Effect of Post-Welding Heat Treatment on ASTM A36 Steel on Tensile Strength

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Abstract
Riding comfort is greatly influenced by the strength and stability of the motorcycle, one of which is the Engine Arm component that connects the frame and the engine.One important factor is the swingarm, which is designed to withstand loads and torsional stiffness.This study aims to examine the effect of air, sand, and furnace cooling media on the SMAW welding of ASTM A36 steel on tensile strength and microstructure after Post Weld Heat Treatment at a temperature of 780°C with a holding time of 60 minutes.The research uses experimental methods with tensile testing to measure tensile strength and strain, as well as microstructural analysis to observe phase changes in the weld metal and Heat Affected Zone (HAZ).The tensile test results show that the air cooling medium produced the highest tensile strength (268.8 MPa) and an average elongation of 8.95%, while the sand medium produced the lowest tensile strength (265.77 MPa) with an elongation of 8.25%.Microstructural analysis revealed that in specimens with sand cooling media, the ferrite phase is dominant, providing toughness, whereas in air cooling media, there is a ferrite phase but with a slight presence of martensite phase structure, resulting in a structure that is soft yet somewhat hard.The research results show that faster cooling media increase tensile strength and alter the microstructure of ASTM A36 steel.

Keywords: Refrigeration Media, Heat Treatment, SMAW Welding, ASTM A36 Steel

I. INTRODUCTION

Motorcycles are currently the main need for the community, especially in Indonesia. In 2021, the Indonesian Motorcycle Industry Association (AISI) reported motorcycle sales reached 5.2 million units, with projected increased demand. Automatic motorcycles dominate the market, with a contribution of 88%. Riding comfort is very important, and one of the main components on an automatic motorcycle is the *Arm Engine* that connects the frame and the engine and functions as a vibration dampen. *The Arm Engine* must be designed to withstand torsional load and stiffness in order to provide stability to the motorcycle.

Figure 1. Location of Engine Mounting on Automatic Motorcycle

On an automatic motorcycle such as the Vario 150, the dynamic force acting on the engine mounting can pose a risk of damage to the joints. Constant movement and vibration may cause weakness or damage to the weld joint, potentially leading to further failure or deformation. The use of *mild steel* as the main material for the engine arm has advantages in terms of strength and durability, but the welding process using the *Shielded Metal Arc Welding* (SMAW) method can cause residual stress and changes in the mechanical properties of the material (Wahyunanta & Drastiawati, 2023).

ASTM A36 steel, which is a low-carbon steel, is often used in SMAW welding because it has good strength and can be formed by machine (Azwinur et al., 2020). Welding using the SMAW method requires special attention to electrode selection, material preparation, electric current, welding position, and welding speed to ensure a good and safe weld joint. Damage to *the Engine Arm* often occurs in the HAZ area caused by excessive pressure and tensile loads. HAZ is the area most susceptible to changes in material properties due to rapid heating during the welding process.

To reduce the possibility of failure in vulnerable areas such as HAZ, a post-welding heat treatment process is carried out which aims to reduce residual stress and improve the mechanical properties of the material. This study focuses on the analysis of the effect of the use of various cooling media during the heat treatment process after welding, as well as its impact on the tensile strength and microstructure of ASTM A36 steel materials. Cooling media such as air and sand are used to regulate the cooling rate to maintain stability and avoid distortion or cracking caused by rapid temperature fluctuations. With the right cooling process, the material can return to a stable state with optimal mechanical properties (Purwanto et al., 2023; Chabiibullah & Rasyid, 2023).

Based on these problems, this study will explore the effect of cooling media variations in the heat treatment process in SMAW welding with ASTM A36 steel material on the tensile strength and microstructure produced. This study aims to identify the cooling medium that can best improve the welding quality, reducing the risk of distortion or cracking in the HZ area. So that finally the results of this study become recommendations that can be applied in the welding industry to optimize processes and increase toughness, especially for applications that involve dynamic loads, such as in motorcycle *Arm* Engines.

II. THEORY

A. SMAW *(Shielded Metal Arc Welding)* *Welding*

SMAW (*Shielded Metal Arc Welding*) is one of the most widely applied welding techniques in various industrial sectors, including biomedical and construction. This process involves the use of flux-coated electrodes that generate an electric arc to melt the parent metal and electrodes, thus forming a sturdy and durable weld joint. Flux serves to protect the weld from oxidation during the welding process, as well as to form a slag layer on top of the weld that functions to protect the molten metal from the influence of air (Sasikumar et al., 2022). The electrodes used in SMAW consist of a metal core and a flux layer that provides protection against molten metals during welding.

In the working principle of SMAW, an electric arc is formed when the tip of the electrode approaches the parent metal, generating enough heat to melt the metal from the electrode and workpiece, which then forms a joint after cooling. This process requires proper regulation of the electric current, arc length, and welding position to ensure that the resulting weld joint is of high quality and free from defects (Aditya Rohman, 2021). The SMAW technique is highly versatile and can be applied to a wide range of welding positions, making it a top choice in the welding industry.

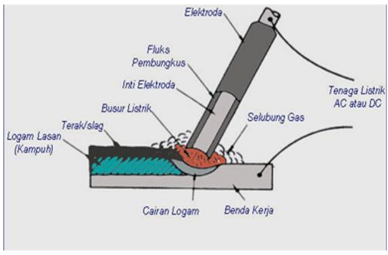

Figure 2. Working Principles of SMAW

B. ASTM A36 Steel Material

ASTM A36 steel is a low-carbon steel that is widely used in welding and construction applications due to its easy-to-form and weldable properties. This steel has a minimum tensile strength of 250 MPa and is often used in structures that do not require high wear resistance. Its mechanical properties, such as toughness and ductility, make ASTM A36 steel suitable for applications involving dynamic loads and heavy structures, such as in building, bridge, and shipping construction. The steel also has a relatively simple chemical composition, with a maximum carbon content of 0.25%, which provides a balance between strength and ductility.

Although ASTM A36 steel has low wear resistance, it remains reliable for structural applications thanks to its good forming and welding capabilities. This steel is also known for its reactivity to electrolytes, which makes it susceptible to corrosion if not properly protected (Randyka, 2019). The Fe-Fe3C diagram is a balance diagram of iron with cementite phase (Fe3C) The requirements for the ASTM A36 Steel Tensile Test are as follows:

Table 1. ASTM A36 Steel Tensile Test Requirements

Tegangan Puncak (Ultimate),	ksi [Mpa]	55 – 80	[400 – 500]
Tegangan Luluh (Yield), min	ksi [Mpa]	36	[250]
Regangan, min	%	23	

Therefore, to begin to understand the process of steel processing, we must first know the Fe-Fe3C balance diagram, which serves to see the reaction of the forming phases that occur, as shown in the figure below:

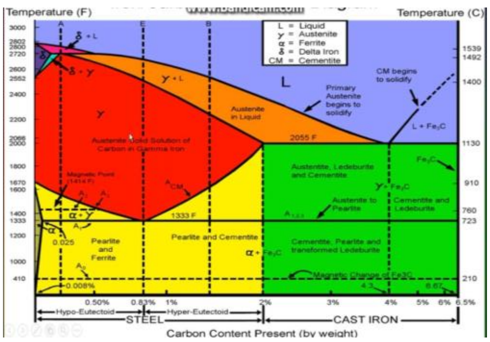

Figure 3. Fe - Fe3C Phase Diagram

C. Annealing

One of the commonly used post-welding heat treatment methods is annealing, Annealing is one of the heat treatment processes carried out on metals as an effort to change the microstructure and improve its mechanical properties, this process involves three main stages, namely: Heating Metal is heated to a certain temperature, usually between 500°C to 980°C, depending on the type of material, Material Immersion is held at that temperature to ensure even heat distribution, Metal Cooling is slowly cooled, usually through air or furnace, the purpose of annealing is to reduce hardness, increase ductility, and overcome internal tensions, among other things. This process is very important in the metallurgical industry to improve the performance of materials after welding or mechanical processes.

In addition to annealing, processes such as hardening and tempering are also often applied to improve the hardness and toughness of the steel after welding. Post-welding heat treatment can be applied using a variety of cooling methods, each of which provides different results depending on the cooling speed and desired structural conditions (Purwanto et al., 2023).

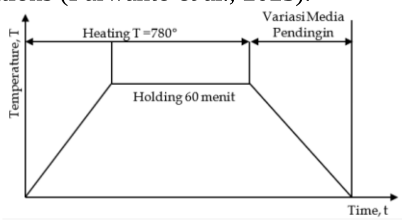

Figure 4. Thermal Cycle Post-Welding Heat Treatment

D. Tensile Testing

Tensile testing is a method used to measure the tensile strength of a material after welding, which is an important indicator of the quality of weld joints. During testing, the material is subjected to a slow tensile load until the material deforms and eventually breaks. The results of these tests are used to determine whether the weld joint meets the strength standards required for industrial applications. Tensile testing also provides information about the extent to which the material can stretch before it eventually fails, which is important information for applications involving dynamic loads (Santoso, 2006).

This tensile testing method also generates a stress-strain curve that illustrates the relationship between the force applied to the material and the change in the length of the material. These curves provide important insights into the strength and flexibility of materials as well as the location of failures in weld joints. The results of tensile testing are very useful for evaluating the quality of welds and for ensuring that the materials used in industrial applications meet the criteria specified by the applicable standards (Wiryosumarto & Okumura, 2000).

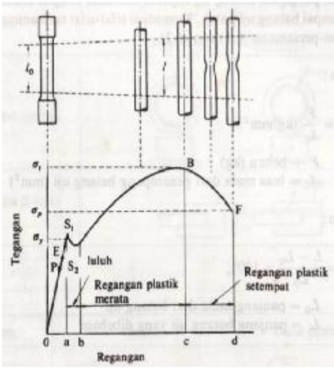

Figure 6. Tension-Stretch Curve

III. METHODS

A. Types of Research

This research uses an experimental method. The purpose of this study is to determine the effect of cooling media on post-welding heat treatment on tensile strength.

B. Research Design

The process begins with the manufacture of specimens, then continues with welding using the E7018 RB 3.2 mm electrode. After welding, the specimen will be processed by heat treatment at 780°C for 60 minutes. After the post-welding heat treatment process, the specimen is cooled using different cooling media, namely air and sand for 60 minutes. After cooling, tensile testing is performed to measure tensile strength, and microstructure analysis is performed using an optical microscope to examine the weld joint and HZ areas.

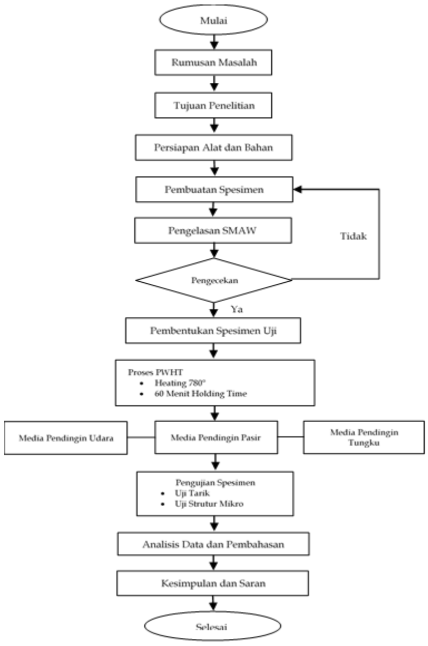

Figure 7. *Flowchart*

C. Data Analysis Techniques

Once the data were collected, the analysis was performed using the IBM SPSS version 16 program to determine whether the variation of the refrigerant media had a significant influence on the tensile strength and microstructure of ASTM A36 steel. The T-test is used to test the hypothesis and check if the significance value is less than 0.05, which indicates that the cooling medium exerts a significant influence on the test results. If the significance value is greater than 0.05, then it can be concluded that there is no significant effect. The results of this analysis will be used to draw conclusions regarding the impact of cooling media in the post-welding heat treatment process of SMAW.

IV. RESULTS AND DISCUSSION

A. Welding Process

The welding process gets good quality welding results.

Figure 8. Welding Results

Figure 8 shows the welding results of ASTM A36 steel with a thickness of 5 mm and E7018 RB electrode of 3.2 mm. The welding technique used is Shielded Metal Arc Welding (SMAW) at the 1G welding position, which is performed by an experienced welder with the same welding machine. The weld field used is a single V-Groove at an angle of 60°.

B. Annealing Process

After welding, the heat treatment process is continued to reduce residual stress and improve the mechanical properties of the material. The heat treatment process is carried out at a temperature of 780°C with a holding time of 60 minutes. This process aims to heat the specimen after welding to allow for repairs in the microstructure and to reduce *internal stress* that can cause cracks or deformation in the weld joint. After heating, the specimen is cooled using a variety of cooling media, namely air and sand to see the effect of each on the mechanical properties and microstructure of the ASTM A36 steel material. The heat treatment process carried out ensures that the material achieves optimal thermal stability, in accordance with welding standards.

Figure 9. Heat Treatment Process

C. Tensile Testing

After the welding and heat treatment process, the specimens are tensile tested in a materials testing laboratory with a tensile testing machine with a capacity of 15,000 kg. The specimens used have standard dimensions according to ASTM E8, which are 200 mm long, 12.5 mm wide, and 5 mm thick. Tensile testing is performed to measure the maximum *tensile strength (Ultimate Tensile Strength*) and strain experienced by the specimen when subjected to tensile loads. This test yields data on tensile and strain stresses on each specimen with different variations of cooling media. The tensile test results showed a difference in tensile strength between specimens with air conditioning and sand media, as can be seen in Table 2.

From the tensile test results, it was obtained that the air cooling medium provided a higher tensile strength with an average of 268.8 MPa, followed by the sand cooling medium of 265.77 MPa. This suggests that a faster cooling rate, such as in an air conditioning medium, results in a higher tensile strength compared to a slower cooling medium.

The difference in tensile strength of the two cooling media after welding is due to the fact that each cooling medium has a different cooling rate , therefore at the fastest cooling rate it will produce a higher tensile strength value while for slow cooling it will have a lower tensile strength value, thus the welding results with air cooling produce the highest tensile strength value. This is because it has the highest cooling rate, and with sand cooling has a lower tensile strength value compared to air the cooling rate is slower. Where if its use requires results with a high tensile strength value, one way that can be done is by treating the heat generated by rapid cooling using an air conditioning medium. However, in slow cooling using sand media, the tensile strength value is low compared to using air.

Table 2. Tensile Test Results

Variasi Media Pendingin	Spesimen	Panjang Awal (mm)	Panjang Akhir (mm)	Massa (Kg)	Beban (N)	Luas Penampang	Tegangan Tarik Max (N/mm^2)	Regangan (%)
PWHT Udara	1	200	220,1	1743,8	17089,44	62,5	273,42	10,05
	2	200	215,37	1717,8	16834,44	62,5	269,35	7,68
	3	200	218,27	1681,4	16477,72	62,5	263,64	9,13
Rata-rata							268,8	8,95
PWHT Pasir	1	200	215,5	1660,6	16237,88	62,5	260,38	7,75
	2	200	216,03	1749,8	17148,04	62,5	274,36	8,01
	3	200	218,02	1674,6	16411,08	62,5	262,57	9,01
Rata-rata							265,77	8,25

D. Microstructure Testing

Microstructure testing was performed to observe phase changes in ASTM A36 steel materials after welding and PWHT. Microstructures were observed in the weld metal and *Heat Affected Zone* (HAZ) regions using optical microscopes. The results of the observations showed that the microstructure in specimens with various cooling media consisted of ferrite, perlite, and martensite phases. The cooling medium used affects the formation of this phase, with a faster cooling rate resulting in more hard, brittle martensite, while slower cooling results in a more ductile ferrite structure.

To determine the percentage of phases in a microstructure, the point count method is used, which calculates points that hit a specific phase in a sample. The results of the calculations showed that in specimens with furnace cooling medium, the ferrite phase was dominant, especially in the HAZ region with 70% ferrite, which provided toughness to the weld joint. On the other hand, in specimens with air conditioning media, although there are only a few martensites, while the ferrite phase is more numerous and noticeably significant.

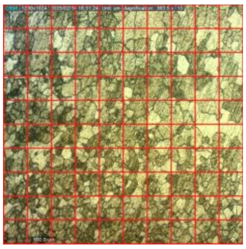

Figure 10. *Point Count* Method in *Weld Metal*

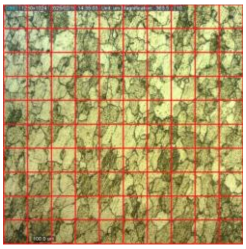

Figure 11. Point *Count* Method on HAZ

V. CONCLUSION

This study results that the cooling medium has a significant influence on the tensile strength and microstructure of ASTM A36 steel welded using SMAW with heat treatment, the tensile test results show that the air conditioning medium produces tensile strength (268.8 MPa) and the sand cooling medium provides a lower tensile strength (265.77 MPa) compared to the air conditioning medium. Microstructure testing revealed that the ferrite phase was more dominant in specimens cooled with furnace media, providing better toughness, whereas martensite formed on rapid cooling produced a hard but brittle structure.

Statistical analysis with the T-test showed significant differences in tensile strength and microstructure between the variations of the cooling media. Overall, this study proves that the selection of the right cooling medium greatly affects the mechanical properties of the welded steel.

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