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The effect of cooling media on impact toughness and tensile strength after GTAW welding of aluminum alloy

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Abstract

Aluminum 5083 is extensively utilized in ship hull construction due to its high impact resistance and superior tensile load capacity, offering a lightweight alternative to steel. In maintenance procedures, welding is a fundamental method for repairing damaged sections, with Gas Tungsten Arc Welding (GTAW) favored for its precise thermal control and minimal distortion. Among the critical factors influencing weld quality, the post-weld cooling process significantly affects the resulting microstructure and mechanical performance. This study examines the effects of various cooling media—namely, Bromus Soluble Oil Cutting Coolant, Castor oil, and Mesran Super SAE 20W-50 oil—on the impact toughness and tensile strength of GTAW-welded Aluminum 5083 with a current of 325 A and 220 V AC voltage. Mechanical properties were evaluated through Charpy impact testing and tensile testing by ASTM standards. The findings reveal that Bromus coolant yielded the highest impact toughness at 0.264 J/mm², whereas Bromus coolant achieved the highest tensile strength at 12.893 Kgf/mm². These results underscore the critical role of cooling medium selection in enhancing the mechanical integrity and durability of welded aluminum structures, as the bromus coolant significantly outperformed alternatives in both impact and tensile assessments.

1. Introduction

Aluminum 5083 is often used in the construction of ship hulls due to its properties that make it suitable for withstanding impact loads from large ocean waves and tensile loads from cargo, while being lighter than steel [1]. Ship hulls require maintenance, one of which involves welding to repair damaged or corroded sections. However, aluminum generally has low weldability, so GTAW (Gas Tungsten Arc Welding) is used for welding aluminum because it requires special treatment to minimize distortion [2]. GTAW welding is used to better control the temperature during the welding process and to ensure a clean weld free from slag, resulting in optimal welding quality [3]. The quality of 5083 aluminum welds can be influenced by many factors, one of which is the post-weld cooling process. The temperature during welding significantly affects the strength of the weld; after welding, residual stresses often occur around the welded area. These are caused by localized high-temperature heating that leads to thermal expansion or shrinkage during cooling, potentially resulting in cracking as the metal returns to room temperature [4].

Cooling media affect the quality and strength of aluminum welds because they can prevent distortion and relieve the stress that occurs during welding. The faster the cooling medium absorbs heat, the more effective it is at reducing distortion and stress in the welded metal [5]. The viscosity of the cooling medium greatly influences the rate of heat absorption, but there are also other properties in the cooling medium that can have an effect. Therefore, further experimental research is needed to determine the most effective cooling medium [6].

Based on this background, it is necessary to analyze the weld quality of 5083 aluminum using GTAW, based on the cooling process applied after welding. Several cooling media are used in this study: Castor oil, motor oil, and coolant. These different cooling media are expected to result in varying mechanical properties because each medium has different characteristics that affect the rate of heat transfer. This leads to different microstructures, which ultimately affect mechanical strength.

This study has two primary objectives. The first is to analyze the effect of post-weld cooling media variations on the impact toughness of Aluminum 5083. The second is to evaluate the influence of these cooling media on the tensile strength of the same material. Through systematic experimental procedures and mechanical testing, this research aims to contribute to a deeper understanding of how cooling methods affect the structural performance of welded aluminum joints.

2. Research Methods

The material used was 5083 aluminum with ER 5356 filler wire of 2.6 mm diameter [7]. The research method began with cutting aluminum plates measuring 55 mm x 10 mm x 10 mm (12 pieces) for impact testing, and 200 mm x 20 mm x 10 mm (12 pieces) for tensile testing. The specimens were prepared with a Single V-Butt Joint groove with a 60° angle [8]. The aluminum pieces were then welded using GTAW with a current of 325 A and 220 V AC voltage [9]. After welding, the aluminum was quickly and spontaneously cooled using Bromus Soluble Oil Cutting Coolant, Castor oil, and Mesran Super SAE 20W-50 oil as the cooling media, then Charpy impact and tensile tests were conducted on the specimens [10].

Before testing, the welded and cooled aluminum was machined into test specimens using a milling machine according to ASTM E23 for impact Charpy testing, as shown in Fig. 1, and ASTM E8 for tensile testing, as shown in Fig. 2.

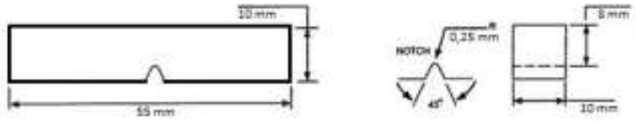

Fig. 1. Shape and Dimension of ASTM E23 for impact testing

a. Overall length (L) : 55 mm
b. Width (W) : 10 mm
c. Thickness (T) : 10 mm
d. Notched Charpy : 45^0
e. Radius notched : 0,25 mm

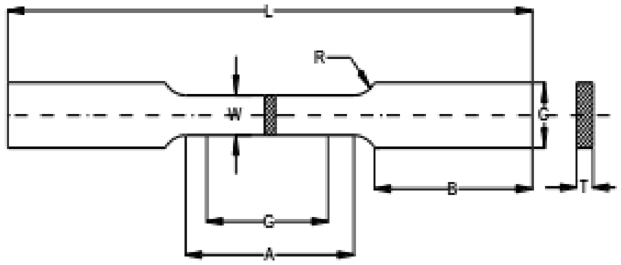

Fig. 2. Shape and Dimension of ASTM E8 for tensile testing

a. Gage length (G) : 50,0 mm
b. Length of reduce section (A) : 57 mm
c. Width (W) : 12,5 mm
d. Thickness (T) : 10 mm
e. Radius of fillet (R) : 12,5 mm
f. Overall length (L) : 200 mm
g. Width of grip section (C) : 20 mm
h. Length of grip section (B) : 50 mm [11]

Finally, the specimens were tested to determine the values of impact toughness and tensile strength after welding with the different cooling media. The following research flowchart shows the sequence of research activities, starting from literature study, variable determination, experimental testing, data analysis, and ending with the conclusion as in Fig. 3.

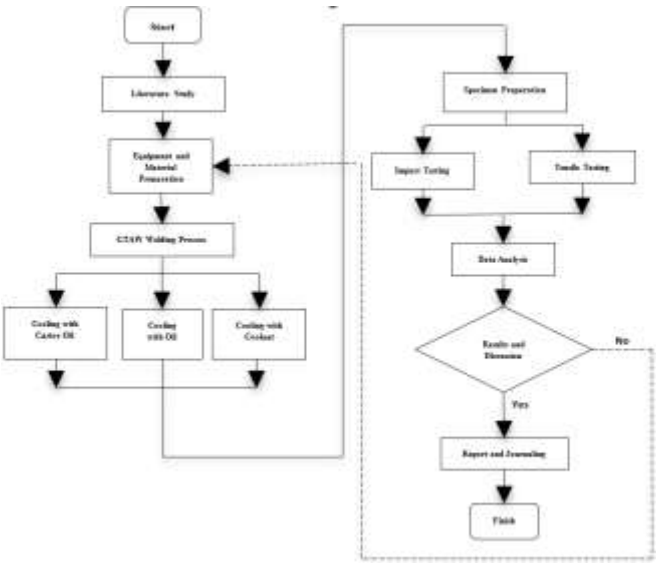

Fig. 3. Research flowchart

3. Results and Discussion

Testing was conducted on 5083 series aluminum that had undergone post-GTAW (Gas Tungsten Arc Welding) cooling using different media, followed by impact and tensile strength tests. The objective of this testing was to determine the impact strength and tensile strength values of the material. The material used in the tests was 5083 series aluminum. The technical specifications for the tests included the use of GTAW (TIG welding) as the welding method, with ER 5356 filler rods having a diameter of 2.6 mm. The weld joint used was a single V-butt joint with a 60° angle. Welding was performed at a voltage of 220 V and a current of 325 A. The cooling media applied were Bromus Soluble Oil Cutting Coolant, Castor oil, and Mesran Super SAE 20W-50 oil. Impact testing was conducted according to ASTM E23 standards, while tensile testing followed ASTM E3 standards.

The testing process was carried out on four specimens for each test variable. The dimensions of the impact test specimens were 55 mm × 10 mm × 10 mm, in accordance with ASTM E23, while the tensile test specimens measured 57 mm × 12.5 mm × 10 mm. All test results were recorded for data processing and considered in the data analysis process. This approach was implemented to enhance the accuracy of the test results and to minimize data errors during the analysis phase.

The impact test was conducted to determine the amount of energy absorbed by 5083 series aluminum under the influence of different cooling media after GTAW welding, in response to the impact load caused by a pendulum strike. The absorbed energy was used to calculate the impact strength by dividing the total absorbed energy of the 5083 aluminum specimens—subjected to different cooling media post-GTAW welding—by the cross-sectional area at the point of impact. The impact test results are presented in the Table. 1.

Table. 1. Impact Test Results

Cooling Media	**No. Spec**	**A (mm^2)**	**E absorb (J)**	**Impak Toughness (J/mm^2)**	**Average (J/mm^2)**
Coolant Bromus	1	87,23	18	0,206	**0,264**
	2	81,53	22	0,270	
	3	85,5	24	0,281	
	4	83,52	25	0,299	
Castor oil	1	87,22	19	0,218	**0,224**
	2	90,18	22	0,244	
	3	89,88	20	0,223	
	4	84,55	18	0,213	
Mesran oil	1	90,01	19	0,211	**0,245**
	2	83,92	22	0,262	
	3	84,35	20	0,237	
	4	85,2	23	0,270	

The parameters used during data acquisition were as follows: Charpy impact testing, machine capacity of 150 Joules, total pendulum weight of 4.18 kg, impact velocity of 3.46 m/s, pendulum arm length of 31.5 cm, and an initial swing angle of 150°. After testing, the total energy absorbed by each specimen was obtained. This total energy was then used to calculate the impact strength (HI).

An example of the impact strength calculation for 5083 aluminum on specimen 1 is as follows:

$\Delta E = 18$ J
$l \;\; = 10{,}12$ mm
$t \;\; = 8{,}62$ mm

the impact strength can be calculated as follows (Eq. 1):

$$\text{HI} = \frac{\Delta \text{E}}{A} \tag{1}$$

$$\text{HI} = \frac{\Delta \text{E}}{l \; x \; t}$$

$$\text{HI} = \frac{18 \text{ J}}{87{,}23 \; mm^2}$$

$$\text{HI} = \frac{18 \text{ J}}{10{,}12 \; mm \; x \; 8{,}62 \; mm}$$

$$\text{HI} = 0{,}206 \; J/mm^2$$ [12]

The material that demonstrated the highest energy absorption capability was the specimen cooled using Bromus coolant, specifically specimen number 4, with an absorbed energy value of 0,299 J. In contrast, the lowest energy absorption was observed in the specimen cooled using Bromus coolant, specifically specimen number 1, with a value of 0.184 J. The highest average impact strength was recorded for the material cooled with Castor oil, with a value of 0,206 J/mm². The fracture of the impact test as shown in Fig. 4.

Fig. 4. The fracture of the impact test

Impact testing yields data in the form of impact strength values, which are obtained by dividing the total energy absorbed by the material by the cross-sectional area of the test specimen. Based on the data presented in the Table. 1. The impact strength values as shown in Fig. 5.

The material exhibiting the highest energy absorption capability was the specimen cooled with Bromus coolant, specifically specimen number 4, with a value of 0,299 J. Conversely, the material with the lowest energy absorption capability was the specimen cooled using Bromus coolant, namely specimen number 1, with a value of 0,206 J. Based on the data in Table.1, the average impact strength values, when presented graphically, as shown in Fig. 6.

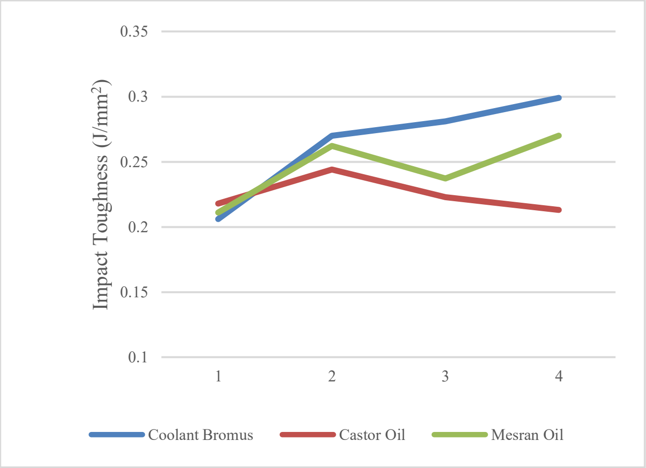

Fig. 5. Impact Strength Value

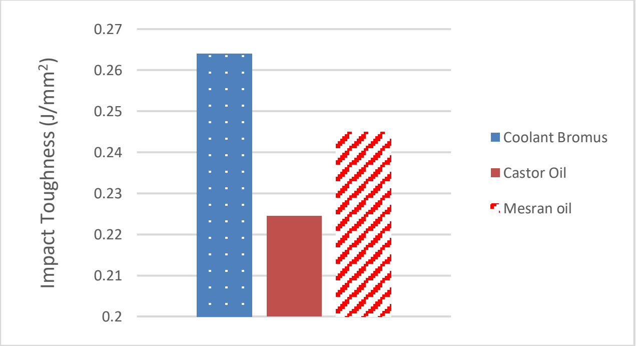

Fig. 6. Average Impact Strength Value

The highest average impact strength was recorded for specimens cooled with Bromus coolant, yielding a value of 0,264 J/mm². Specimens cooled using Mesran oil exhibited an average impact strength of 0,245 J/mm². Meanwhile, specimens cooled with Castor oil showed an average impact strength of 0,224 J/mm² [13].

Tensile testing was conducted to determine the tensile strength absorbed by 5083 aluminum material, influenced by different cooling media following GTAW welding, due to the tensile load applied. After all specimens were subjected to tensile testing and the necessary data were obtained, data processing and calculations were carried out to generate stress-strain graphs for each specimen. The tensile test results provided the mechanical properties of the specimens. The data are presented in the Table. 2. The fracture of the tensile test sown in Fig. 7.

Table. 2. Tensile Test Results

Cooling Media	**No. Spes**	**A (mm²)**	**Min. *Force* (Kgf)**	***Tensile Strength* (Kgf/mm²)**	***Average Tensile S.* (Kgf/mm²)**	***Displacement* (mm)**	**Elongation (%)**	***Yield Force* (Kgf)**
***Coolant* Bromus**	1	94,85	1326,87	13,99	12,893	5,47	5,47	1159,12
	2	99,21	1329,80	13,40		5,25	5,25	1171,38
	3	88,68	1005,84	11,34		4,11	4,11	915,40
	4	93,33	1256,37	12,84		4,89	4,89	1046,23
Castor oil	1	96,34	887,88	9,22	9,053	2,86	2,86	833,12
	2	94,17	854,56	9,07		3,05	3,05	770,48
	3	95,55	837,11	8,76		3,04	3,04	798,11
	4	95,80	865,71	9,16		2,91	2,91	803,84

Mesran oil	1	92,83	989,90	10,66	9,825	3,60	3,60	918,07
	2	93,40	779,39	8,34		2,73	2,73	730,05
	3	93,73	945,52	10,09		4,14	4,14	849,48
	4	94,43	962,87	10,21		3,73	3,73	909,54

Fig. 7. The fracture of the tensile test

Tensile testing yields data in the form of tensile strength values, which are obtained by dividing the total energy absorbed by the material by the cross-sectional area of the test specimen. Based on the data in Table 2, the tensile strength values, when plotted graphically, as shown in Fig. 8.

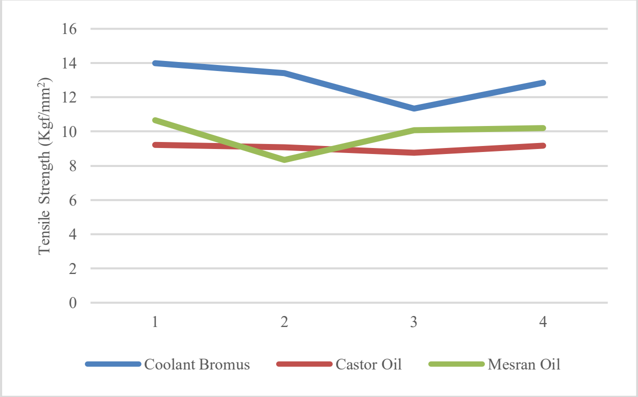

Fig. 8. Tensile Strength Values

Based on the data in the Table. 2, The average tensile strength values, when presented graphically, are as shown in Fig. 9.

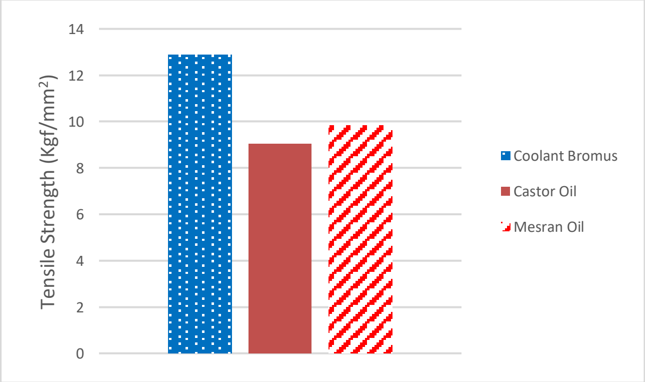

Fig. 9. Average Tensile Strength

Again, based on the average tensile strength test results, the specimen with the best tensile properties was the one cooled using Bromus coolant, exhibiting an average tensile strength of 12.893 Kgf/mm² and an average elongation of 4.93 mm. The specimen cooled with Castor oil showed an average tensile strength of 9.053 Kgf/mm² and an average elongation of 2.97 mm. The specimen cooled with Mesran oil demonstrated an average tensile strength of 9.825 Kgf/mm² and an average elongation of 3.55 mm [14].

The aforementioned data demonstrate that the coolant exhibits consistent superiority in both impact and tensile tests. This enhanced performance is presumably attributed to the superior thermal properties of Bromus coolant, which possesses higher heat capacity and boiling point compared to other cooling media. These characteristics enable more efficient heat absorption and reduced evaporation during the cooling process. Furthermore, Bromus coolant is specifically engineered to resist thermal degradation, allowing it to maintain optimal cooling performance even under high-temperature exposure [15].

4 Conclusion

The test results indicate that the specimen cooled using Bromus coolant demonstrated the highest impact energy absorption capability, with a value of 0.264 J. Meanwhile, the specimen exhibiting the highest tensile strength characteristics was the one cooled with Bromus coolant, with an average tensile strength of 12.893 Kgf/mm².

Based on the average tensile strength test results, it was found that the specimen with the best tensile strength characteristics was the one cooled using Bromus coolant. This specimen exhibited an average tensile strength of 12,893 Kgf/mm² and an average elongation of 4.93 mm. The specimen cooled with Castor oil had an average tensile strength of 9,053 Kgf/mm² and an average elongation of 2.97 mm. Meanwhile, the specimen cooled with Mesran oil demonstrated an average tensile strength of 9,825 Kgf/mm² and an average elongation of 3.55 mm. Based on the results of both the impact and tensile tests conducted on 5083 aluminum material with different cooling media following GTAW welding, it can be concluded that the specimen with the best energy absorption capability in the impact test was the one cooled with Bromus coolant, with a value of 0.264 J. On the other hand, the specimen with the best tensile strength characteristics was the one cooled using Bromus coolant, exhibiting an average tensile strength of 12.893 Kgf/mm² and an average elongation of 4.93 mm. This superior performance is likely attributed to the thermal properties of Bromus coolant, which possesses a higher heat capacity and boiling point compared to the other cooling media. These properties enable it to absorb more heat and resist evaporation during the cooling process. Furthermore, Bromus coolant is engineered to withstand thermal degradation, allowing it to maintain its cooling performance even under high-temperature exposure.

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