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Impact of Cooling Media on The Tensile Strength of SMAW Welding on AISI 1060 Carbon Steel

Marthen Paloboran[1*], Thesya Atarezcha Pangruruk[2], Thomas Pagasis[3], Rey Rahmad[1]

[1]*Automotive Engineering Education Department, Faculty of Engineering, Universitas Negeri Makassar, Indonesia*
[2]*Statistics Department, Faculty of Mathematics and Natural Science, Mulawarman University, Samarinda, Indonesia*
[3]*Mechanical Engineering Department, Faculty of Engineering, Cendrawasih University, Jayapura, Indonesia*

[*)] Corresponding author(s)
E-mail: marthen.paloboran@unm.ac.id

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Abstract

The cooling process of steel after undergoing the welding process will affect the changes in the microstructure of the steel and will also have an impact on the tensile strength, elasticity and strain and brittleness of the steel. This study aims to determine the mechanical properties of AISI 1060 steel, including tensile strength, elasticity, and length increase after the material goes through the welding process. The welding method applied in this study is V-weld with a position of 1G, which is carried out on 9 specimens with dimensions of 200 x 20 x 8 mm (L x W x T). The welded specimens are then cooled for 10 minutes before tensile testing is carried out. The results of the study showed that the used oil cooling medium has a greater tensile strength compared to the cooling media of tap water and well water. The high tensile strength value causes the steel to undergo a greater strain process, resulting in strain values of 2.2380%, 0.053%, and 0.1063% for steel cooled with used oil, tap water, and well water, respectively.

Keywords: *AISI 1060; Carbon steel; SMAW welding; Tensile test; 1G position*

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1. Introduction

The construction industry is progressing rapidly, particularly with the advancement of materials used across various fields, especially steel. This development is attributed to factors such as strength, durability, affordability, and versatility in shaping (Dsilva et al., 2023; Firoozi et al., 2024). However, not all construction materials can be fabricated to the desired size and shape, which highlights the need for material forming or joining technologies, with welding being a key technique (Fydrych et al., 2023). Currently, there are at least 15 different types of welding, ranging from Gas Metal Arc Welding (GMAW) to Atomic Hydrogen Welding (AHW), each with its own advantages and disadvantages (Coldiez, 2025). Among these, Shielded Metal Arc Welding (SMAW) is the most widely used metal joining method today. Its popularity stems from its portability, allowing it to be performed in various locations, and its applicability to a wide range of metal materials. Special skills are necessary for welders looking to utilize this type of welding (Liu & Hu, 2021).

Numerous studies have explored SMAW welding technology in various applications. One notable study conducted by Mulyatno & Jokosisworo (2012), focused on determining the tensile strength of ST 42 steel used in marine plates. The findings indicated that the optimum average tensile strength of welded joints occurred in normal joints without any heat treatment, achieving an average tensile strength of 464.50 N/mm². In contrast, the lowest tensile strength was observed in abnormal welded joints that underwent heat treatment at 6000°C, resulting in an average tensile strength of 351.23 N/mm².

SMAW welding was performed to compare the mechanical properties of S45C and SKD11 steel using AWS E 6016 electrodes across different welding positions. The results indicated that S45C steel exhibited a higher hardness value than SKD11 steel in the 1G and 2G positions, while SKD11 steel was superior in the 3G position (Ramadhan et al., 2023). Additionally, Matin et al. (2024) studied the tensile strength, bending strength, and microstructural changes of API 5L X52 material with variations in SMAW welding current. In their study, the welding current was varied to 70 A, 100 A, and 115 A. The findings revealed that as the welding current increased, both the tensile strength and flexural strength of the material also increased.

Patil & Kadam (2021), conducted a study on the microstructural changes that occur when joining stainless steel 304 with mild steel 1018. In their process, they used a consumable stainless steel 309L grade electrode with a diameter of 3.15 mm. The results indicated that the likelihood of carbide precipitation in the material was low when using a low welding current, but the risk increased with higher welding currents.

Enhancing the quality and mechanical properties of materials involves not only selecting the right welding technology but also utilizing a cooling medium following the welding process (Pandey et al., 2018). A study investigated the microstructural changes and improved welding quality of AA-2219-T6 alloy steel using four different cooling mediums: normal air, fan, water, and a mixture of water and oil (Hussain et al., 2024). The results indicated that at a temperature of 55°C, using water as a cooling medium produced the highest particle density of Al2Cu in the welds of AA-2219-T6. Furthermore, the hardness and mechanical properties of the alloy were found to be superior when water was used compared to the other cooling media.

A study similar to the one conducted by Kumar et al. (2022), examined friction stir-welded (FSW) materials of AA2014 and AA7075 using three different cooling methods: conventional air cooling (CAC), forced air cooling (FAC), and water flow cooling (WFC). The results indicated that water flow cooling produced better tensile strength, hardness, and elongation compared to the other cooling methods. Additionally, a study by Ates & Kaya (2014) analyzed the mechanical properties and microstructure of AISI 304 stainless steel joined with AISI 1060 carbon steel through a friction welding process. The findings revealed that the tensile strength of the friction welding joints increased with higher friction and compressive pressures. It was also noted that the tensile strength on the AISI 304 stainless steel side was greater than that of the AISI 1060 steel.

Table 1. Components of AISI 1060 Steel

Elements	Content (%)
Iron, Fe	98.35 – 98.85
Manganese, Mn	0.60 – 0.90
Carbon, C	0.55 – 0.66
Sulfur, S	≤ 0.050
Phosphorous, P	≤ 0.040

Source: MachineMFG (2024)

This study aims to determine the tensile strength of AISI 1060 medium carbon steel by using different cooling media, specifically well water, tap water, and used oil. AISI 1060 steel has been selected due to its widespread application in the industrial sector, particularly in aircraft and vehicle components, owing to its strong, durable, and versatile properties. The use of tap water as a cooling medium, which has a different mineral composition compared to well water, will provide new insights and information regarding the tensile strength of AISI 1060 steel.

This test involves using several types of coolants, as each type has a different cooling rate. These varying cooling rates influence the material's microstructure, hardening rate, distortion, and stress (Ngafwan et al., 2024; Yang et al., 2023). Generally, a faster cooling rate yields greater hardness in the material compared to a slower cooling rate (Rahman et al., 2025; Yulianto et al., 2025). Rapid cooling creates a uniform and dense microstructure, enhances the depth of the hardening process, reduces material distortion, and increases stress levels (Priyambodo et al., 2023; Shen et al., 2022).

2. Materials and Methods

This study aims to investigate how the choice of cooling media—well water, tap water, and used oil—affects the tensile strength of AISI 1060 carbon steel. The components and properties of AISI 1060 carbon steel are presented in Tables 1 and 2.

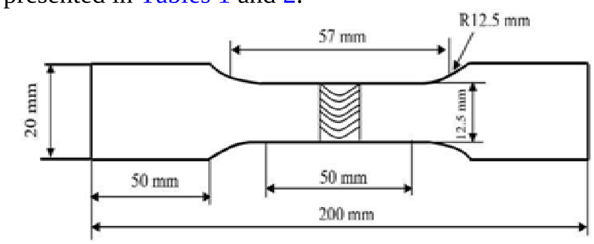

Figure 1. Details of the Dimensions of the AISI 1060 Steel Material Specimen

Table 2. Properties of AISI 1060 Steel

Properties (Unit)	-
Density (g/cm^3)	7.85
Melting point (ºC)	1,510
Tensile strength, ultimate (MPa)	620
Tensile strength, yield (MPa)	485
Modulus of elasticity (GPa)	190-210
Bulk modulus (typical for steel), (GPa)	140
Shear modulus (typical for steel), (GPa)	80
Poisson’s ratio	0.27–0.30
Elongation at break (in 50 mm)	10%
Reduction of area	45%
Hardness, Brinell	183
Hardness, Knoop	204
Hardness, Rockwell B	89
Hardness, Vickers	192
Th. expansion co-efficient (µm/m°C)	11
Th. conductivity (W/mK)	49.8

Source: MachineMFG (2024)

A total of 9 specimens were used, with 3 specimens allocated for each of the 3 repetitions per cooling medium. Each specimen measured 200 mm in length and 8 mm in thickness, as detailed in Figure 1. The cooling process lasted 10 minutes, with pH levels of 7.4 for tap water and 6.6 for well water. The electrode wires used were Kobelco LB-52U E7016 and LB-52 E7018, both 2.6 mm. V-weld welding was performed in the 1G position, with weld sizes shown in Figure 2, while an example of a specimen is shown in Figure 3. The tensile testing took place at the Makassar City Work Training Centre, while specimen preparation and welding were conducted at the Automotive Engineering Education Laboratory, Makassar State University.

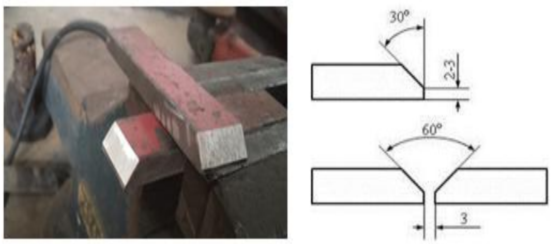

Figure 2. Shape and Size of V-weld

Figure 3. Example of a Specimen for Tensile Testing

The cooling method and media used in this test are considerably more effective than those in similar studies. By maintaining the same shape and size of the specimen, along with a consistent cooling time, we can effectively control the material's cooling rate. Additionally, the type of cooling medium employed is commonly found in everyday life and does not require any further processing or treatment, making it both readily available and affordable.

3. Result and Discussion

3.1. Tensile Test Results with Tap Water Cooling Medium

After conducting three tests for each cooling medium, this section will focus on calculating and analyzing material properties, which include average maximum stress, maximum tensile stress, elongation, maximum tensile strain, and elastic modulus values.

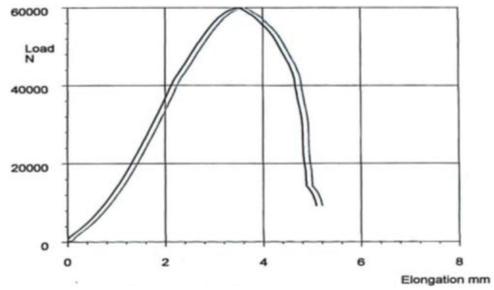

Figure 4. Tensile Test Graph of Specimen-1 for Tap Water Cooling Media

Table 3. Data from the Test Results of Specimen-1 for Tap Water Cooling Media

Machine name	RTF			Test type	Tension		
Strain input 1	Not used			Test speed	5.0 mm/min		
Chart speed OFF				Machine rigidity	0 mm/kN		
Point data(Stress)	572.23	0	572.23	Point data(Strain)	0	0	0
MPa	0	0	0	%GL	0	0	0
Elastic modulus anal.	Interval	1E-006	0.0001	Initial sample length	Distance	75 mm	
Stress	Pitch	5E-006 MPa		Origin of elongation	Init. load	0.3 %RO	
Elong adjust	No			Break point measurem	0.5 N		
Save SS curve	Yes						

Test date	2024/03/12	Temperature	25 C
Humidity	60 %RH	Sample name	Baja Aisi 1060 Media Pendingin
Lot No.		Preparation	
Operator	Haeruddin Hafid,S.T.,M.T.	User	Rey Rahmad
Comment 1	Pendingin Air PDAM	Comment 2	Sample 1

TestID=2380 Test No	Width mm	Thickness mm	Sectional ar mm2	Maximum poin Load N	Break point Elongation mm	Upper yield Stress N/mm2	Lower yield Stress N/mm2	Elastic modu N/mm2	Elastic modu N/mm2
1	12.500	8.0000	100.00	59873.	-0.0597	598.73	*******	9336.4	9336.4

TestID=2380 Test No	Young N/mm2	ElasticSlope N/mm
1	9336.4	12449.

Tensile testing was conducted at the Makassar Vocational Training and Productivity Center to determine the material properties after a cooling process using tap water. The results showed a maximum tensile force of 62,497 kN and a maximum tensile stress of 624.97 MPa. The material experienced an elongation of 0.1062 mm, resulting in a maximum strain of 0.053%. With these figures, the calculated elastic modulus value of the material is 1176.97 GPa. The results of the material testing using tap water as the cooling medium are illustrated in Figure 4 and summarized in Table 3.

3.2. Tensile Test Results with used Oil Cooling Medium

Testing AISI 1060 carbon steel using used oil as a cooling medium requires applying a maximum tensile force until the material reaches its breaking point. The maximum tensile force for the material increases by 12.8%, or 8 kN, compared to when a tap water cooling medium is used. The steel treated with oil cooling demonstrates greater ductility and is less prone to breaking compared to the one cooled with tap water. This is evidenced by the increase in material length, which is 42 times greater than that of the tap water-cooled material. Additionally, the maximum tensile strain of the oil-cooled material is 2.238%.

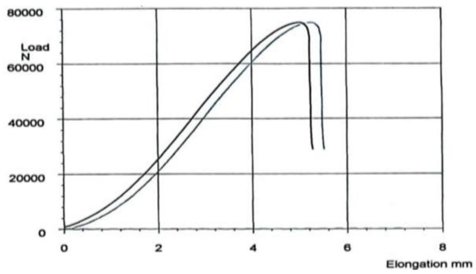

Figure 5. Tensile Test Graph of Specimen-2 for the used Oil Cooling Medium

Table 4. Test Result Data of Specimen-2 for the used Oil Cooling Media

Machine name	RTF			Test type	Tension		
Strain input 1	Not used			Test speed	5.0 mm/min		
Chart speed OFF				Machine rigidity	0 mm/kN		
Point data(Stress)	572.23	0	572.23	Point data(Strain)	0	0	0
MPa	0	0	0	%GL	0	0	0
Elastic modulus anal.	Interval	1E-006	0.0001	Initial sample length	Distance	75 mm	
Stress	Pitch	5E-006 MPa		Origin of elongation	Init. load	0.3 %RO	
Elong adjust	No			Break point measuren	0.5 N		
Save SS curve	Yes						

Test date	2024/03/12	Temperature	25 C
Humidity	60 %RH	Sample name	Baja Aisi 1060 Media Pendingin
Lot No.		Preparation	
Operator	Haeruddin Hafid,S.T.,M.T.	User	Rey Rahmad
Comment 1	Pendingin Oli Bekas	Comment 2	Sample 2

TestID=2384 Test No	Width mm	Thickness mm	Sectional ar mm2	Maximum poin Load N	Break point Elongation mm	Upper yield Stress N/mm2	Lower yield Stress N/mm2	Elastic modu N/mm2	Elastic modu N/mm2
1	12.500	8.0000	100.00	74838.	5.0023	748.38	*******	2777.3	2777.3

TestID=2384 Test No	Young N/mm2	ElasticSlope N/mm
1	2777.3	3703.1

The plasticity of the material cooled with used oil is higher than that of the material cooled with tap water. This is attributed to the lower elastic modulus of the oil-cooled material, which is measured at 31,497 GPa, compared to the tap water-cooled material. The results of the tensile tests for the material using used oil as a cooling medium are detailed in Figure 5 and Table 4.

3.3. *Tensile Test Results with Well-Water-Cooling Medium*

The strength measurement from the tensile test results of AISI 1060 steel using well water as a cooling medium is shown in Figure 6 and Table 5. The figure and table indicate that the maximum tensile force is 59,594 kN, and the maximum tensile stress is 595.94 MPa. These values represent the lowest tensile force and stress compared to the two previous results. After conducting the tensile test, the material elongates by 0.21253 mm from its original length, resulting in a tensile strain of 0.001063, or 0.1063%. Additionally, the elastic modulus is calculated to be 560.62 GPa.

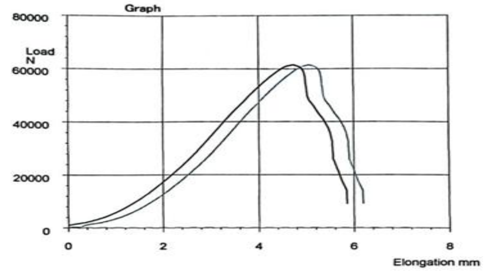

Figure 6. Tensile Test Graph of Specimen-1 for Well Water-Cooling Medium

Table 5. Test Result Data of Specimen-1 for well Water-Cooling Media

Machine name	RTF			Test type	Tension		
Strain input 1	Not used			Test speed	5.0 mm/min		
Chart speed OFF				Machine rigidity	0 mm/kN		
Point data(Stress)	572.23	0	572.23	Point data(Strain)	0	0	0
MPa	0	0	0	%GL	0	0	0
Elastic modulus anal.	Interval	1E-006	0.0001	Initial sample length	Distance	75 mm	
Stress	Pitch	5E-006 MPa		Origin of elongation	Init. load	0.3 %RO	
Elong adjust	No			Break point measuren	0.5 N		
Save SS curve	Yes						

Test date	2024/03/12	Temperature	25 C
Humidity	60 %RH	Sample name	Baja Aisi 1060 Media Pendingin
Lot No.		Preparation	
Operator	Haeruddin Hafid,S.T.,M.T.	User	Rey Rahmad
Comment 1	Pendingin Air Sumur	Comment 2	Sample 1

TestID=2386 Test No	Width mm	Thickness mm	Sectional ar mm2	Maximum poin Load N	Break point Elongation mm	Upper yield Stress N/mm2	Lower yield Stress N/mm2	Elastic modu N/mm2	Elastic modu N/mm2
1	12.500	8.0000	100.00	61396.	-0.2192	613.96	*******	4017.0	4017.0

TestID=2386 Test No	Young N/mm2	ElasticSlope N/mm
1	4017.0	5356.0

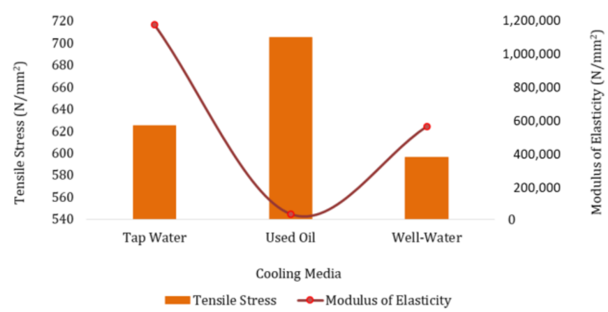

Figure 7. Effect of Cooling Media on Tensile Strength and Elastic Modulus of AISI 1060 Welds

Based on the results of the previous data analysis, it was obtained that the use of used oil cooling media will affect the material's ability to withstand tensile stress by 12.8% greater than tap water and 18.2% from well water, as shown in Figure 7. The opposite occurs in the elastic modulus value of AISI 1060 welding results, where the use of used oil will reduce the material's ability to withstand elastic deformation due to tensile loads. These findings are consistent with research by Tarigan et al. (2023) and Aakarsh et al. (2023) on tensile tests of ST 37 steel and low carbon steel using oil and water as cooling media.

Figure 7 shows that the tap water cooling media will increase the object's ability to return to its original shape after the load is removed se. However, a high elastic modulus number also indicates that the material is difficult to shape (Kostic et al., 2022). The high elastic modulus value suggests that the steel is unable to withstand large fracture loads. In the three figures provided, it is observed that the fracture load for the water-cooling medium is approximately 10 kN, while for the oil cooling medium, it is around 30 kN.

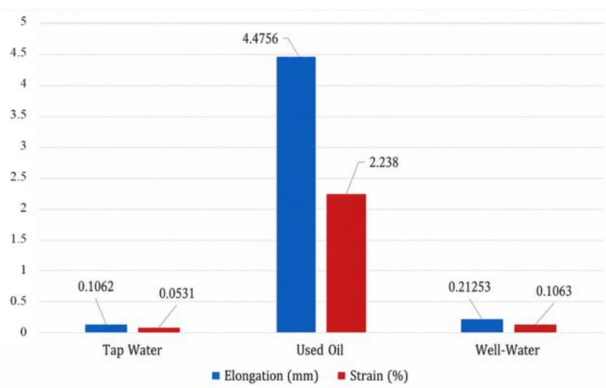

Figure 8. Effect of Cooling Media on Strain and Elongation of AISI 1060 Welds

Figure 8 illustrates the impact of different cooling media on the strain and elongation of AISI 1060 steel. In the figure, the strain of a material is directly proportional to the increase in its length until it reaches its breaking point. It is evident that using used oil as a cooling medium results in a greater strain or elongation compared to other cooling media. This finding further confirms the previous observation that materials exhibiting higher strain are easier to form, and they have a higher breaking point (Urabe, 2022).

4. Conclusion

This research revealed several important findings that may contribute to future studies on the effect of cooling media on the mechanical properties of SMAW-welded AISI 1060 carbon steel. The results showed that the highest tensile strength was achieved when the welded specimens were cooled using used oil, followed by tap water and well water, with tensile strengths of 704.92 N/mm², 624.97 N/mm², and 595.94 N/mm², respectively. Furthermore, the tensile strength was found to be inversely proportional to the elastic modulus. The highest elastic modulus was obtained with tap water cooling (111,697 kN/mm²), followed by well water (560.62 kN/mm²), while used oil produced the lowest elastic modulus (31,498 kN/mm²). These findings indicate that tap water, with a pH of 7.4, provides better elastic properties, whereas used oil enhances tensile strength. In terms of strain, the comparison among used oil, well water, and tap water resulted in a ratio of 42:2:1, indicating that steel cooled in used oil exhibited greater ductility, allowing it to undergo higher deformation before fracture. Overall, the analysis demonstrated that used oil was the most effective cooling medium because it promoted a faster cooling rate and a more effective hardening process, leading to superior tensile strength. Conversely, well water was the least effective cooling medium. In addition, specimens cooled with used oil exhibited greater plasticity and were more susceptible to plastic deformation, whereas specimens cooled with tap water displayed higher elasticity, as reflected by their higher elastic modulus.

5. Acknowledgement

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