Analysis of the Effect of Cooling Fluid Flow and Welding Time on Tensile Strength in Spot Welding Tools

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Abstract. In this study, the effect of coolant flow and welding time on the joint quality in the spot welding process, especially on St 40 steel material, was evaluated. Spot welding, a common method in the automotive industry, involves the use of electric current to join metal plates by heating and melting the plates. The addition of coolant flow significantly reduces the diameter of the Heat Affected Zone (HAZ) by increasing heat transfer from the electrode to the coolant and maintaining the temperature of the weld material below 1,500 ºC. The lowest HAZ diameter was recorded at a flow of 5 litres/minute, while the highest was at a flow of 2 litres/minute. In addition to the HAZ diameter, the tensile strength of St 40 material is also affected by the balance between cooling rate and welding time. Based on experimental analysis with twenty-five trials at five variations of fluid flow and welding time, as well as tensile test according to ASTM E8M standards, optimal results were obtained at certain fluid flow rates and welding times, namely: 2 litres/minute at 5.0 seconds (96.10 MPa), 3 litres/minute at 6.0 seconds (104.89 MPa), 4 litres/minute at 7.0 seconds (114.00 MPa), and 5 litres/minute at 8.0-9.0 seconds (116.72 MPa and 125.76 MPa).

Keywords: Cooling Fluid Flow, Heat Affected Zone (HAZ), Spot Welding, Tensile Strength

1 Introduction

Today's technology requires us to stay informed about its progress and the times. The development of this technology is closely tied to the advancement of the industrial world, particularly in the fabrication industry (welding), which has seen rapid technological development in the construction and manufacturing sectors. Therefore, welding in the construction and manufacturing sectors is widely used, including bridge construction, shipping, the bodywork industry, and so on. Welding can also be used to repair metal defects in metal casting results and thicken worn metal (Hafiz, 2019). Various types of welding in Indonesia. The welding process that is popularly used in the automotive industry, especially for car bodies or framework, uses spot welding.

Spot welding is a welding method that works using electric current to connect metal plates (Nugroho, 2018). The welding process is by clamping one or more plates using electrodes. The welding cycle involves applying pressure to the plate and then flowing a large amount of electric current. Due to the large amount of electric current given, the part of the plate that is pressed and given current will heat up and melt. The electrode pressure applied to the plate will be released shortly after the current is passed, allowing the welded plate to adhere perfectly.

The quality and strength of spot welding are very important for the design of the life and safety of a vehicle (Iskandar, 2021). The process is easy, economical, and fast, making it suitable for mass production. The heat supply provided is quite accurate and

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regular, and the mechanical properties of the weld are competitive with the parent metal and do not require welding wire. This welding process is neater and does not contain welding slag. The cooling media in this welding process significantly impact the characteristics of the welding results, as they control the quality of optimal welding outcomes, including tensile strength and resistance to external influences (Sarjianto, 2023). The placement of the cooling system in spot welding significantly impacts the welding process of the work material on a large scale. Therefore, the cooling media and welding time are the benchmarks for determining the tensile strength of the steel plate welding joint.

The material used in this study is St 40. It is a material often used in joining different types of materials in the industrial world (Julian, 2019). The use of St 40 steel plate in spot welding is due to its resistance to corrosion, ease of shaping and welding, and its ability to withstand both high and low temperatures, all of which contribute to its high-quality product design (Suprapto, 2023). To determine the mechanical properties of steel joints, tensile tests can be carried out on the material.

Based on the explanation above, the researcher analyzed several welding parameters, namely the effect of coolant flow and time variation on St 40 material on tensile strength values. It is hoped that this study will be able to determine the optimal conditions for the best material joints.

2 Methodology

2.1 Equipment

The spot welding process was conducted using a Krisbow DN-16 spot welding machine (Model KW14-1031). Tensile testing was performed with a Universal Testing Machine (UTM).

2.2 Material

The material used in this study was a 2 mm-thick St 40 steel plate with ASTM E8M tensile test standards.

2.3 Research Procedures

Preparing for Spot Welding Equipment Installation. The spot welding machine that will be used for this research is located in the Mechanical Laboratory of the Mechanical Engineering Department, Politeknik Negeri Bali.

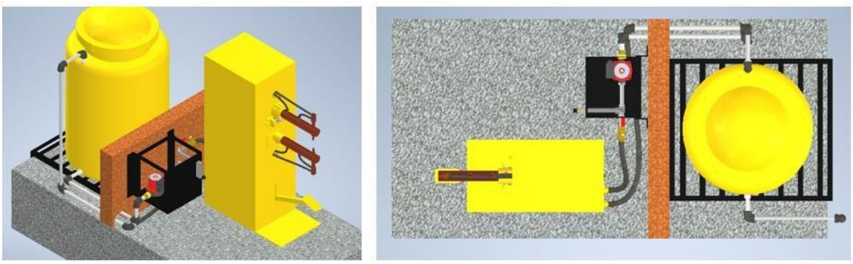

Figure 1. Spot Welding Equipment Installation

Research Procedure Using Spot Welding Tools. A total of 50 St 40 steel plate specimens were prepared, which were then combined into 25 pairs for welding. The preparation of tensile test specimens followed the ASTM E8M (2013) standard. The geometry of the specimens can be seen in Figure 2, which shows the top and side views of the St 40 steel plate. The cooling water flow rate was adjusted on the flow meter according to the requirements of data collection. The spot welding machine was then prepared by setting the current (ampere) and welding time parameters. The timer control switch was positioned to allow the operator to easily cut off the electric current during welding according to the predetermined time. The St 40 steel plates were positioned in a lap joint configuration, as illustrated in Figure 3.

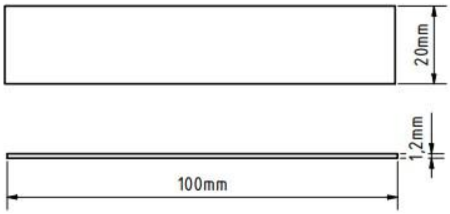

Figure 2. Top and Side View of St 40 Steel Plate

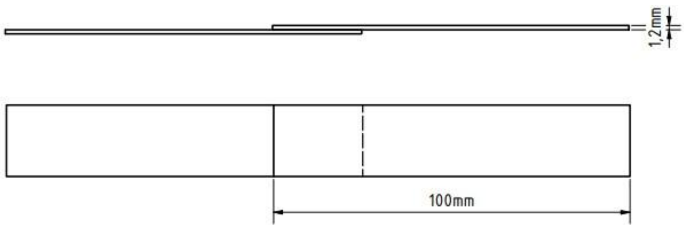

Figure 3. Side and Top View of St 40 Steel Plate

During the welding process, each specimen was placed on the spot welding machine, ensuring that the welding point was aligned with the spot welding electrode. Once the current flowed through the electrode and into the steel plate, the welding time was recorded using a stopwatch to evaluate the influence of fluid flow and welding duration on the quality of the weld. After the set time elapsed, the electric current was automatically switched off by the machine, while the applied welding force was maintained. This allowed the weld to cool under pressure, ensuring proper nugget formation. The results of the spot welding process are presented in Figure 4.

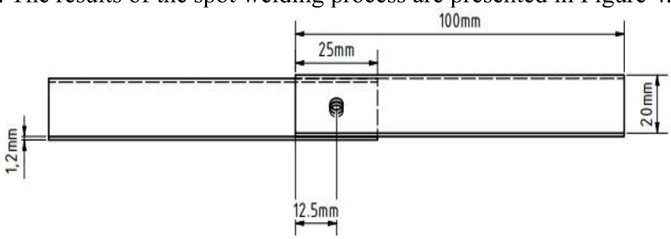

Figure 4. Spot Welding Results on St 40 Steel Plate

Following the welding process, the diameter of the welding nugget and the Heat Affected Zone (HAZ) were measured. The nugget diameter was measured five times using a vernier caliper for each specimen. At the same time, the HAZ was also measured for every specimen under varying fluid flow and time intervals, again using a vernier caliper.

Tensile Testing Process. The preparation of the ASTM E8M tensile test specimens was carried out after the welding process. Once the welded joints were firmly connected and cooled, the specimens were shaped using a milling machine by the ASTM E8M tensile test standard for St 40 steel plates (Adhyawantara, 2023), as shown in Figure 5. Each specimen was fabricated from two identical steel plates with the following dimensions: length 225 mm, width of the clamped area 50 mm, length of the clamped grip area 75 mm, thickness 1.1 mm, width of the unclamped area 30 mm, length of the unclamped area 150 mm, and a radius of 25°. The two steel plates were then joined in a lap joint configuration with an overlap size of 50 mm. After overlapping, the width of the unclamped area remained 30 mm, while the length increased to 250 mm. The thickness doubled to 2.2 mm, and the overall specimen length became 400 mm. The resulting welded specimens are illustrated in Figure 6.

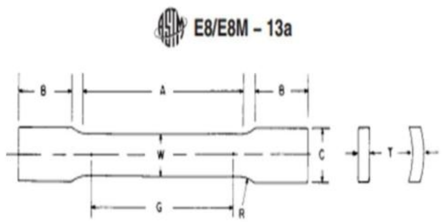

Figure 5. Tensile Test Specimen Standards (Adhyawantara, 2023)

Figure 6. Preparation of Tensile Test Specimens

Before performing the tensile test, measurements were taken of the width and thickness of the overlap area to ensure conformity with the required dimensions. The tensile testing process was then conducted using a Universal Testing Machine (UTM). The results of the tensile test are presented in Figure 7.

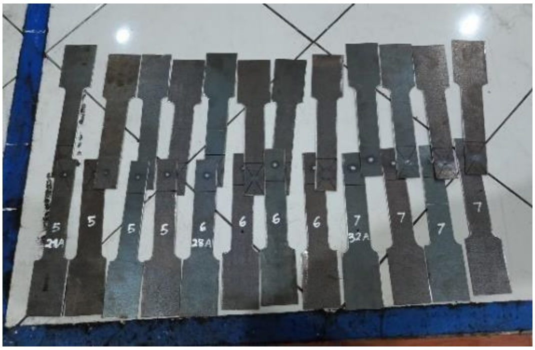

Figure 7. Tensile Test Results

3 Result and Discussion

3.1 Research result

The results of the electrode trace diameter measurements and the HAZ area measured using a vernier caliper can be seen in Tables 1 and 2.

Table 1. Measurement of Weld Nugget Diameter and HAZ

No.	Current (A)	Flow rate (l/min)	Time (s)	Specimen	Diameter	
					Nugget (mm)	HAZ (mm)
1	6	2	5	1	5	8.20
			6	2		9.90
			7	3		10.10
			8	4		11.60
			9	5		12.30
2	6	3	5	1	5	7.00
			6	2		8.40
			7	3		9.90
			8	4		10.50
			9	5		11.95
3	6	4	5	1	5	7.25
			6	2		8.20
			7	3		9.00
			8	4		9.85
			9	5		10.75
4	6	5	5	1	5	6.00
			6	2		7.75
			7	3		8.10
			8	4		9.20
			9	5		10.15

Table 2. Results of HAZ Average Diameter

No.	Flow rate (l/min)	Total number of HAZ (mm)	Average HAZ (mm)
1	2	52.15	10.43
2	3	47.75	9.55
3	4	45.05	9.01
4	5	41.5	8.30

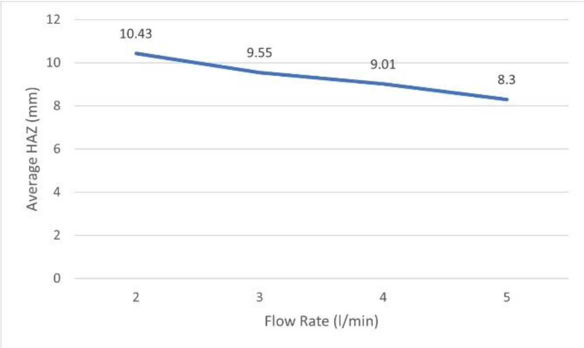

Figure 8. Fluid Flow Graph Against HAZ Diameter

Based on Figure 8, it can be seen that the addition of coolant flow to the welding process causes a decrease in the average diameter of the HAZ resulting from the spot welding process. This decrease is caused by the faster the coolant flow circulates, the more heat transfer from the electrode to the cooling water will be, so that it will increase the ability to maintain the temperature of the electrode and the material to be welded not exceeding a temperature of 1,500 ºC, which results in maintaining the electrode from wear and the weld diameter (weld nugget) at a fixed size of 5.00 mm. When the material is cooled after being heated, especially in the HAZ area, the cooling rate will significantly affect the phase transformation in the material. Rapid cooling tends to produce a hard and brittle martensite structure in the material, while slow cooling allows the formation of a softer and more ductile phase in the material.

It can be seen that the lowest HAZ diameter is at a fluid flow of 5 litres/minute with a result of 8.30 mm, and the highest HAZ diameter is at a fluid flow of 2 litres/minute with a result of 10.43 mm. Therefore, controlling the coolant rate is very important in the spot welding process to avoid problems in the HAZ area and ensure that the material still has the desired mechanical properties.

3.2 Discussion

Phenomena in Tensile Testing. In tensile testing, the tensile stress formula is used to determine the stress experienced by a material when subjected to tensile load. Tensile stress (σ) is calculated by dividing the applied tensile force (F) by the original cross-sectional area of the specimen (Ao). In this study, the tensile stress of each specimen was obtained based on its cross-sectional area and the applied load. These results are summarized in Table 3.

Table 3. Tensile Test Results Data

No.	Flow rate (l/min)	Times (s)	Tensile testing results (MPa)
1	2	5	96.10
		6	72.58
		7	67.43
		8	50.93
		9	41.02
2	3	5	60.34
		6	104.89
		7	85.17
		8	73.45
		9	62.99
3	4	5	52.28
		6	62.38
		7	114.00
		8	92.90
		9	85.00
4	5	5	39.18
		6	45.38
		7	60.41
		8	116.72
		9	125.76

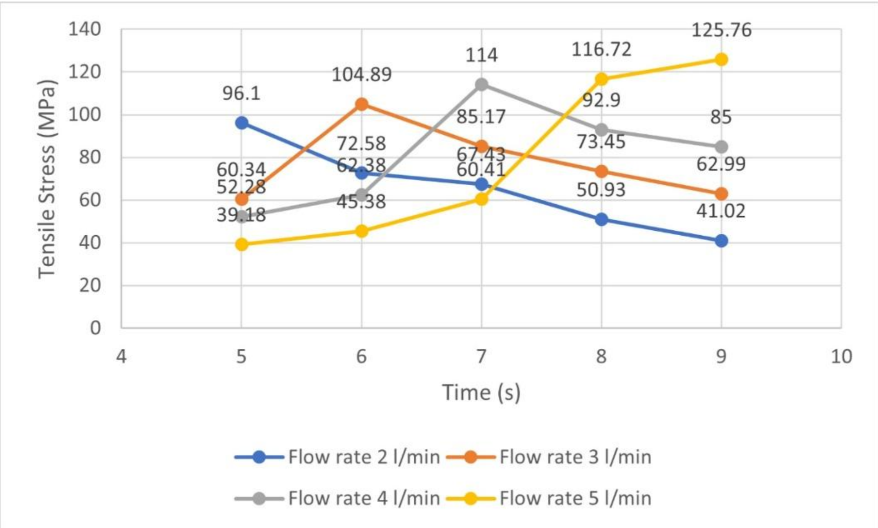

Figure 9. Tensile Stress Versus Welding Time Graph

Based on Figure 9, it is evident that the higher the tensile stress applied to the St 40 material, the greater the control over the coolant flow rate, which is directly proportional to the welding time. This is because when the cooling is too fast or the time is too short which causes a brittle joint and the melting point of the material during the welding process is not achieved, resulting in a very low tensile stress value, and vice versa, slow cooling and the right welding time help achieve the most optimal tensile strength by maintaining the structural integrity of the welded joint.

The figure above shows that a flow rate of 2 litres/minute at a welding time of 5.0 seconds with a tensile stress result of 96.10 MPa is optimal for cooling the St 40 material during the welding process, compared to a fluid flow of 3.4.5 litres/minute at the same time and welding time of 6.0, 7.0, 8.0, 9.0 in different fluid variations.

The flow rate of 3 litres/minute at a welding time of 6.0 seconds with a tensile stress result of 104.89 MPa has optimally cooled the St 40 material during the welding process, compared to a fluid flow of 2.4.5 litres/minute at the same time and welding time of 5.0, 7.0, 8.0, 9.0 in different fluid variations.

The flow rate of 4 litres/minute at a welding time of 7.0 seconds with a tensile stress result of 114.00 MPa is optimal in cooling the St 40 material during the welding process, compared to a fluid flow of 2, 3, and 5 litres/minute at the same time and welding time of 5.0, 6.0, 8.0, 9.0 in different fluid variations.

The flow rate of 5 litres/minute at a welding time of 8.0, 9.0 seconds with a tensile stress result of 116.72 and 125.76 MPa has optimally cooled the St 40 material during the welding process, compared to a fluid flow of 2, 3, and 4 litres/minute at the same time and welding time of 5.0, 6.0, 7.0 in different fluid variations.

4 Conclusion

From the results of the research and analysis, it can be concluded that the addition of coolant flow in the spot welding process significantly reduces the HAZ diameter and influences the tensile stress of St 40 material. Faster fluid flow improves heat transfer from the electrode to the coolant, helping to keep the electrode and weld material temperatures below 1,500 ºC, which reduces electrode wear and maintains a stable weld nugget size of 5.00 mm. For example, at a flow rate of 5 litres/minute, the HAZ diameter was reduced to 8.30 mm, while at a slower flow rate of 2 litres/minute, the diameter reached 10.43 mm. However, this result does not necessarily guarantee an optimal tensile strength value, indicating that effective control of the cooling rate is crucial to optimizing the quality of the weld joint and ensuring that the material retains the desired mechanical properties.

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