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Investigation of the effects of shielding gas flow rate on weld penetration in MIG welding

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Abstract

In today's industry, the welding process that enables the joining of various materials is of great importance for the success and sustainability of the production process, being used in diverse environments such as open-closed spaces, underwater, among others. This joining method is constantly being developed and diversified in the face of dynamic and rapidly changing industrial conditions along with increasing global competition. In this study, the effect of different protective welding gas flow rates on the penetration of welding has been examined by welding a low carbon steel sheet material and an automation steel-made connecting element using the MIG welding process. While keeping the other welding parameters of the test samples constant, the welding process was carried out at 8 different gas flow rate values. As a result of the measurements, the welding penetration was examined, and the gas flow rates that provide optimum welding penetration values for both the sheet material and the connecting element were determined. The flow rates observed to provide optimum welding penetration values were 10 L/min and 11 L/min. With this study, an environmentally friendly approach was adopted by avoiding excessive use of shielding gas in the welding production process, aiming to achieve a higher quality and less costly product in this production process.

Keywords: Gas welding, gas flow rate, weld penetration.

1. Introduction

The demand for high-strength and cost-effective metal joining methods continues to increase in the manufacturing sector. Welding technology stands out as one of the most commonly used techniques to meet these growing needs. One of the preferred methods in the metal joining process is the gas metal arc welding, also known as MIG welding [1]. Metal inert gas (MIG) welding is a highly convenient welding method for industrial use due to its provision of high welding penetration and rapid production [2]. While this method is favored for joining metal alloys used in various applications such as pressure vessels, automotive components, pipelines, building construction, and aerospace [3], it is primarily preferred for joining alloyed steels, aluminum alloys, and magnesium alloys [4].

MIG welding is a welding procedure characterized by a continuously feed metal wire being heated and melted onto the welding point, enabling the joining of metals with a high deposition rate [5]. This welding process is commonly classified as semi-automatic since the welder controls the welding machine while the metal wire feed and welding current are automatically adjusted. MIG welding technology has become popular

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in various fields for joining metal alloys. The parameters in MIG welding are critical factors that affect the quality, efficiency, and cost of the weld joint [6]. Weld strength in MIG welding is influenced by various parameters such as current, voltage, gas flow rate, wire diameter, plate thickness, torch angle, and many more, making it a complex welding process. Therefore, achieving the desired weld quality involves adjusting the welding process to optimal parameter values [7]. Incorrect parameter settings generally result in poor welding penetration and adversely affect weld quality.

In MIG welding parameter selection, the diameter and composition of the wire electrode and shielding gas should be selected before welding. In the next stage, the parameters that can be adjusted in the first order are welding current, arc voltage and welding speed. Secondary adjustable parameters are torch angle, free wire length, welding direction and shielding gas flow rate [8]. One of the shielding gas mixtures used in the MIG gas welding process is the Ar + CO_2 shielding gas mixture. The composition of the shielding gas also has effects on weld seam strength and melting characteristics. Porosity adversely affects the seam properties and leads to a loss of cross-sectional area, for which the selection of a suitable shielding gas or gas mixture can effectively control the porosity rate [9]. In the shielding gas composition, argon gas does not react and facilitates arc formation [10]. Carbon dioxide gas in the content of shielding welding gases has effects such as preventing oxidation, better penetration, being an economical option and providing a more intense arc formation. If the ratio of carbon dioxide gas is too high, it may cause notch effect by creating a rough surface due to excessive spattering [11].

There are studies on the effect of welding parameters on penetration in the literature. In their study, Yıldız and Karadeniz [12] investigated the welding parameters affecting the penetration in MAG welding. As a result of their study, an increase in penetration was observed with the increase in welding current, arc voltage and gas flow rate, and they also observed that the maximum weld penetration depth was formed at an optimum value with the increase in welding speed. Solahudin and colleagues [13] concluded that with increasing gas flow rate, weld penetration, weld height and weld width decreased after a certain constant and certain value. Noyan [14] investigated the effect of MIG gas arc welding parameters on the welding properties in butt welding of extruded alloy aluminium tubes and one of the results of this study is that more pore defects occur in the weld seam when 12 l/min shielding gas flow rate is used instead of 18 l/min shielding gas flow rate. Tekbaş [15] investigated the microstructure and mechanical properties at different welding parameters using robotic MAG welding method and observed that tensile strength increased with increasing gas flow rate at the same welding speed and amperage values.

This study aimed to investigate the effect of varying flow rates of shielding gas on the weld penetration of different metal pairs through the application of the MIG welding method in a fully automated circular welding process. Based on the results of the penetration tests conducted, the optimum flow rate of the shielding gas was determined. This determination aims to enhance welding quality, leading to the production of stronger products while limiting excessive usage of shielding gas. Consequently, this approach aims to reduce operational costs and exhibit an environmentally friendly approach by minimizing the consumption of shielding gas.

2. Material and Method

In the study, first of all, the products were made ready for welding. Afterwards, the welding process was carried out. After the welding process was completed, a penetration test was performed. Finally, the suitability of the welding processes was checked according to the data obtained from the penetration test results. The processes performed in these stages can be seen in the flow diagram in Figure 1.

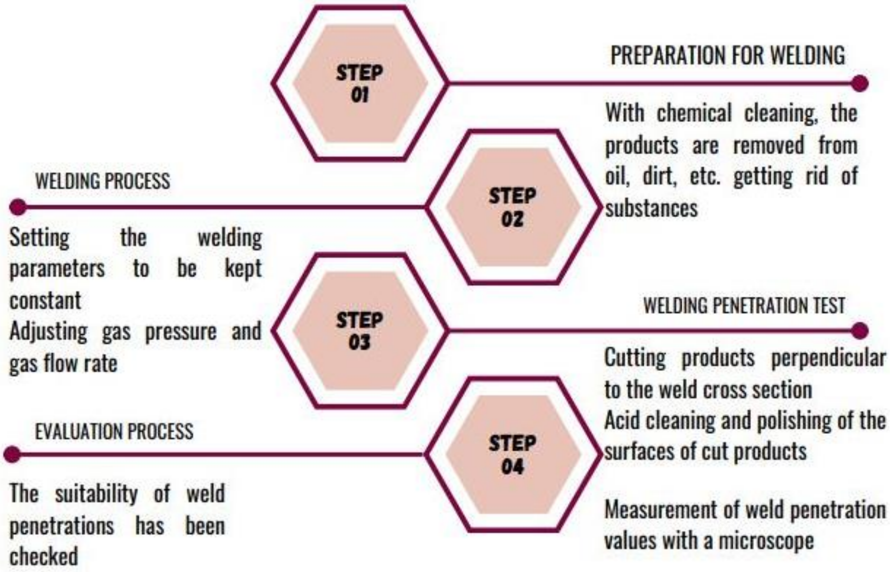

Fig. 1 Study steps

2.1 Materials

In this study, a three mm thick 6224 grade sheet material and a fastener made of free machining steel were welded by MIG welding process. The chemical compositions of 6224 (DD13) sheet material and fastener are shown in Table 1. The mechanical properties of these two steel materials are shown in Table 2**.**

Table 1. Chemical composition of 3 mm 6224 (DD13) sheet metal and fastener

Material	C (%)	Mn (%)	P (%)	S (%)	Si (%)	Al (%)	Cu (%)	Cr (%)	Ni (%)	Ti (%)	V (%)	Mo (%)
6224 grade	0.039	0.250	0.014	0.002	0.026	0.040	0.055	0.036	0.042	0.010	0.006	0.003
Fastener	0.08	1.131	0.081	0.291	0.0107	-	0.104	-	0.042	-	-	0.013

Table 2. Mechanical properties of 3 mm 6224 (DD13) sheet metal and fastener

Material	Yield Strength (N/mm^2)	Tensile Strength (N/mm^2)	Elongation %
6224 (DD13)	269	383	39
Fastener	185.6	651.3	10

In this study, AS SG2 brand welding wire with a diameter of 1 mm was used in the circular MIG welding process of 6224 (DD13) sheet metal and fastener. The chemical composition of the welding wire used is shown in Table 3 and its mechanical properties are shown in Table 4.

Table 3. Chemical composition of welding wire

	C (%)	Mn (%)	P (%)	S (%)	Si (%)	Al (%)	Cu (%)	Cr (%)	Ni (%)	Mo (%)	V (%)	Ti+Zr (%)
Avg.	0.060	1.5	0.005	0.018	0.90	<0.01	0.08	0.04	0.04	0.01	0.01	0.01

Table 4. Mechanical properties of welding wire

Yield Strength (N/mm^2)	Tensile Strength (N/mm^2)	Elongation %
480	560	27

In this study, Ar+CO_2 shielding welding gas was used. The welding process parameters other than gas flow rate were kept constant and circular MIG welding process was carried out at eight different shielding gas flow rates. These gas flow rates are 6 L/min, 7 L/min, 9 L/min, 10 L/min, 11 L/min, 13 L/min, 14 L/min and 18 L/min respectively.

2.2 Preparation of test specimens for welding process

6224 (DD13) sheet metal and free machining steel fasteners were cleaned of foreign materials such as oil, dust, dirt, etc. on the products before the welding process and made ready for the welding process. The ambient temperature where the welding process takes place is 20 °C. The welding parameter values, which were kept constant, were determined by experimental studies carried out prior to this study. These parameter values are given in Table 5. For the welding process, firstly, welding parameter adjustments were made on the welding machine. Then, after the products were placed in their specific welding fixture, the circular MIG welding process was carried out fully automatically at 8 different protective gas flow rates. The images of the welded samples are shown in Figure 2. In this research, only the effect of shielding gas flow rate on weld penetration was focused on, and the other welding parameters were kept constant, and the study process was carried out carefully.

Table 5. Welding parameters

Parameters	Values
Welding Voltage	21.8 V
Welding Current	114 A
Welding Speed	20 cm/min
Wire Feeding Speed	5.6 m/min
Material Thickness	3 mm
Peak Current	0.2 A
Free Wire Length	12 mm

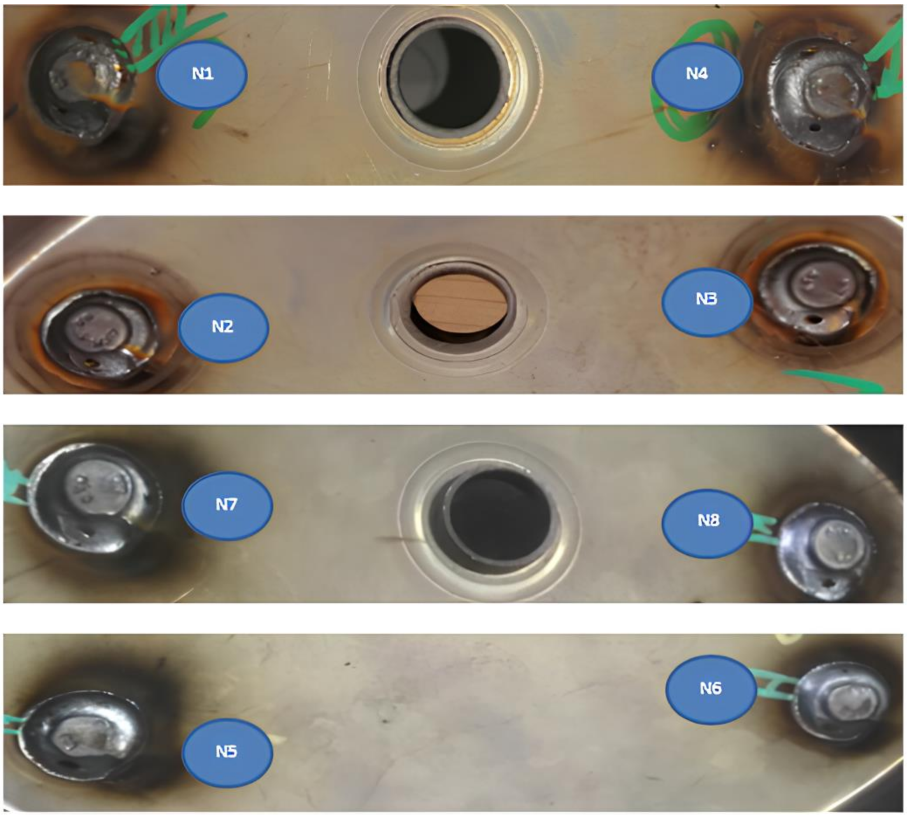

Fig. 2 Finished welded products

2.3 Penetration Test

In order to see the effect of the amount of protective welding gas flow rate on the welded products, a penetration test was performed based on the Quality Level D of the standard TS EN ISO 5817, which is a quality standard that defines various classes and acceptance levels that determine the quality of welds, flaws and defects in the weld structures, weld zone and molten zone. In the penetration test, the product to be tested is first cut from the center of the weld zone at the weld seam width. The weld section of the cut piece is polished with sandpaper. The polished specimens are placed in the prepared acid solution. The samples waiting in the acid solution are removed from the solution and washed with water. Finally, the penetration of the products is examined with the help of a microscope. The process steps of the penetration test are shown in Figure 3.

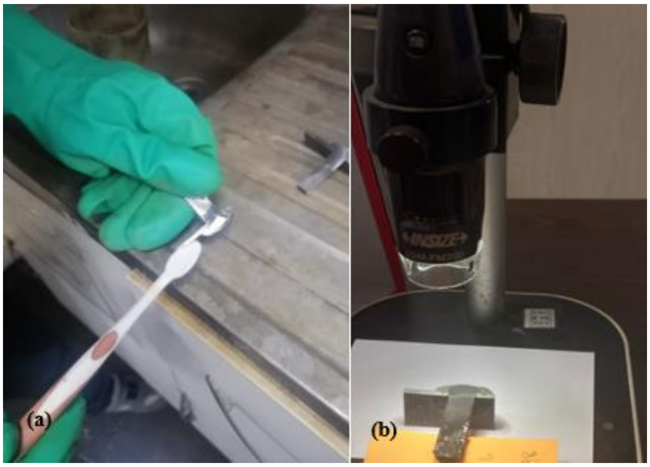

Fig. 3 (a) Acid cleaning and (b) measurement

The weld penetration adequacy of the test samples was compared according to the values shown in Figure 4.

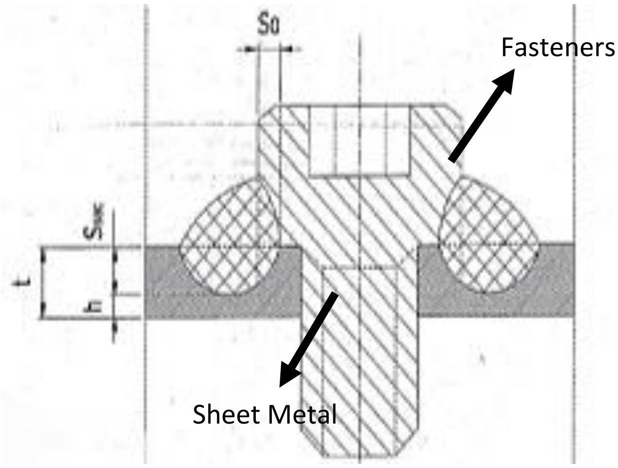

Fig. 4 Weld penetration evaluation parameters

$$60\ t\% \geq S_{sheet} \geq 20\ t\% \quad (1)$$

$$2.4 \geq h \geq 1.2 \quad (2)$$

$$1.5 \geq S_0 \geq 0.5 \quad (3)$$

According to the expressions in (1), (2) and (3), it was decided whether the penetration of the test specimens was sufficient or not. The parameters in the expressions; t is the sheet thickness, Ssheet is the penetration depth in the sheet material and h is the parameter obtained by subtracting the amount of penetration depth from the sheet thickness. The expression S_0 indicates the penetration depth of the weld in the fastener.

3. Results and Discussion

The test samples were successfully welded by MIG welding process. The images of the test specimens joined by MIG welding at different shielding welding gas flow rates, cut perpendicular to the weld section and measured by microscope penetration measurements are given in Figure 5 and 6. In N1 samples, sheet material penetration was less than fastener penetration. In N2 samples, sheet material penetration was higher than fastener penetration. In N3 samples, sheet material penetration was higher than fastener penetration. In N4 samples, sheet metal and fastener penetrations were close to each other. In sample N5, sheet material penetration and fastener penetration were at the same value. In N6 samples, sheet material penetration was higher than fastener penetration. In samples N7, the sheet metal penetration was higher than the fastener penetration and the welding of this specimen was considered as non-conforming due to the low penetration to the fastener. In samples N8, the sheet metal penetration was less than the fastener penetration and the welding of this specimen was considered non-conforming due to the low penetration of the sheet metal.

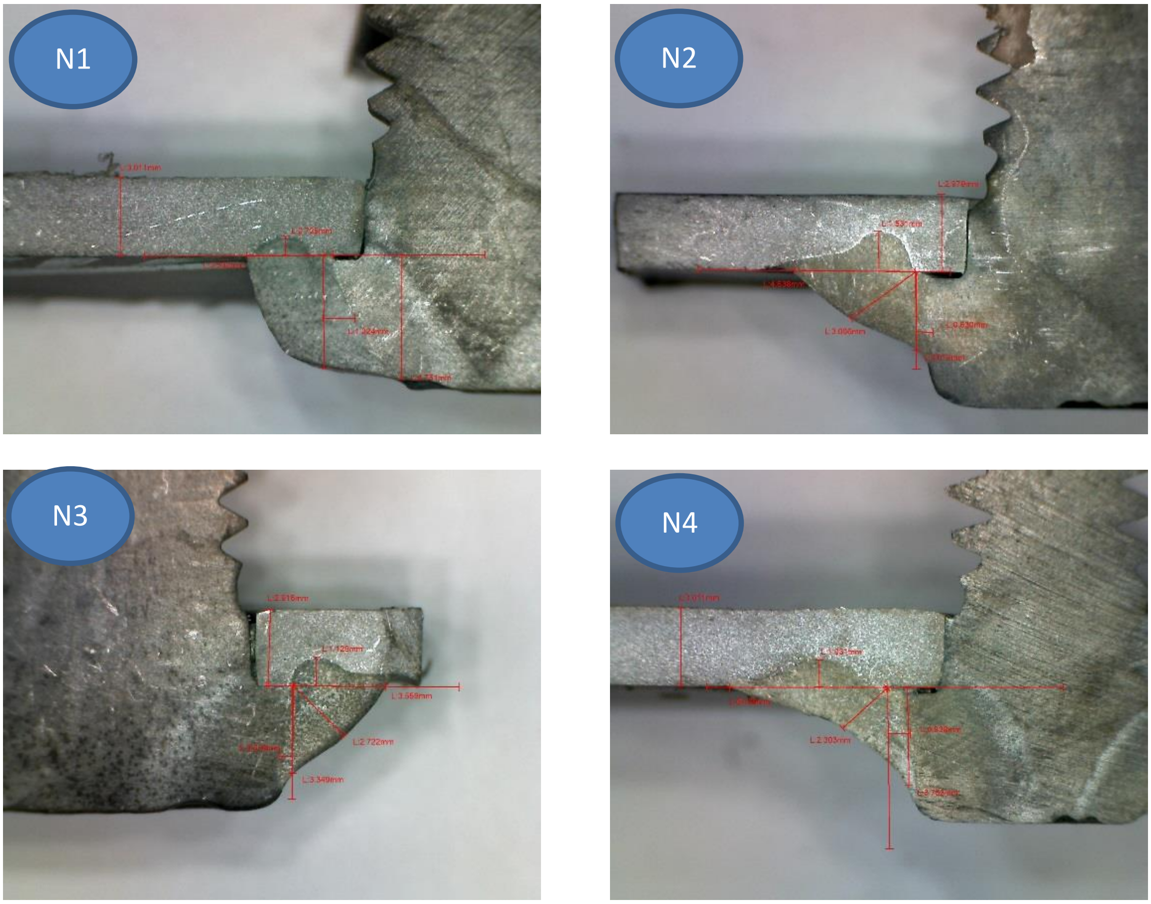

Fig. 5 Penetration test results of the test specimens-1

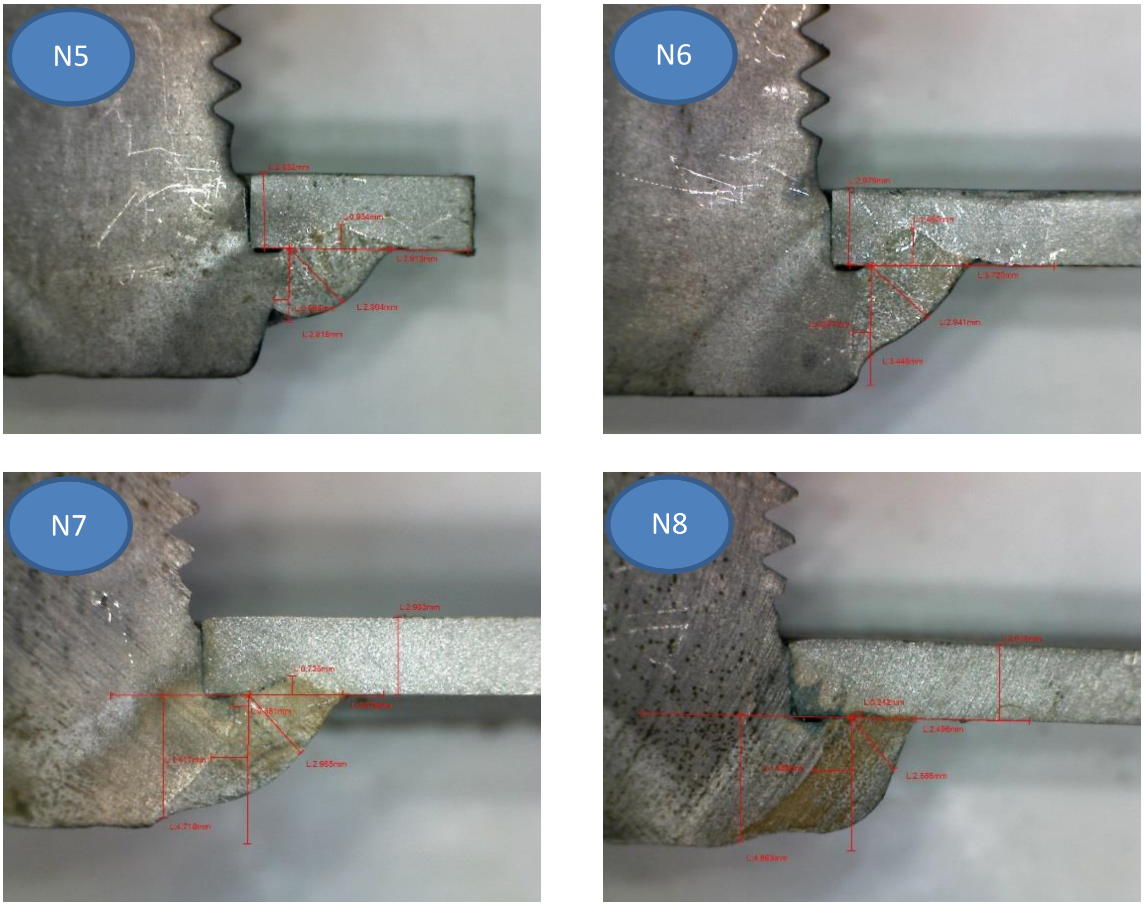

Fig. 6. Penetration test results of the test specimens-2

The penetration results obtained from the images of the test samples cut perpendicular to the weld section in Figure 4 are presented in Table 6.

Table 6. Penetration test results at different welding gas flow rates

Samples	Gas flow rate (L/min)	Penetration (S_{sheet}) (mm)	h (mm)	S_0 (mm)	Availability
N1	6	0.725	2.182	1.353	OK
N2	7	1.531	1.421	0.66	OK
N3	9	1.128	1.821	0.516	OK
N4	10	1.031	1.948	0.838	OK
N5	11	0.934	2.016	0.934	OK
N6	13	1.450	1.610	0.564	OK
N7	14	1.063	1.934	0.403	NO
N8	18	0.224	2.770	1.482	NO

When the graph of S_{sheet} values given in Figure 7 is analyzed, the best penetration value in the sheet material is reached when the shielding welding gas flow rate is 7 L/min and the worst penetration value is reached when the shielding welding gas flow rate is 18 L/min.

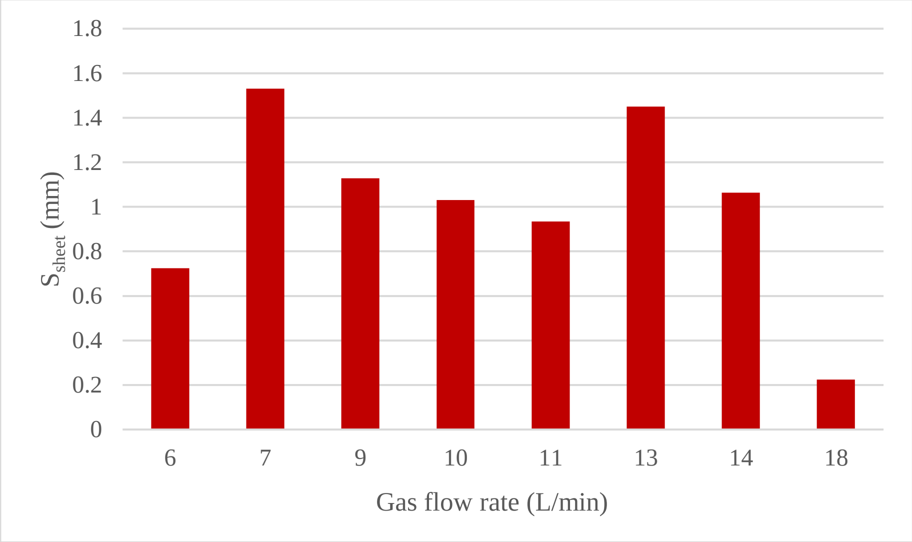

Fig. 7 S_{sheet}-gas flow rate graph

When the graph of S_0 values given in Figure 8 is analyzed, the best penetration value in the fastener is reached when the shielding welding gas flow rate is 18 L/min and the worst penetration value is reached when the shielding welding gas flow rate is 14 L/min.

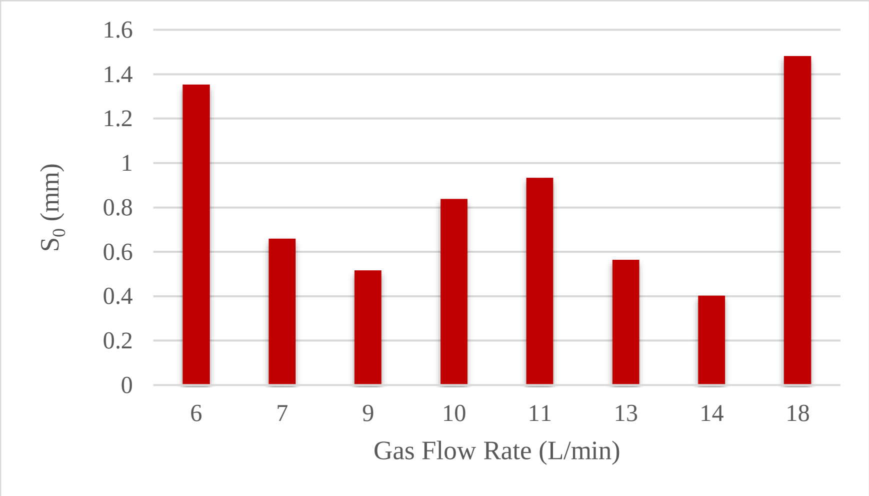

Fig. 8 S_0- gas flow rate graph

It is seen that the shielding welding gas flow rates that provide the most ideal penetration values in terms of S_{sheet} and S_0 values obtained from the penetration test results of the test specimens are 10 L/min and 11 L/min.

4. Conclusion

In this study, 6224 (DD13) sheet metal and free machining steel products were joined by MIG welding at different shielding gas flow rates. The datas obtained from this study:

- Shielding welding gas flow rates of 10 L/min and 11 L/min gave the best results in terms of S_{sheet} and S_0 values.

- At a flow rate of 10 L/min, the weld penetration amount was 34.36% of the sheet thickness, and at a flow rate of 11 L/min, it was 31.13%. Increases and decreases in penetration values occur when the gas flow rate is decreased or increased.
- It should also be noted that the gas flow rate depends on parameters such as torch angle, free wire length, current, voltage, etc., which are kept constant in this study.
- Setting the gas flow rate at appropriate values prevents wasteful gas consumption.

5. Acknowledgment

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