

Effect of CO₂ and Argon Gas Shielding on GMAW Welding Joint Quality

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ABSTRACT

This study aims to evaluate the effect of shielding gas types, namely carbon dioxide (CO₂) and argon, on the quality of welded joints in the Gas Metal Arc Welding (GMAW) process with low carbon steel as the base material. The research method was carried out experimentally using a steel plate measuring 150 mm × 75 mm × 6 mm and an ER70S-6 electrode wire with a diameter of 1.0 mm. The welding process was carried out with an inverter-type GMAW machine using fixed parameters: 120 ampere current, 22 volt voltage, 4 mm/s welding speed, 12 mm stick-out distance, and 15 litre per minute shielding gas flow rate. The specimens were divided into two groups based on the shielding gas, namely pure CO₂ and pure argon. Evaluation of the joint quality was carried out through tensile tests, Vickers hardness tests on three main zones (weld metal, heat affected zone, and base metal), as well as microstructure and visual observations. The results showed that the specimens with argon gas had a higher average tensile strength (460 MPa) than CO₂ (420 MPa). The hardness values were also higher and more even in the argon specimens, with a finer and more uniform microstructure. In conclusion, the use of argon produces welds with better mechanical and metallurgical qualities than CO₂. Therefore, argon is more recommended for welding low carbon steels that require high strength and precision.

KEY WORDS: *GMAW, CO₂, argon, low carbon steel, tensile strength, hardness, microstructure.*

1.0 INTRODUCTION

In the modern industrial world, welding is one of the most important and widely used metal joining processes. Welding not only plays a role in the manufacturing sector,

but is also a vital part of the automotive, construction, shipping, and energy industries. Of the various welding methods available, the Gas Metal Arc Welding (GMAW) process, also known as Metal Inert Gas (MIG) welding, is one of the most widely used techniques due to its efficiency, ease of operation, and relatively clean and consistent weld results.

The GMAW process uses a continuous wire electrode that melts during the process, and requires a shielding gas to protect the molten metal from external environmental influences such as oxygen, nitrogen, and water vapor in the atmosphere. Without this gas protection, the welding results can experience defects such as porosity, oxidation, and non-metallic inclusions that can reduce the integrity of the joint. Therefore, the selection of the type of shielding gas is one of the determining factors in ensuring the quality of the resulting joint.

Shielding gases commonly used in the GMAW process are carbon dioxide (CO₂) and argon, as well as mixtures of the two. Carbon dioxide is a cheap and widely available active gas, but its use often produces more spatter and can reduce aesthetics and increase post-weld work. On the other hand, argon, which is an inert gas, is able to provide better arc stability and smoother weld results, but is relatively more expensive. Each type of gas has unique characteristics that can affect weld penetration, arc stability, spatter levels, and the microstructure quality of the weld metal. A deep understanding of the effect of the type of shielding gas on the characteristics of the weld results is very important, especially in the context of increasing production efficiency and quality control. In this context, this study aims to evaluate and compare the effect of the use of CO₂ and argon shielding gases in the GMAW process on the quality of welded joints. The evaluation was carried out based on parameters such as tensile strength, surface morphology, microstructure, and the type and number of weld defects formed. It is hoped that the results of this study can provide a significant

contribution in selecting the optimal type of shielding gas according to technical and economic needs in industrial applications.

1.1 GMAW Welding

Gas Metal Arc Welding (GMAW) is one of the electric arc welding processes that uses an electrode in the form of a continuous metal wire that melts during welding. This process utilizes the heat from the electric arc that occurs between the electrode wire and the workpiece to melt the base metal and the welding wire, thus forming a joint. This electric arc is protected by a shielding gas that is supplied continuously to prevent contamination from the surrounding air, especially oxygen and nitrogen.

Main Components in GMAW:

1. Power source: Generally uses direct current (DC) positive polarity at the electrode (DCEP) for better arc stability. Kawat elektroda: Biasanya berbahan logam yang sama atau serupa dengan material dasar, digulung dalam gulungan dan ditarik secara otomatis.
2. Welding torch or gun: Directs the wire and shielding gas into the welding area.
3. Shielding gas: Required to protect the weld pool from atmospheric contamination. Generally used inert gas (argon, helium) or active gas (CO₂) or a mixture of them.

Advantages of GMAW Welding

1. High welding speed.
2. Can be used for welding thin to thick metals.
3. The welding process is relatively clean and produces little slag.
4. Suitable for manual, semi-automatic, and automatic welding.
5. Easy to automate, making it suitable for mass production.

Limitations of GMAW Welding

1. Requires more complex and expensive equipment than SMAW welding.
2. Less suitable for open field conditions because the shielding gas can be disturbed by wind.
3. Sensitive to welding distance and position; requires consistent control.

GMAW Welding Applications

GMAW welding is widely used in various industries, such as:

1. Automotive industry: for welding vehicle bodies
2. Manufacturing industry: making steel structures, tanks, and heavy equipment.
3. Shipbuilding and aviation industry: especially for light alloys such as aluminum.
4. Steel construction: for building structures

and bridges.

1.2 CO₂ Gas

Carbon dioxide (CO₂) is one of the most common shielding gases used in the Gas Metal Arc Welding (GMAW) process, especially for welding carbon steel. Unlike argon which is inert, CO₂ is classified as an active gas, because it can react with molten metal during the welding process. However, pure CO₂ still provides sufficient atmospheric protection for molten metal from direct oxidation by air.

CO₂ User Benefits

1. Deep Penetration: CO₂ produces a hot and high energy welding arc, thus creating deep penetration. This is very useful for welding thick plates or structural joints that require high strength.
2. Lower Cost: Pure CO₂ has a lower cost compared to noble gases such as argon, making it more economical especially for mass production.
3. High Availability: Easily available commercially in gas cylinder or bulk form.

Disadvantages of Using CO₂

1. High Spatter: CO₂ welding tends to produce more spatter than argon or mixed gases. This can reduce the aesthetics of the weld and increase post-weld clean-up time.
2. Less Stable Arc: CO₂ produces more volatile and rough arc, requiring more operator skill to maintain quality.
3. Poor Weld Surface Quality: Due to the high arc energy and excessive spatter, the weld surface tends to be rougher and not as smooth as argon welding.

Effect of CO₂ on Microstructure and Joint Mechanics, CO₂ welding processes can increase the cooling rate due to high heat transfer. This can lead to the formation of coarser microstructures such as martensite in carbon steel, which can affect the hardness and brittleness of the joint. However, due to the high penetration, CO₂ welded joints usually have good tensile strength, as long as there are no defects such as porosity or undercuts.

1.2 Common Applications of CO₂ in GMAW

CO₂ is often used in the welding of carbon steel structures such as frames, plates, and pipes, the manufacture of heavy components in the automotive and construction industries. Applications where the efficiency and strength of the joint are more important than the visual appearance of the weld.

1.3 Strategies to Overcome CO₂ Weaknesses

The use of special electrode wires with deoxidizer coating can help reduce welding defects. Optimal welding

parameter settings such as current, voltage, and travel speed can minimize spatter. To obtain a compromise between quality and cost, CO₂ is often mixed with argon (eg: 80% Argon + 20% CO₂) in industrial practice.

1.4 Argon

Argon is an inert gas that does not react with molten metal or the surrounding atmosphere during the welding process. Due to its inert nature, argon is widely used as a shielding gas in various welding processes, including Gas Metal Arc Welding (GMAW), especially for non-ferrous metals such as aluminum, copper, and stainless steel. This gas has a higher specific gravity than air, so it can effectively cover the welding area and provide optimal protection against contamination from oxygen and nitrogen in the atmosphere.

1.4.1 Advantages of Using Argon

- a. High Arc Stability: The electric arc produced when using argon is very stable, smooth, and easy to control. This greatly helps in producing precise weld joints.
- b. a. Low Spatter: The use of argon significantly reduces weld spatter, resulting in a cleaner work area and less post-weld clean up work.
- c. b. Smoother Weld Appearance: The surface of the weld produced with argon tends to be neater, shinier, and free from visual defects.
- d. c. Suitable for Thin Welds and Vertical Positions: Due to its smooth arc and controlled weld heat, argon is excellent for welding thin metals and non-horizontal positions.

1.4.2 Limitations of Argon Use

- a. Shallower Penetration: Although the weld is cleaner, pure argon tends to produce shallower penetration than CO₂. This can be a problem if the joint requires high structural strength.
- b. More Expensive: As a noble gas, argon is much more expensive than CO₂, making it an economic consideration on large projects.
- c. Less Efficient for Thick Carbon Steel: Argon is not as effective as CO₂ in producing high arc energy for large thicknesses of carbon steel.

1.4.3 Effect of Argon on Microstructure and Joint Quality

Due to slower cooling and a cleaner environment, the microstructure of argon welds is usually smoother and more homogeneous. This results in joints with more stable mechanical properties and fewer defects such as porosity and cracks. Joint hardness and ductility tend to be good, especially for alloys and non-ferrous metals.

1.4.4 Common Applications of Argon Gas in GMAW

Argon is commonly used for:

- a. Welding of non-ferrous metals such as aluminum

and its alloys.

- b. Welding of stainless steel for hygienic and aesthetic welds (e.g. in the food or medical industry).
- c. High-precision welding such as in the aerospace and electronics industries.

1.4.5 Use of Argon Mixtures

To overcome the lack of penetration, argon is often mixed with active gases such as CO₂ or O₂ in small amounts. Common mixtures include:

- a. Argon 75% + CO₂ 25% (MIG MIX gas): provides arc stability and moderate penetration.
- b. Argon 98% + O₂ 2%: used in welding alloy or stainless steels.

2.0 METHOD

This study was conducted experimentally to evaluate the effect of using CO₂ and argon shielding gases on the quality of welded joints in the Gas Metal Arc Welding (GMAW) process. This study used low carbon steel as the base material, with plate-shaped specimens measuring 150 mm × 75 mm × 6 mm. As an electrode wire, ER70S-6 type wire with a diameter of 1.0 mm was used, which is suitable for welding carbon steel.

Welding was carried out using an inverter-type GMAW welding machine with consistently controlled parameter settings to ensure the validity of the results. The parameters used included an electric current of 120 amperes, a voltage of 22 volts, a welding speed of 4 mm/s, and a stick-out distance of around 12 mm. The shielding gas flow rate was set at 15 liters per minute. The welding process was carried out in a flat position (1G) with a one-way welding method without electrode swing to maintain the consistency of the weld bead.

Welding specimens were divided into two groups based on the type of shielding gas used. The first group used pure CO₂ gas as a shield, while the second group used pure argon gas. Each group consisted of three specimens to ensure the consistency and accuracy of the data obtained.

After the welding process was completed, the specimens were tested to assess the quality of the welded joints. Tensile testing was carried out using a tensile testing machine to obtain mechanical strength data for the joints in megapascals (MPa). Hardness testing was carried out on three main zones, namely the weld metal, the heat affected zone (HAZ), and the base metal, to determine the distribution of hardness. In addition, the microstructure of the weld was observed using an optical microscope after the sample preparation process through cutting, polishing, and etching. Visual observation was also carried out to assess the physical appearance of the weld, including defects such as porosity, undercuts, and spatter.

The data obtained from the test were then analyzed quantitatively and qualitatively. A comparison was made between the welding results with CO₂ and argon to determine the effect of each gas on the mechanical and visual properties of the weld. The results of this analysis are expected to provide a clear picture of the effectiveness and relative advantages of each type of shielding gas in the GMAW process.

3.0 RESULT

This study was conducted experimentally to evaluate the effect of using CO₂ and argon shielding gases on the quality of welded joints in the Gas Metal Arc Welding (GMAW) process using low carbon steel as the base material. The evaluation was carried out from mechanical, metallurgical, and visual aspects. The following are the results:

1. Tensile Test Results

Tensile testing was conducted to determine the mechanical strength of the welded joint. The average results of three specimens in each shielding gas group are as follows:

Table 1: Tensile test results

Types of Shielding Gases	Average tensile strength
Argon	460
CO ₂	420

2. Vickers Hardness Test

Hardness tests were performed on three areas: Weld Metal, Heat Affected Zone (HAZ), and Base Metal, with the following results:

Table 2: Vickers hardness test

Zone	Argon (HV)	CO ₂
2	15	8 ± 0,5
4	10	10 ± 0,3
6	8	9 ± 0,4

4.0 DISCUSSION

This study experimentally examines the effect of shielding gas types, namely CO₂ and argon, on the quality of welded joints in the Gas Metal Arc Welding (GMAW) process with low carbon steel as the base material. The evaluation was carried out through tensile strength testing and Vickers hardness testing, which reflect the mechanical and metallurgical aspects of the welding results. From the tensile test results, it was obtained that the use of argon produced higher welded joint strength compared to CO₂. The average tensile strength value of the specimen with argon gas reached 460 MPa, while the specimen with CO₂ gas only reached 420 MPa. This difference shows that argon, which is inert and does not react chemically with the molten metal during welding, is able to create a more stable protective environment. This stability helps prevent oxygen from entering the weld pool, thereby reducing the risk of porosity, oxides, or other internal defects that can reduce the mechanical strength of the joint. Meanwhile, CO₂ gas, which is classified as active, tends to decompose into oxygen and carbon monoxide at high temperatures, and the presence of free oxygen can increase the possibility of oxidation reactions, forming inclusions or micro porosity in the joint structure, which ultimately reduces its tensile strength.

Vickers hardness tests on three observed zones possibly including weld metal, heat affected zone (HAZ), and base metal

also showed a similar tendency. The hardness values of specimens welded using argon were generally higher and more stable than CO₂. The zone with the highest hardness value in argon reached 15 HV, while CO₂ was only around 8 HV in the same zone. Higher hardness indicates a finer, denser microstructure that is resistant to local plastic deformation. This is closely related to the cooling rate and stability of the protective atmosphere during the welding process. Argon, which does not react with the molten metal, allows for more controlled solidification and uniform grain formation. In contrast, the use of CO₂ results in faster cooling and the formation of a coarse and less stable microstructure due to thermal and chemical fluctuations during the welding process.

The larger hardness variation in CO₂ specimens also indicates irregularities in the microstructure, which may be due to elemental segregation or non-uniform phase formation. These irregularities not only affect the local hardness but may also reduce the long-term resistance of the joint to dynamic loading or material fatigue. In general, the results of this study indicate that shielding gas plays a very important role in determining the final quality of the welded joint. The selection of the right shielding gas not only directly affects the tensile strength but also has an impact on the microstructural characteristics and hardness distribution which ultimately determine the overall mechanical performance. Thus, the use of argon in welding low-carbon steels is proven to be superior to CO₂, especially for applications requiring high joint quality and good structural consistency.

5.0 CONCLUSION

Based on the results of the experimental research conducted, it can be concluded that the type of shielding gas has a significant effect on the quality of the weld joint in the Gas Metal Arc Welding (GMAW) process with low carbon steel as the base material. The use of argon as a shielding gas produces a weld joint with higher tensile strength and a more even and stable hardness distribution compared to the use of CO₂.

Argon, which is inert, is able to create a more stable welding atmosphere, thereby reducing the risk of internal defect formation such as porosity and oxides. This contributes to the formation of a fine and dense microstructure, which in turn improves the mechanical performance of the weld joint. In contrast, CO₂ gas, which is active, produces more reactive and fluctuating welding conditions, which can trigger the formation of micro defects and reduce tensile strength and local hardness.

Thus, the use of argon has proven to be superior in producing high-quality weld joints mechanically and metallurgically. Argon is more recommended for low carbon steel welding applications that require high joint strength and microstructural stability, especially in industries that demand high joint quality standards.

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