrasonic test was conducted using an ultrasonic testing machine, which revealed defects as depicted in the figure. In Figure 1, an echo signifies a lack of penetration 12 mm away from the workpiece edge in the MIG welding specimen. In Figure 2, an echo indicates a lack of penetration 11 mm away from the workpiece edge in the TIG welding specimen. Observations from Figures 1 and 2 suggest that TIG welding exhibits better performance compared to MIG welding [24-26].

Table 1: Details in test name and method of MIG welding.

Key Word		Product Name	
Test File Name	MIG welding	Method File Name	Flat Bar
Report Date	10-Oct-21	Test Date	10-Oct-21
Test Mode	Single	Test Type	Tensile
Speed	5mm/min	Shape	Plate
No of Batches:	1	Qty/Batch:	1

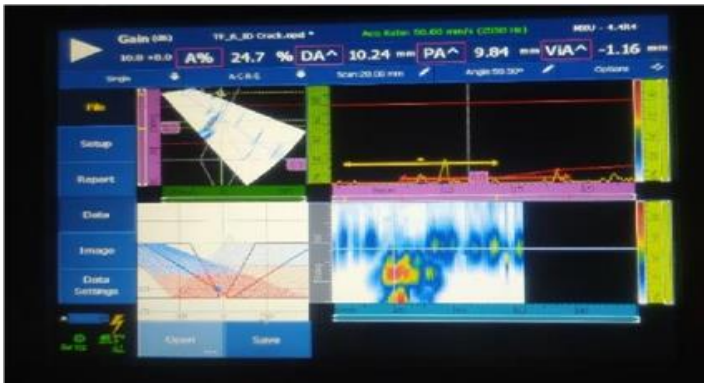


Figure 14: Lack of penetration in TIG welding, echo indicating at a distance of 11mm from the edge of the workpiece.

Tensile Test

Tensile testing was performed on TIG and MIG welded mild steel specimens to determine parameters like Ultimate Tensile Load (kN), Ultimate Tensile Stress (N/mm^2), Breaking Load (kN), and Breaking Stress (N/mm^2). The resulting data is depicted in Figures [13, 27, 28].

Table 2: Tensile test data for MIG welding of mild steel (AISI-1020).

Name	EASL1 Strain	Elastic	Slope Standard	YP (%FS) Force
Parameters	Force 1 N	Force 10 – 20 N	Force 10 – 20 N	0.1 %
Unit	%	N/mm^2	N/mm	N
MIG1	0.01115	27688.2	48177.5	--
Average	0.01115	27688.2	48177.5	--
Standard Deviation	--	--	--	--
Range	0.00000	0.00000	0.00000	--

Name	Thickness	Width	Gauge Length
Unit	mm	mm	mm
MIG1	8.0000	26.1000	120.0000

Name	YP (Disp.) Strain	YP (Points) Force	YP (Points) Stress	YP (Points) Stroke
Parameters	Stroke 1 mm	3 Points	3 Points	3 Points
Unit	%	N	N/mm^2	mm
MIG1	0.83308	42760.9	204.793	4.99220
Average	0.83308	42760.9	204.793	4.99220
Standard Deviation	--	--	--	--
Range	0.00000	0.00000	0.00000	0.00000

Table 3: Tensile testing data of TIG welding.

Key Word		Product Name	
Test File Name	TIG1.xtak	Method File Name	Flat Bar Tensile.xmak
Report Date	10-Oct-21	Test Date	10-Oct-21
Test Mode	Single	Test Type	Tensile
Speed	5 mm/min	Shape	Plate
No of Batches:	1	Qty/Batch:	1

Name	Thickness	Width	Gauge Length
Unit	mm	mm	mm
TIG1	8.0000	24.6000	120.0000

Name	YP (Disp.) Strain	YP (Points) Force	YP (Points) Stress	YP (Points) Stroke
Parameters	Stroke 1 mm	3 Points	3 Points	3 Points
Unit	%	N	N/mm^2	mm
TIG1	0.83310	61722.9	313.633	7.24637
Average	0.83310	61722.9	313.633	7.24637

Name	EASL1 Strain	Elastic	Slope Standard	YP (%FS) Force
Parameters	Force 1 N	Force 10 – 20 N	Force 10 – 20 N	0.1 %
Unit	%	N/mm^2	N/mm	N
TIG1	0.00683	16506.2	27070.1	--
Average	0.00683	16506.2	27070.1	--

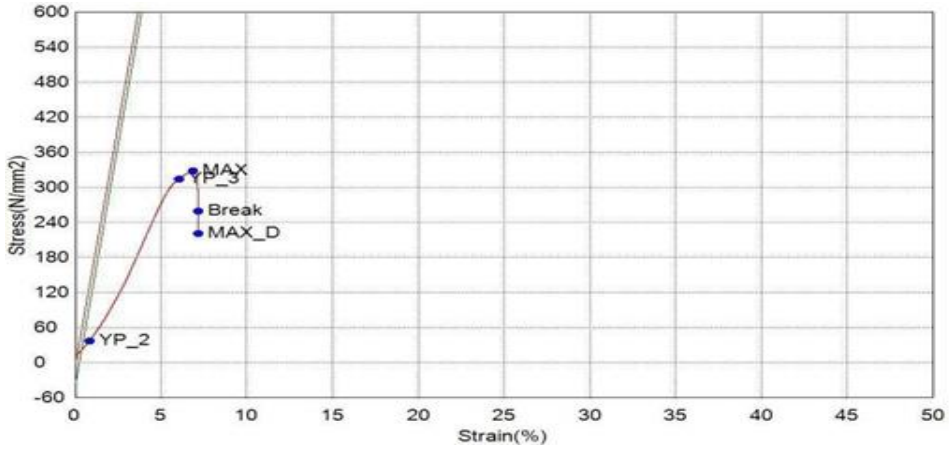


Figure 15: Tensile test curve for TIG welding.

MIG Welding Properties

These properties are found from the experimental analysis as follows:
Yield stress: 204.793 N/mm^2
Elastic stress: 27688 N/mm^2
Breaking stress: 180 N/mm^2
Breaking force: 37709.3 kN
All data are shown in Figure 16.

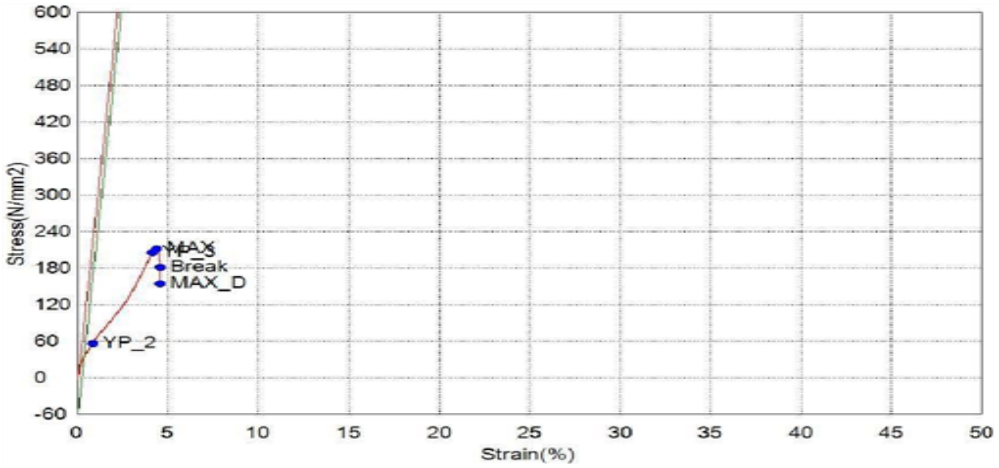


Figure 16: Tensile test stress-strain curve for MIG welding.

TIG Welding Properties

These properties are found from the experimental analysis as follows:
Yield stress: 313.633 N/mm^2
Elastic stress: 16506.2 N/mm^2
Breaking stress: 257.890 N/mm^2
Breaking force: 50.572 kN
All data are shown in Figure 17.

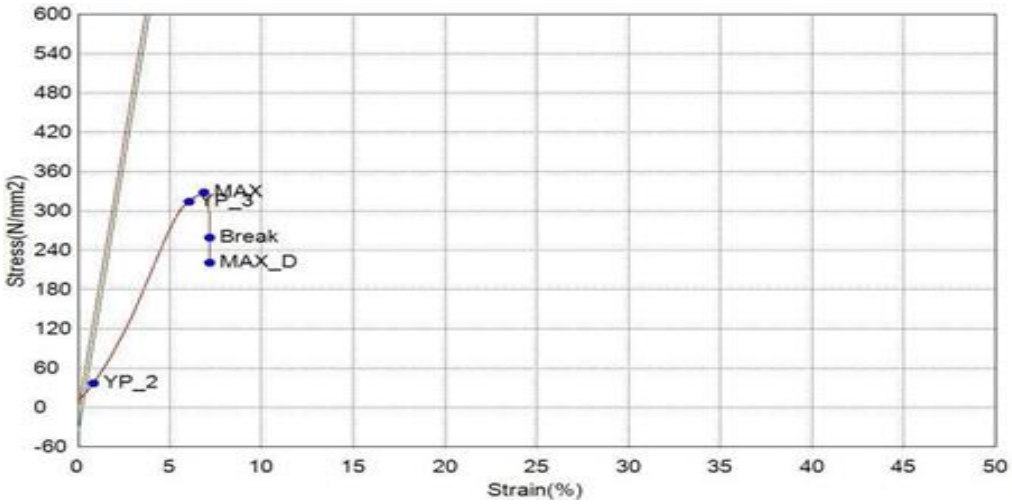


Figure 17: Tensile test stress-strain curve for TIG welding.

SUMMARY

Alloys possess notable characteristics like a high strength-to-tensile ratio, low density, and dependable corrosion resistance, making them well-suited for lightweight applications [29]. The pursuit of enhanced fuel efficiency and decreased CO_2 emissions in the aerospace, marine, and automotive sectors have transformed the utilization of magnesium alloys as lightweight substances [30]. Aluminum and Magnesium alloys have been identified as suitable materials to replace traditional steel for weight reduction, CO_2 emission reduction, and also for effective fuel economy in the automobile industry. MIG and TIG welding as cost-effective with high gap bridging capability have successfully been used to obtain Aluminum and Magnesium alloy joints with satisfactory properties [31]. The findings on MIG and TIG welding of various alloys have been summarized in the following table.

Table 4: MIG and TIG welding of Various alloys in different industries.

Welding method and parameter-optimized	Workpiece	Findings	Ref.
MIG welding. Effect of double pulsed current.	2mm thick 6061- T6 Al alloy with 1.2mm ER5356 (AlMg) as welding wire.	Due to the improved droplet transferwith the double-pulsed current, there was an enhancement in the bead appearance and refinement in the microstructure of the fusion zone.	[29]
MIG and TIG welding.	Mg alloys in niche markets (e.g., super-economy, 3l/100km vehicles) and other classes of vehicles.	Magnesium has a high potentialin an automobile. 60kg of magnesium alloy is achievablein an automobile.	[30]
MIG welding.	3mm x 150mm x 200mm plates of AA 5052 and AA 6061Al alloy with ER 5356 welding wire.	Both the longitudinal, and transverse stresses distortion in AA 5052 were higher than in AA 6061.	[32]
TIG welding. Effect of three different welding wires.	2mm x 50mm x 50mm plates of 6061 Al alloy with ER (5356, 4043, and 4047) filler wires.	Better microstructure and mechanical properties obtained with ER 5356.	[33]
TIG welding. Effect of cryogenic treatment at different welding currents.	3mm x 50mm x 125mm plate of AA-5083 Al alloy with ER 5356 filler rod.	Samples welded at higher welding current have higher ultimate tensile strength and better grain refinement.	[34]
TIG welding. Effect of notch radius.	3.2mm AA 6061 Al alloy with 3.15 mm ER 4043 (Al-4-6% Si) as filler metal.	Tensile strength and toughness ofspecimen with notch were higherthan those without a notch. Fracturepropagated through the base metalfor samples without notches whilefracture propagation was through theweld metal for samples with a notch.	[35]
TIG welding. Effect of welding parameter on the depth of weld penetration.	2.5mm x 50mm x 100mm plate of AA 5052 Al alloy with AA 4043 filler rod.	A depth penetration of 2.02 mm was obtained at the optimal welding parameters.	[36]
TIG welding. Effect of pulsed current.	5mm thick AA 6061 Al alloy with 3mm AA 4043 (Al- 5% Si) as filler metal.	Tensile strength increased with an increase in peak current and pulse frequency while the reverse was the case with a pulse on time and base current.	[37]

TIG welding. Effect of welding current and gas flow rate.	6mm x 50mm x 100mm AA 5052 Al alloy with 1.6 mm AA 4043 filler rod.	Welding current, voltage, speed, and the gas flow rate of 180 A, 20 V, 100mm/min and 11 Ipm respectively gave the best joint quality.	[38]
MIG and TIG welding processes. Effectof the welding techniques on the microstructure.	AA 6061 and AA 7020 Al alloy plates of thickness 6mm and 5mm respectively.	Joints without cracking, porosity and oxidation defects.	[39]
MIG welding. Effect of two different welding wires.	2mm x 150mm x 150mm 7075 Al alloy with ER 5356 and ER 4043.	ER 5356 showed better tensile strength and Vickers hardness than ER 4043.	[40]
TIG welding. Effect of titanium and strontium addition in AA 4043 filler rods.	12mm x 175mm x 350mm AA 6082- T6 Al alloy with 9.5mm AA 4043 filler rod modified with titanium and strontium.	Modified microstructure andmechanical properties due to the titanium and strontium-modified filler rod.	[41]
MIG and TIG welding techniques. The two techniques were compared.	Hollow pipes to obtain K-joint. The chord (4.75mm in thickness) and brace (3.2mm in thickness) have adiameter of 50.8mm with AA 4043 filler wire.	TIG welding showed better microstructural and mechanical properties compared to MIG welding process.	[42]
MIG and TIG welding. The two welding processes were compared.	6mm x 50mm plate of AA6062 Al alloy.	The MIG welding process showed better Microstructural and mechanical properties compared to the TIG welding process.	[43]
TIG welding. Effect of the welding process onthe joint and fatigue efficiency.	Rolled and extruded AZ 31 and AZ 61 Mg alloy plates of 2 mm thickness.	Joint efficiency above 90% obtained for all the joints and fatigue strength efficiency of 60% in all the welded samples except for the extruded AZ31 Mg alloy.	[44]
TIG welding. Effect of the welding process onthe welded sample.	ZE 43 Mg alloy plate.	The welding process did notreduce the mechanical performance of the welded alloy.	[45]
MIG welding. Effect of weld Aluminum. content and heat input.	AZ31B Mg alloy and Q235 steel plates (3mm x 50mm x 200mm) with AZ31 and AZ61 welding wires.	80% improvement in the tensile strength of the Mg alloy base metal.	[46]
MIG welding. Effect of the welding method on the properties of the welded joints.	3mm x 50mm x 100mm plates of AZ91, AM-Lite and AM50 Mg alloys.	Improved tensile and bending strengths.	[47]
MIG and TIG welding. Effect of after welded.	3mm x 150mm six plates of Austenitic stainless steel (304).	The ultimate load of the TIG welded specimen is 57600N for the MIG welded specimen is 56160N; the Ultimate strength of the TIG welded specimen is 675.33 Mpa whereas for the MIG welded specimen is 652.029 N/mm^2. TIG welding is the best process for austenitic-grade material.	[48]

DISCUSSION

This study is performed and analyzed using MS-1020 materials welded by MIG and TIG welding processes. To ensure the various defects in welding, AISI 1020 material is welded. The improvement of welding defects also has been studied. There are so many welding tests such as destructive and nondestructive tests. Destructive tests are tensile, bending tests, etc. Non-destructive tests are X-ray, Ultrasonic, magnetic particle tests, etc. In this research work, the tensile and Ultrasonic test, liquid penetration test, and tensile tests have been performed. It is investigated that current and voltage parameters for MIG welding are the major parameters affecting the weld characteristics. The penetration of the weld is directly proportional to the welding current. Tungsten inert gas (TIG) and metal inert gas (MIG) welding processes are studied for welded mild steel (AISI-1020), with similar metals. In this research, based on experimental analysis data and strain stress curve, the TIG welding is the best.

CONCLUSION

Welding is the oldest and most common technique of metallic structure. It is needed to reduce the defects of welding joining as much as possible to ensure the best quality of welding joining. In this work, the various defects of the TIG and MIG welding processes have been studied. This investigation is performed and analyzed with AISI-1020 mild steel along with similar materials welded by the MIG and TIG welding process in order to ensure the various defects and mechanical reliability of the similar material. The mechanical properties such as tensile strength, and ultimate strength were assessed. This experimentation has provided a significant result by considering small experimentation values. The parameters are contributing to the response and all have been considered for experimentation of MIG and TIG welding. Among the parameter's voltage are 26 volts and current 200 amps.

The following conclusions may be drawn from this study:

a) To avoid lack of penetration (LOP) the optimum current values are 150A and 180A for 3mm and 5mm plates for MIG welding.
b) Similarly, for TIG the current values are 65A and 80A for 3mm and 5mm plates respectively.
c) The welding speed should be less than 0.35 m/min for 8mm in MIG welding.
d) To avoid lack of penetration (LOP) the optimum velocity of nozzle tip distance is 12mm for an 8mm plate.
e) The cost of experiments can be reduced by selecting a proper orthogonal array.
f) Ultrasonic testing is a rapid and effective NDT method.

FUTURE RESEARCH DIRECTIONS

The significant impact of corrosion and wear resistance on the performance of alloy structures, especially in welded joints, has been insufficiently addressed. Consequently, there exists a necessity for conducting further studies to comprehensively explore this aspect. Titanium alloys offer exceptional qualities like a high strength-to-weight ratio and remarkable corrosion resistance, positioning them as fitting choices for lightweight applications in aerospace, and marine, and both titanium and magnesium alloys are vastly used in automotive sectors. Despite these advantages, the available literature on MIG and TIG welding of comparable titanium and magnesium alloys and their competitive benefits compared to other welding methods is notably scarce. Also, this study could be expanded to encompass additional stainless-steel

variants, aiming to explore the comparison of mechanical properties and various parameters through microstructure analysis. Such an extension could yield insights into cost-reduction strategies and recommendations for appropriate materials in various industrial processes. As a result, there is a pressing requirement for further research acts on these domains.

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