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Analysis of Heat Input in Gas Metal Arc Welding (GMAW) Based on Tensile Strength and Impact of Environmental Improvement

Novi Sukma Drastiawati*, Tri Hartutuk Ningsih, Aris Ansori, Indra Herlamba Siregar, Ahmad Saepuddin, and I Made Arsana

Universitas Negeri Surabaya, Department of Mechanical Engineering, Surabaya, East Java, Indonesia, 60231

Abstract - Sustainable development is a concept that considers the needs of future generations. In the industrial field this concept has been applied such as saving energy, as well as in the field of welding. The aim of this study is welding applications by analyzing heat input on tensile strength and efforts to improve the environment for sustainability. The material used is SS400 Steel. SS400 steel is a material used for the construction of buildings and structures, industrial equipment, industrial machinery, and transportation. The transportation industry, especially Railways, is related to the joining process on each of its components. The method used in Gas Metal Arc Welding (GMAW) with current of 150 A and a voltage of 7.3V, then the welding time is calculated. The further stage is to determine of Heat Input and tensile testing. The welding variable uses a protective gas flow rate of 10 liters/minute and 15 liters/minute. The welding time of 10 liters/minute takes 122 seconds and 180 seconds at 15 liters/minute. Heat Input of 10 liters/minute is 0.60 KJ/mm and 0.83 KJ/mm at 15 liters/minute. The resulting tensile strength at the 10 liters/minute variation is 469.07 MPa and 15 liters/minute is 455.67 MPa. These results show that with welding that takes a shorter time and lower Heat Input, the mechanical strength (tensile strength) produced is still better, thus is one of the advantages of GMAW that can minimize Heat Input for sustainable activities such as of estimated welding time to save energy for environmental improvement.

Keywords: GMAW, heat input, protective gas flow rate, sustainability, welding time

1 Introduction

The development of the transportation industry shows a positive growth trend in 2022. Based on data from the Central Statistics Agency (BPS), the warehousing and transportation sector grew 21.27% in the second quarter, up 5.91% from the first quarter [1]. The policy of improving and changing the face of the national railway has been put forward and included in the 2015-2019 government agenda that develops mass transportation. Railway modes can play an important role as an economic driver of national economic growth by utilizing their comparative advantages as an efficient mass transportation system. Improvements in the transportation sector must be accompanied by innovation to produce products that have high performance and efficiency. The transportation industry, especially Railways, is related to the joining process on each of its components, so it is necessary to

* Corresponding author: novidrastiawati@unesa.ac.id

carry out joining techniques that produce maximum mechanical strength, one of which is welding [1].

JIS SS 400 steel is one of the most commonly used types of steel for general steel structures. It is provided in the form of plates, sheets, flats, beams, and sections. This steel excels in weldability and machinability. It has Density of 7860kg/m^3 and Young Modulus of 190000-210000N/mm^2. This material has a Tensile Strength of 400-510 N/mm^2, 205-245 N/mm^2 Yield Strength, 0.26 of Poisson Ratio, 160 HB of hardness, and melting point at 1430^{o}C. It corresponds to DIN17100 St 44-2, ASTM A36, ASTM A283 Grade D, and EN S 275/BS 43A. The chemical elements contained in this steel include 0.2% C, 0.05% max of S, and 0.05% max of P, Si, and Mn [2].

Welding techniques and engineering are used intensively in manufacturing industries, such as: bridge construction, motor vehicle, cars, shipping industries, aircraft, railways, and pressure vessels. Welding techniques have various advantages for production such as cost-effectiveness, size or dimension, and variety of weld structure shapes. In addition to these advantages, welding techniques cause adverse effects, including: the strength and toughness of the material decreased and welding defect such as cracks and porosity are obtained which cause a lower in the quality of the weld joint [3]. One of the welding processes that is often used is the GMAW (Gas Metal Arc Welding) welding process, which is also called gas arc welding. GMAW welding is a welding process that is able to conduct large amounts of heat at high speeds. GMAW welding has a high arc concentration and better elasticity than other welding methods. Compared with SMAW (Shielded Metal Arc Welding) which has a medium welding speed, GMAW has a faster welding speed. This makes the GMAW welding method faster so that the use of electrical energy becomes more efficient [4].

Heat input research states that the presence of current variations can affect the amount of heat rise and can affect the mechanical properties of SA516 G70 steel material. This material has a low carbon steel with a carbon content of 0.25% (SS400 content of 0.2%) and an elongation of 21% (SS400 21%). The results obtained were in the form of an increase in tensile strength with high heat input due to the increase in welding current variation where the highest tensile strength value was found in the specimen treated at a current strength of 140 A of 536.627 MPa while the smallest value in the specimen without preheat treatment with a current (amperage) of 120 A was 503 MPa [5].

The welding process arc temperature coverage about 6100^{0}C to melting the compounds related to the base metal and the filler metal into atoms, ionizes the shielding gas. Therefore, the existence of vapors and toxic gases, as well as metal vapors, and infrared radiation can be harmful to health [6], [7]. Welding is important for assembly process in manufacturing. This process needs more energy and resources. According to reports, the industrial area provides more than 50% of electricity consumption in the world. The amount of energy consumed by welding processes and other production activities in the industry processes is about 70% of this energy [8].

In previous studies was reported, it was concluded that in the life cycle analysis, the GMAW process shown more efficient than SMAW. GMAW Classification has the least environmental impact due to less energy consumption. Ecological indicators, which indicate relationships between humans and the environment, shows that GMAW classification, with a score of 6.9 out of 10, is preferably than SMAW welding. Sociological indicators, which represent interactions among economy, surrounding, and the society. It has shown that GMAW welding is more efficient thna SMAW welding because of technique improved, increase on the error rate of the operator, and high efficiency. Good performance from technology indicators is GMAW than SMAW welding, score 7.5 of 10 [9].

2 Materials and methods

The research method used in the research is an experimental method. The experimental method is a research procedure carried out to reveal the causal relationship between independent variables and bound variables. The experimental research method is a research method used to find the influence of certain treatments on others under controlled conditions[10]. The experimental method carried out is to research the influence of welding parameters, the welding speed that produces heat input. In this study, alternative materials are used at affordable prices and are easy to find but have almost the same mechanical properties, SS400 with a thickness of 6mm which will be welded using butt joint joints and 1G welding positions. The current used is 150A, voltage is 7.3Volt, and the electrode type ER70S-6 diameter is 0.8 mm and the gap on welding is 2mm. The welding variable uses a protective gas flow rate of 10 liters/minute and 15 liters/minute. Electrode is the main need needed to carry out the welding work process in the construction sector. Various types of electrodes or welding wire are used in the welding process, depending on the type of material to be worked with. One of the welded wires or electrodes that is fed is an electrode that is wrapped as a filler metal in the welding or welding process. The selection of electrodes can determine the welding results and mechanical properties, such as tensile strength.

Table 1. Chemical composition electrode ER70S-6 [11]

Chemical Composition	C	Mn	Si	P	S	Ni	Cr	Mo	V	Cu
Percentage (max %)	0.06 to 0.15	1.4 to 1.85	0.80 to 1.15	0.025	0.035	0.15	0.15	0.15	0.03	0.50

Table 2. Mechanical properties ER70S-6

Electrode	Tensile Test Chary			V-Notch Impact Test
	Yield Strength	Tensile Strength	Elongation	
ER70S-6	(MPa)	(MPa)	(%)	-30°C
	400	480	22	27 J

2.1 Tensile Testing

Tensile test is a material treatment to determine the maximum tensile and strain capabilities of a material. The tensile test itself is carried out by applying an axial force load to the point where the material experiences maximum tension and strain until it breaks or breaks. The purpose of the tensile test is to determine the ability of resistance in pull at a certain level of power. Test standard used AWS B4.0:2016 An American National Standard [12]. Tensile test specimen can be shown in the Fig. 1.

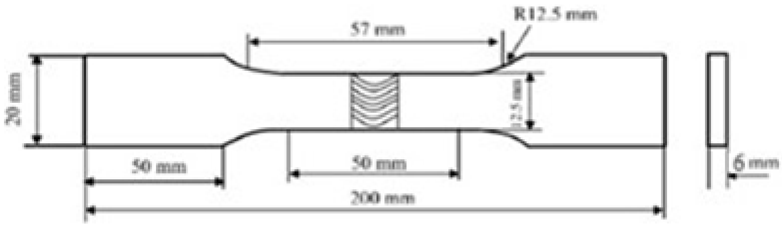

Fig. 1. Tensile test specimen [12].

2.2 Heat Input Calculation

One of the welding plans is the arrangement heat input, it can be done by regulating the current, voltage or adjust welding speed. High of heat input will cause the occurrence of large distortion both angular distortion, curved, or buckling on thin plates. Heat input is a critical parameter for arc welding processes and it should be controlled to confirm quality of welding results. Heat input can be defined as the amount of electrical energy that is supplied during welding process. Heat input can be shown in the following Equation (1).

$$NI = \frac{I \ x \ V}{v} \quad [13](1)$$

with
I = welding current (A)
V = voltage (V)
v = travel speed (mm/sec)
HI = heat input (KJ/mm)

3 Results and discussion

Tensile test result data:

Fig 2. Tensile test specimens used for 10 liters/minute variable.

Fig 3. Tensile test specimens used for 15 liters/minute variable.

The tensile test results on the specimen shown the fracture is located in the gauge length and the right at the gauge length.

Table 3. Tensile test result data

Specimen		b (mm)	d (mm)	A (mm^2)	P (Kg)	Tensile strength (σ =P/A0)(MPa)	Average tensile strength(MPa)	Heat Input (KJ/mm)	Welding Time (s)
10 liters/ minute	1	12.5	6	75	3543.80	472.50	469.07	0.60	122
	2	12.5	6	75	3498.60	466.68			
	3	12.5	6	75	3510.40	468.05			
15 liters/ minute	1	12.5	6	75	3450.40	460.01	455.67	0.83	180
	2	12.5	6	75	3390.80	452.10			
	3	12.5	6	75	3411.80	454.90			

Based on the results of the tensile test obtained and calculated as in the table data above, the next step is to process the data and present it in the form of a graph as shown in the figure below to make it easier to analyze the following data.

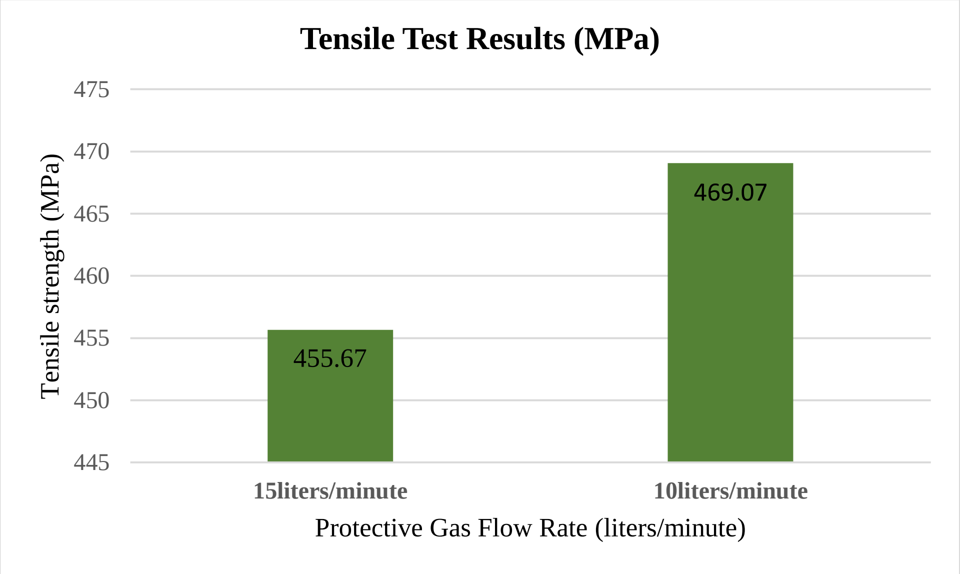

Fig 4. Graph of tensile test results.

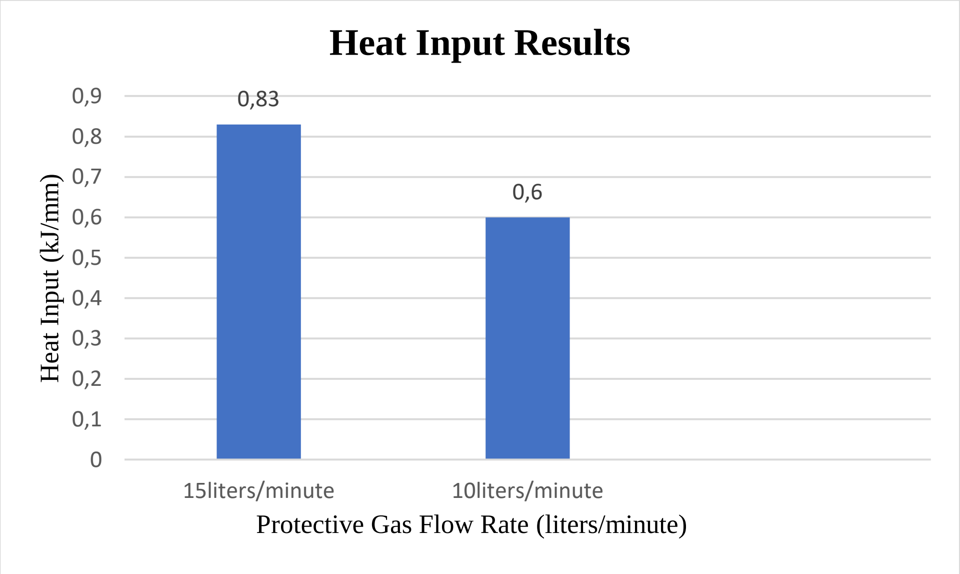

Fig 5. Graph of heat input results.

The welding variable uses a protective gas flow rate of 10 liters/minute and 15 liters/minute. The welding time of 10 liters/minute takes 122 seconds and 180 seconds at 15 liters/minute. Heat Input of 10 liters/minute is 0.60 KJ/mm and 0.83 KJ/mm at 15 liters/minute. The resulting tensile strength at the 10 liters/minute variation is 469.07 MPa and 15 liters/minute is 455.67 MPa. Tensile strength value increased by 3% with shorter welding times. The difference in tensile strength results in the two variables is not too large, but it can be found that with the gas flow rate variable of 10 liters/minute, a higher tensile strength value is obtained. These results show that with welding that takes a shorter time and lower heat input, the mechanical strength (tensile strength) produced is still better and with faster welding times, the consumption energy use can be minimized. Heat input in welding refers to the amount of thermal energy delivered to the workpiece during the welding process. It is determined by factors such as welding current, voltage, travel speed, and the welding process itself. To calculate the heat input, can take the reading of amperage and voltage while welding and divide it by the travel speed. The greater the heat input produced, the greater the energy consumption required to perform welding.

Analysis of the impact of welding on the environment regarding the GMAW welding method compared to SMAW (Shielded Metal Arc Welding), known as Manual Metal Arc Welding (MMAW). In the economic field, there are indicators about the process seen in welding, namely in the form of reducing costs in the use of materials, the impact of protective gases, electrodes where these three things will affect the heat input, as well as improve the efficiency of the welding process per the amount of electricity used. Improving the environmental performance of a production process implies decreasing of consumption energy input, reducing hazardous materials due to process impact, minimizing production costs, minimizing risk, and optimizing working conditions. SMAW method produces more fumes, climate change, human toxicity, low efficiency (60%) and GMAW method produces no slag, high efficiency, high efficiency (80-98%), and fully automated[14], [9], [15]. Referring to some of the analyses above, thus is one of the advantages of GMAW that can minimize heat input for sustainable activities such as of estimated welding time to save energy for environmental improvement.

4 Conclusion

The use of a larger gas flow rate produces a heat input value that is not affected by the resulting tensile strength value, there is no big difference even with a smaller gas flow rate, the tensile strength is better so that GMAW welding can be selected using a gas flow rate of 10 liters per minute (10l/m). These results show that with welding that takes a shorter time and lower heat input, the mechanical strength (tensile strength) produced is still better, thus is one of the advantages of GMAW that can minimize Heat Input for sustainable activities such as of estimated welding time to save energy for environmental improvement. On the long-term welding activities, it will save money, sustainability practices, and will protect the environment and employee’s health.

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