The Effect of Post Weld Heat Treatment and Its Efficiency on the Axle Housing of 440 Steel Automotive Press Hot

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Abstract. This study discusses the effect of Post Weld Heat Treatment (PWHT) and welding efficiency on the axle housing of Steel Automotive Press Hot (SAPH) 440, where the axle housing is a critical component in automotive vehicles. The research was conducted using the Double-Electrode Gas Metal Arc Welding (DE-GMAW) method for welding efficiency, with butt joints. Macro- and micro-structure tests, as well as hardness tests using the Vickers Test, were also performed. These tests aim to provide insights into welding quality, defects, and the effect of PWHT on SAPH 440. From the results, the ideal welding parameters for Axle Housing welding are 300 A current, 29 V voltage, 140 cm/min welding speed, and 110 cm/min filler wire speed. Macrostructure testing shows that the obtained sizes exceed the standard, and using the DE-GMAW allows axle housing welding to be performed faster than conventional methods. Microstructure testing shows a difference between non-PWHT with ferrite grains of ±5-10 μm and with-PWHT specimens with larger and coarser grains of approximately ±25 μm, due to grain growth. Micro Vickers testing shows that the non-PWHT has a higher hardness value in the heat-affected zone (HAZ) area, around 176.28 HV, while the with-PWHT specimens have a lower hardness value in the HAZ area, around 150.64 HV. However, the with-PWHT is much tougher, proving that grain growth and reduced internal stress have occurred. The selection of SAPH 440, solid wire as filler, and the use of MAG gas are a suitable combination for axle housing welding.

Keywords: Gas Metal Arc Welding, Welding parameter, Microstructure, Mechanical properties, Defects.

1 Introduction

The welding process is a crucial metallurgical process in joining metals by melting part of the base metal and filler metal, with or without pressure and with or without additional metal, using thermal energy to create a homogeneous joint. The demand for automotive products continues to increase, with competitive pricing, good quality, and attractive features. Automotive manufacturers continuously make improvements to meet customer demands, particularly focusing on safety. Therefore, systems that support work efficiency are needed to enhance product productivity.

Almost all manufacturing companies utilize welding technology. In this study, the analysis focuses on the effect of Post Weld Heat Treatment on the welding of Axle Housing, a key component in four-wheeled vehicles. The process involves trials, visual inspection, Post Weld Heat Treatment, macro and microstructure testing, and hardness testing using the Vickers Test. The Double-Electrode GMAW method was used with the expectation that welding could be performed faster with better quality, fulfilling customer requirements.

The objective of this research is to identify good welding results by considering the correct process, and to understand the outcomes of macro testing, micro testing, and hardness testing using the Vickers Test. This study also aims to obtain optimal welding parameters and analyze the effects of Post Weld Heat Treatment on the welding of Axle Housing with SAPH 440 material.

2 Research Methodology

The research process involved several preparations, including selecting the test material, choosing the filler metal, preparing the equipment, consumables, setup, creating the robot program, welding, and testing. The test material used in this study was SAPH 440 with a thickness of 3.2 mm. This material is categorized as Rolled Steel Plate, according to JIS G3113 (1990), and is widely used for automotive structures, particularly Axle Housing. Based on the Schaeffler diagram, the selected filler metal was a solid wire type (roll wire) that matched the chemical composition data of SAPH 440, specifically %Ni and %Cr of 0.2. This is a key requirement for the welding process, as the chemical composition of the base material must match the filler metal. Two rolls of filler metal were used: one for the primary filler and one for the auxiliary filler (No Load Voltage), following the Double-Electrode GMAW method. The gas used in this study was MAG gas (a mixture of 80% Argon and 20% CO_2). Argon gas does not react with oxygen, resulting in a cleaner weld with less spatter compared to using pure CO_2. However, due to the high cost of Argon, 20% CO_2 was added to reduce the overall cost.

After setting up the robot configuration with 6 axes, the welding power source, and other accessories, the test material was mounted on the jig, and an arc test was performed on the test piece using the same material specification, SAPH 440 with a thickness of 3.2 mm. A robot program was then created, and the robot movements were double-checked with the arc off to prevent collisions with the material, jig, or nearby objects. Once the robot's movement was confirmed to be correct, the welding process was initiated by inputting the welding parameters that had been used on the test piece.

In a proper welding process, it is essential to understand and consider aspects such as pre-weld, during welding, and Post Weld Heat Treatment. Pre-Welding involves heating the material to remove contaminants such as oil, rust, water, and grease, which could cause welding defects on the material's surface. During Welding, key welding factors must be considered, such as adjusting welding parameters, monitoring wind speed around the welding area, and applying proper welding techniques. PWHT (Post Weld Heat Treatment) is a heat treatment process applied to the material to relieve residual stress formed during the previous welding process. Residual stress can cause the material to become hard but with low toughness. Therefore, heat treatment is performed to restore the desired properties. The heating process reaches a temperature of 500°C with a heating rate of 40 minutes, followed by soaking for approximately 180 minutes. The material is then cooled to room temperature at a cooling rate of 25 mm/min. **Figs. 1** and **2** shows the robot movement program and set up PWHT temperature for SAPH 440, respectively.

Fig. 1. Robot Movement Program

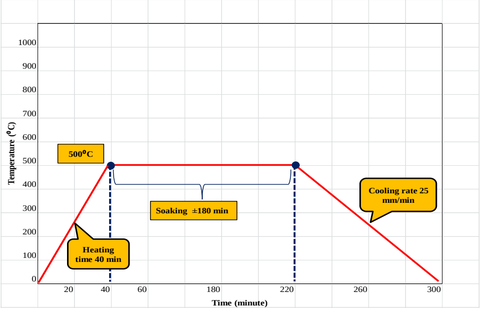
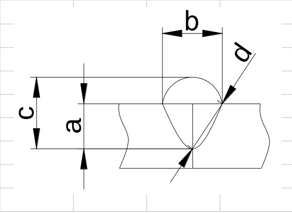


Fig. 2. PWHT Temperature for SAPH 440

Table 1 shows the actual welding parameters and results using the conventional method, which utilizes a single wire input. An improvement was made by using the Double-Electrode GMAW method to enhance welding efficiency. Figure 3 show the standard bead requirements for welding Axle Housing. After several trial processes, the optimal welding results for Axle Housing were achieved with a combination of 300A current, 29V voltage, a welding speed of 140 cm/min, and a filler wire speed of 110 cm/min. This was made possible by using the Double-Electrode GMAW method, which utilizes two wire inputs, one of which serves as the filler. This method results in faster welding and reduces welding defects.

Table 1. Actual conventional welding parameters.

No.	Current (A)	Voltage (V)	Speed (cm/min)	Filler Wire (cm/min)	Shield Gas (ltr)	Bead Size (mm) wide	Bead Size (mm) high	Remark
1	220	23	75	Non	15	5.6	1.98	OK



STANDARD (mm)
a. Min 1.92
b. Min 4.80
c. Min 2.56
d. Min 2.24

Fig. 3. Standard Bead and Welding Penetration for Axle Housing

3 Results and Discussion

Visually, the welding results were free of spatter, the bead size exceeded the standard, and the bead was clean and smooth. The details are shown in the following figure. Thus, the difference in actual conventional welding speed, which was only 75 cm/min, compared to the 140 cm/min achieved using the DE-GMAW method, demonstrates improved welding efficiency with the Double-Electrode GMAW method. In the macro test, two material samples were cut following the process steps of cutting, grinding, sanding, and etching until the macro section results were visible. A visual inspection was performed to check for defects, and the bead and welding penetration were measured to determine if they met the standard, as shown in **Fig. 4**.

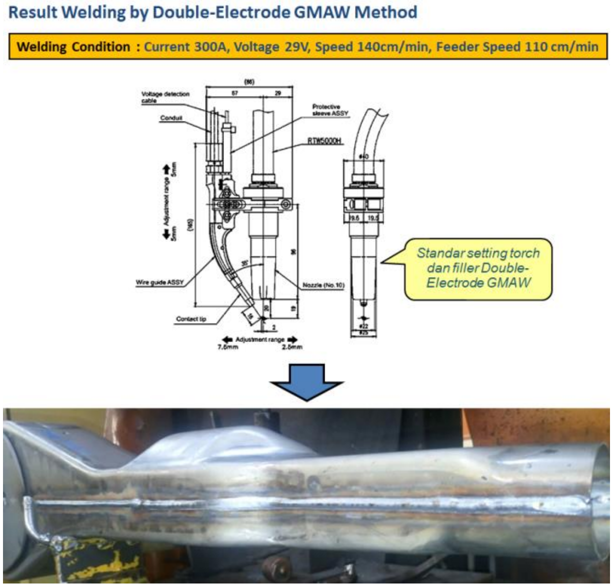


Fig. 4. Axle Housing Welding Results

Fig. 5. show the analysis of point a (deep penetration) minimum standard 1.92 mm, actual 2.16 mm (meets the standard). Point b (bead width) minimum standard 4.80 mm, actual 7.83 mm (meets the standard). Point c (bead height) minimum standard 2.56 mm, actual 4.59 mm (meets the standard). Point d minimum standard 2.24 mm, actual 3.55 mm (meets the standard). The metal grains appear fine. **Fig. 6.** show point a (deep penetration) minimum standard 1.92 mm, actual 1.98 mm (meets the standard). Point b (bead width) minimum standard 4.80 mm, actual 8.07 mm (meets the standard). Point c (bead height) minimum standard 2.56 mm, actual 4.12 mm (meets the standard). Point d minimum standard 2.24 mm, actual 3.23 mm (meets the standard). The metal grains are large and coarse. The data and analysis above indicate that the Axle Housing welding results using the Double-Electrode GMAW method in the macro test are OK and meet the standard requirements.

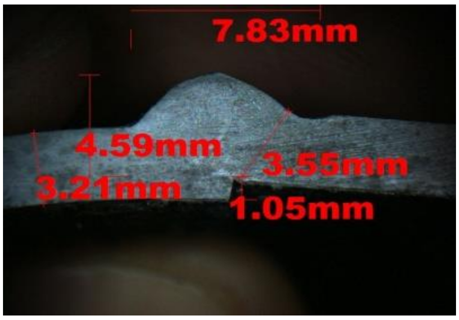


Fig. 5. Macro Test Without PWHT

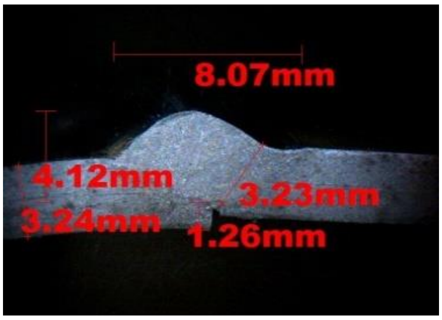


Fig. 6. Macro Test With PWHT

From the two cutting samples, one underwent the PWHT process, and the microstructure of the material was compared. The micro test was performed using Nital 2% etching solution, and the study was conducted at three magnifications: 100x on the base metal, 200x on the HAZ, and 500x on the weld metal. **Figs. 7** and **8** shows the differences between the Non-PWHT and PWHT materials at 100x magnification with a scale of 200 µm in the base metal area, and at 200x magnification with a scale of 100 µm in the HAZ area.

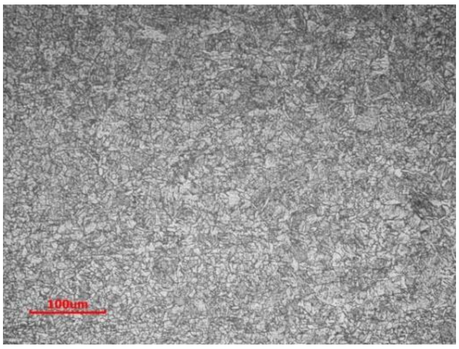


Fig. 7. Microstructure without PWHT

Fig. 8. Microstructure with PWHT

Fig. 9 show the microstructure of Non-PWHT in the weld metal area at 500x magnification with a scale of 50 µm shows ferrite (light) and pearlite (dark), indicating that the ferrite is finer in size, approximately ±5-10 µm. **Fig. 10** show the difference between the previous Non-PWHT image and the With-PWHT image can be observed. In the microstructure of the With-PWHT weld metal area at 500x magnification and a scale of 50 µm, the ferrite grains are larger and coarser, approximately ±25 µm. This occurs due to grain growth during the PWHT process, which also serves to reduce internal stress caused by the prior welding process.

The PWHT process is performed to restore the microstructure of a material and relieve residual stress from previous welding, as well as to improve the toughness of the material due to grain growth. According to the Hall-Petch law, as the grain size D increases, the strength σ decreases, and vice versa, where, σ_y is strength of smaller grains, σ_i is strength of larger grains, K is strengthening coefficient, and D is diameter of smaller grains.

$$\sigma_y = \sigma_i + K.D^{-1/2} \quad (1)$$

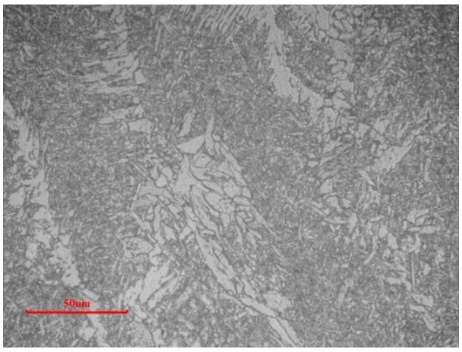


Fig. 9. Microstructure without PWHT

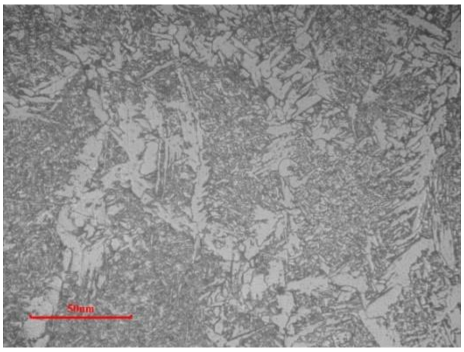


Fig. 10. Microstructure with PWHT

Fig. 11 show the graph of variations in hardness distribution based on Vickers hardness testing, where uneven point values can be seen in both Non-PWHT and With-PWHT specimens. Based on the data, it can be observed that the Non-PWHT specimen has higher hardness values than the With-PWHT specimen. This is due to the following reasons i.e. in the Base Metal area, the hardness values are lower compared to the weld metal and HAZ areas because it is farther from the welding zone. In the Weld Metal area, the hardness values are higher than in the HAZ and Base Metal areas due to rapid heating and cooling, which causes grain refinement and results in high hardness in this region. In the HAZ area, the hardness values are intermediate between those of the Base Metal and Weld Metal, as this is the transition zone between the two regions. When compared to the specimen with PWHT, the hardness level is lower due to the larger microstructure. The PWHT process also functions to reduce internal stress caused by previous welding.

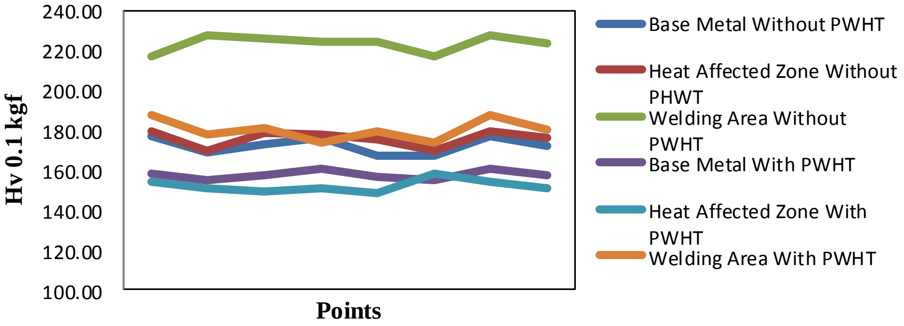


Fig. 11. Vickers hardness test result of weld 440 SAPH.

Based on the research above, the effects of PWHT on the welding of Axle Housing with SAPH 440 material are as follows, material with PWHT experiences ferrite grain growth of approximately ±15 µm. Material with PWHT has a lower hardness value than Non-PWHT material but has higher toughness, making the material more durable. The PWHT process can relieve residual stress (reduce internal stress) caused by the previous welding process.

4 Conclusions

From the research results and analysis, the following conclusions can be drawn:

1. The ideal welding parameters for Axle Housing welding are 300A current, 29V voltage, 140 cm/min welding speed, and 110 cm/min filler wire speed.
2. Macrostructure testing shows that the obtained sizes exceed the standard, and using the DE-GMAW method allows Axle Housing welding to be performed faster than conventional methods.
3. Microstructure testing shows a difference between Non-PWHT material with ferrite grains of ±5-10 µm and With-PWHT material with larger and coarser grains of approximately ±25 µm, due to grain growth.
4. Micro Vickers testing shows that the Non-PWHT material has a higher hardness value in the HAZ area, around 176.28 HV, while the With-PWHT material has a lower hardness value in the HAZ area, around 150.64 HV. However, the With-PWHT material is much tougher, proving that grain growth and reduced internal stress have occurred.
5. The selection of SAPH 440 material, solid wire as filler, and the use of MAG gas are a suitable combination for Axle Housing welding.

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