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Optimizing of Groove Angle in Welding Cast Aluminum A356 for Product Repair

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ABSTRACT

The purpose of this study was to investigate the effect of groove angle on the tensile strength, impact toughness, and hardness of A356 cast aluminum and to determine the most optimal groove angle for welding A356 cast aluminum. The research method used was a pure experiment by conducting tensile, impact, and hardness tests on welding specimens with groove angles of 0°, 30°, 55°, and 75°. The test results showed that the 75° groove angle had advantages over other groove angles with a maximum stress of 26.396 N/mm², a maximum strain of 10.341%, an elastic modulus of 1625.144 N/mm², an impact toughness of 0.1518 J/mm², and a Vickers hardness of 24.7 HVN. Based on the test results, it was concluded that the groove angle of 75° is the most optimal angle for welding A356 cast aluminum in the context of repairing cast aluminum products.

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INTRODUCTION

Technological advances and innovations, the manufacturing industry in this era continues to evolve, resulting in increased efficiency, better product quality, and greater production flexibility. Technologies such as automatic welding, laser welding, and other advanced welding methods have increased production efficiency, precision, and speed. These innovations not only allow welding on various types of materials, but also improve the quality of the resulting joints, reduce defects, and increase the durability of the final product (Ramadhan et al., 2020).

A356 cast aluminum is an aluminum alloy that is often used in industrial castings because of its good characteristics and the ability to improve its mechanical properties through heat treatment (Davis, 1993). After casting, A356 cast aluminum has high strength, corrosion resistance, and the ability to be formed into complex shapes. The heat treatment process can further improve its mechanical properties. Many industries, such as machine manufacturing, the automotive industry, and construction use A356 cast aluminum to make complex components with tight tolerances. The heat treatment process after casting is often carried out to increase strength, hardness, and fatigue resistance.

In welding, the bevel angle is very important because it affects weld penetration, current control, and final quality. The right angle ensures optimal penetration and prevents deformation, so experience in selecting the bevel angle is very important (Rahmatika et al., n.d.). A356 cast aluminum is a commonly used alloy in the casting industry due to its good mechanical properties and further enhancement through heat treatment. This alloy is used in various industries to produce components with tight tolerances and high strength (Kaufman, 2004).

In a wheel rim casting industry in Yogyakarta, there was a problem of defective wheel rim products from A356 aluminum casting so that repairs were needed by welding. In welding A356 cast aluminum for repair purposes, the selection of groove angle and electrode type has a significant effect on the final welding results. There were several influences from both factors such as the selection of the right groove angle is very important in welding A356 cast aluminum for repair purposes.

Previous studies had shown that variations in groove angle have a significant effect on the mechanical properties of welded joints, for example a study on welding aluminum 6061 using the GTAW (Gas Tungsten Arc Welding) method showed that variations in groove angle affect the mechanical strength of the material with a thickness of 6 mm, where angles of 90 ° and 60 ° give different results in terms of tensile strength and joint quality (Husnul Fata et al., 2020). Other studies had shown that variations in groove angles in 6061 aluminum welding using the GTAW method, such as 60° and 80°, provide different tensile strengths, with 80° producing a maximum average tensile strength of 147.27 MPa and a strain value of 21.02% (M. D. Almanda et al., 2020) . A study by (Zhang et al., 2020) showed that the right groove angle can reduce porosity and increase tensile strength in 6xxx series aluminum welding. Meanwhile, research by (Kumar et al., 2019) identified that a smaller groove angle tends to produce deeper penetration but risks causing cracking if not properly controlled. Research by (Yang et al., 2021) showed that the combination of optimal groove angle and TIG welding parameters can produce welded joints with strength equivalent to the base material. These studies have not specifically discussed the A356 alloy, the results can be used as a reference in determining the optimal groove angle for welding this alloy.

The optimal groove angle also helps achieve the desired penetration into the material, which is crucial for maintaining the strength and structural integrity of the repaired area, as well as improving the quality of the weld by reducing the risk of underfilling and ensuring good filling of the damaged part. The purpose of this study was to investigate the effect of groove angle on the tensile strength, impact toughness, and hardness of A356 cast aluminum and to determine the most optimal groove angle for welding A356 cast aluminum.

METHOD

This study used a pure experimental method that aims to determine the best groove angle variation in A356 cast aluminum welding. This study used independent variables in the form of 4 groove angle variations, namely 0º, 30º, 55º, and 75º. Furthermore, there were 3 dependent variables in this study, namely tensile strength testing, impact toughness testing, and vickers hardness testing of A356 aluminum welding results. The replication of specimens carried out in each test amounted to 3 specimens and the average value was taken.

The beak angle was varied between 0º to 75º based on the research of (Yang et al., 2021) on aluminum welding which showed the highest tensile strength was obtained at a current of 130 amps with a beak angle of 80º, reaching 150.4 N/mm². Likewise, the highest strain value at a beak angle of 80º is 0.7%.

Welding Process

The welding process of A356 aluminum uses GTAW (Gas Tungsten Arc Welding) or TIG welding with groove angle variations of 0º, 30º, 55º, and 75º, using ER4043 filler. Table 1 shows the parameters of A356 aluminum welding.

Table 1. Welding Parameters

No.		Welding parameters
1.	Materials	Aluminum A356
2.	Welding process	TIG (*Tungsten Inert Gas*)
3.	Electrode	ER 4043
4.	Weld current	195 Ampere
5.	Polarity	AC
6.	Shielding Gas	Argon
7.	Welding groove	*Square Groove* (0º), V *Groove* (30 º, 55º, 75º)
8.	Weld position	1G

Design of *Groove*

The welding process on A356 aluminum uses 2 types of grooves, namely Square Groove and V Groove. Square Groove for angles of 0º and V Groove for angles of 30º, 55º, and 75º as shown in Figure 1.

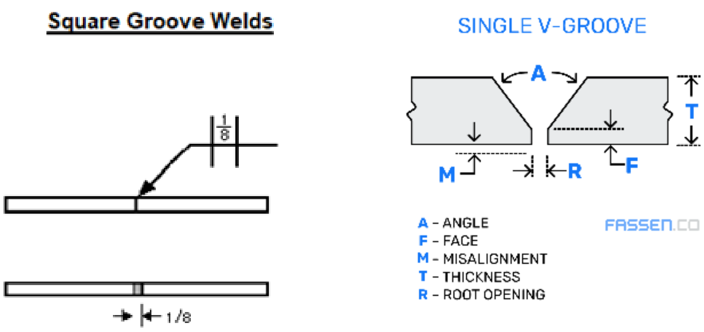

Figure 1. Design *of* Groove

Tensile Test Specimen

The tensile test specimen is the result of welding A356 cast aluminum and machined with a milling machine to form a curve. Figure 2 is the size of the tensile test specimen based on the ASTM standard from the welding results of A356 aluminum in the center of the test specimen.

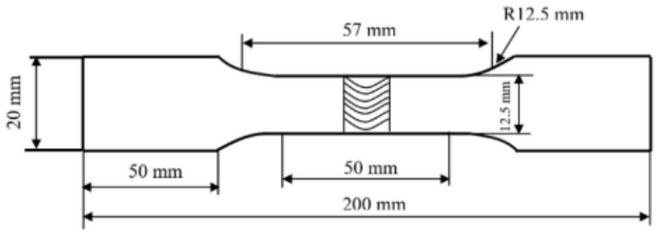

Figure 2. Dimension of tensile test specimen.

Impact Test Specimen

The impact test specimen uses a charpy impact specimen design. After the welding process, the specimen goes to the machining process to obtain the size according to the charpy impact design. Figure 3 is the size of the impact specimen from A356 aluminum welding used for toughness testing.

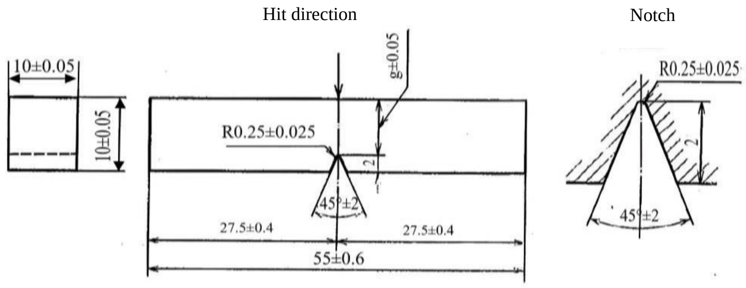

Figure 3. Dimension of impact test specimen.

Hardness Test Specimen

To facilitate the Vickers hardness test, after the welding process the specimen goes to the machining process to obtain the size according to the design. Figure 4 is a design image of the welding results of A356 aluminum used for the Vickers hardness test. Furthermore, the Vickers hardness test was carried out with a load of 60 kg and the indentation size on the specimen was investigated to determine the hardness value.

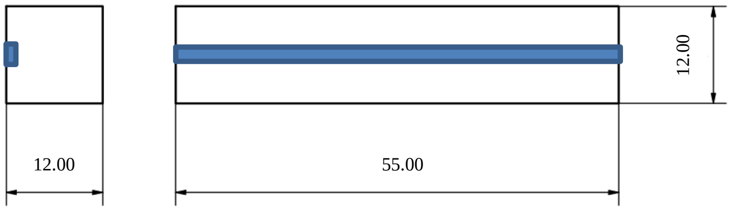

Figure 4. Dimension of hardness test specimen.

RESULTS AND DISCUSSION

Tensile Test Results

After conducting tensile strength tests on welding specimens with variations of angles 0°, 30°, 55°, and 75°, the results of the tests that have been carried out are then presented in a diagram to compare one specimen with another which will then be explained as follows:

a. Tensile Strength Value

From the results of the tensile strength test carried out, each specimen with different groove angle variations shows different average stress values. The tensile test results are shown in Figure 5 which is a diagram of the average tensile strength values of 3 specimens with the same variables.

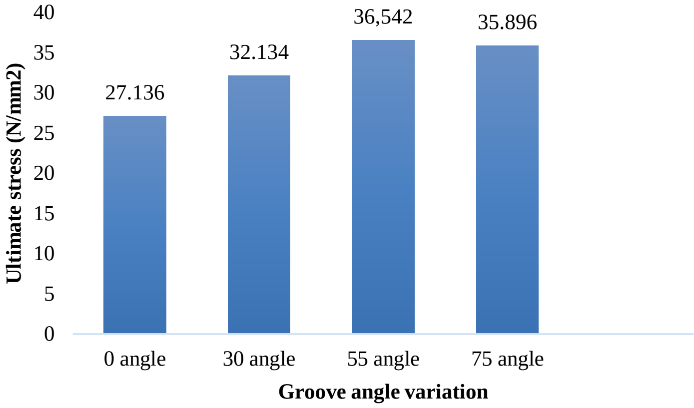

Figure 5. Ultimate tensile strength diagram

From Figure 5, it can be seen that the specimen with a groove angle variation of 0° obtained the lowest average tensile strength value of 27.13 N/mm^2. Then the specimen with a groove angle variation of 55° produced the highest average tensile strength value of 36.54 N/mm^2. This phenomenon occurs because at a groove angle of 0 the joint at the weld root does not diffuse well so that the strength is not maximal. Furthermore, at groove angles of 55° and 75° the diffusion of the weld metal with the parent metal is good so that it has a maximum value. This is in accordance with the findings of (Naufal et al., 2016) that the groove angle in welding greatly affects the mechanical strength of the weld joint.

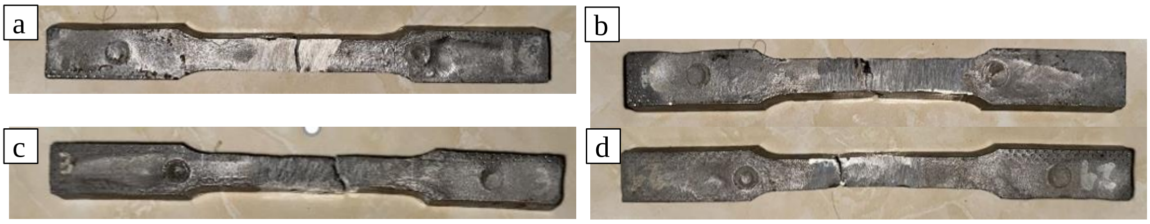

Figure 6. Fracture results of tensile test: (a) groove angle 0°, (b) groove angle 30°, (c) groove angle 55° and (d) groove angle 75°.

Figure 6 shows the fracture form of tensile test results. Based on the image, it shows a brittle fracture phenomenon, considering that there is no necking in the test object. The fracture results for groove angles 30º, 55º and 75º are also located in the parent metal of Aluminum material, which indicates that the weld strength has met the welding tensile test standards (Zhou et al., 2017).

b. Strain Value

From the results of tensile strength testing carried out on each specimen with different groove angle variations, it shows different average strain values. Figure 7 is a diagram of the average strain values of 3 specimens with the same variables.

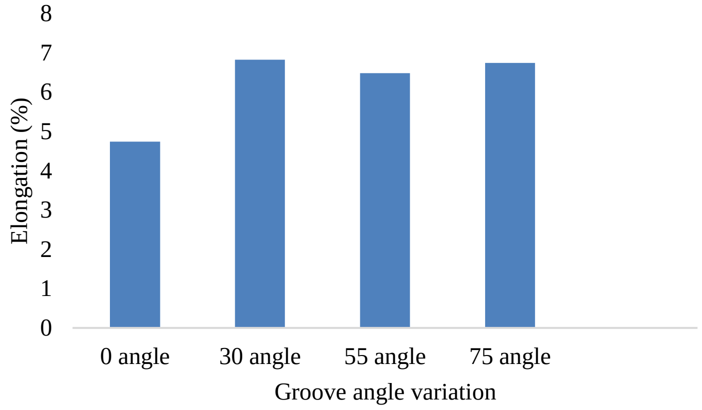

Figure 7. Diagram of average strain value in tensile test

From figure 7, it can be seen that the specimen with a groove angle variation of 0º obtained the lowest average strain value of 4.74%. Then the specimen with a groove angle variation of 75º produced the highest average strain value of 6.78%. Thus, we can conclude that the groove angle variation of 75º has the best level of ductility because it has the highest strain.

Impact Test Results

After conducting Charpy impact toughness tests on welding specimens at angle variations of 0º, 30º, 55º, and 75º, the results of the tests that have been carried out are presented in a diagram (Figure 8) to compare one specimen with another.

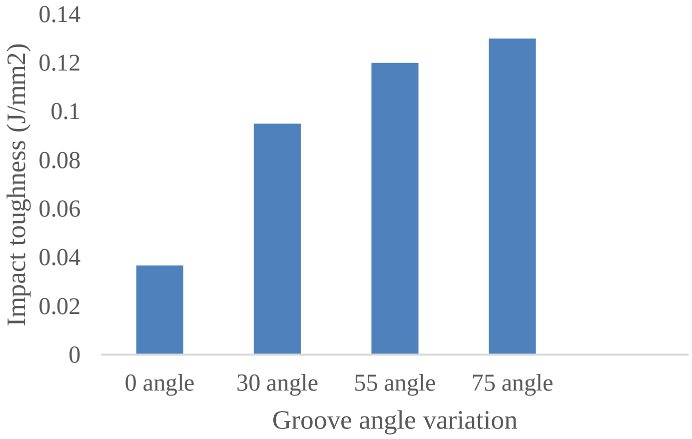

Figure 8. Impact Test Result Diagram

From Figure 8, it is known that the specimen with a groove angle variation of 0o obtained the lowest average impact toughness value of 0.036 J/mm^2. Then the specimen with a groove angle variation of 75^o produced the highest average impact toughness value of 0.130 J/mm^2. The welded joint at a groove angle of 75^o showed the best impact toughness because at this groove angle it provided very good diffusion between the weld metal and the parent metal. The impact toughness value is generally considered low, indicating brittle fracture. This is caused by the grain boundary strength being stronger than the grain strength so that the fracture path splits the grains in the specimen (Malik et al., 2022).

Hardness Test Results

Hardness tests were conducted on the weld metal of the welding area. After conducting the Vickers hardness test on the welding specimens at various angles of 0^o, 30^o, 55^o, and 75^o, the results of the tests that had been conducted were presented in a diagram (Figure 9) to compare one specimen with another.

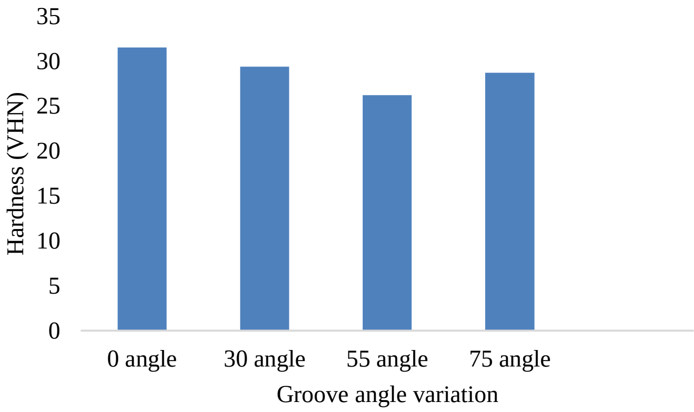

Figure 9. Diagram of hardness test results.

From Figure 9, it is known that the level of weld metal hardness in the specimen with a groove angle variation of 55^o gets the lowest average Vickers hardness value of 26.2 VHN. Then the specimen with a groove angle variation of 0^o produces the highest average Vickers hardness value of 31.5 VHN. At a groove angle of 75^o, the Vickers hardness value is 28.7 VHN. This shows that the surface hardness of the weld metal has almost the same value because the welding process uses the same welding parameters. The difference in hardness values is more due to the cooling rate after the welding process, with the rate of speed at a groove angle of 0^o being the fastest so that it tends to produce higher hardness (Wang & Zhang, 2018).

From the tests that have been carried out, it was found that the best repair specimen was obtained in welding with a groove angle variation of 75^o. The repair specimen with a groove angle of 75^o has a tensile strength value of 35.89 N/mm^2, a strain value of 6.74%, an impact toughness value of 0.13 J/mm^2, and a Vickers hardness value of 28.7 VHN.

Based on the results of the study above, data was obtained that was less linear with other variables. This difference is possible due to the use of manual welding which depends on the condition of the welder. This is a weakness of the study which can later be followed up with the use of automatic welding to reduce data bias.

CONCLUSION

Based on the results of the study conducted on A356 cast aluminum welding, the following conclusions can be drawn:

1. Specimens with 75^o groove angle variation welding obtained a tensile strength value of 35.89 N/mm^2, a strain value of 6.74%, a hardness value of 28.7 VHN and the highest impact strength of 0.13 J/mm^2. Thus, 75^o groove angle variation welding has a superior impact strength than other groove angle variation specimens.
2. The 75^o groove angle variation can be used as a solution in selecting the groove angle based on the mechanical properties and results of the tests that have been carried out because it has an average value that is superior to other groove angle variations.

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REFERENCES

Davis, J. R. (1993). *ASM Specialty Handbook : Aluminum and Aluminum Alloys*. ASM Internasional.

Husnul Fata, Muhammad Razi, & Syukran. (2020). Pengaruh variasi sudut kampuh bevel groove terhadap kekuatan tarik material Stainless Steel 304. *Journal of Welding Technology*, *2*(1).

Kaufman, J. G. (2004). *Aluminum Alloy Castings: Properties, Processes and Applications*. ASM International.

Kumar, S., Singh, R., & Mishra, R. S. (2019). Effect of groove geometry on weld quality in aluminum alloys: A review. *Materials Science and Engineering*, 123–134.

M. D. Almanda, H. Yudo, & U. Budiarto. (n.d.). Analisa Pengaruh Variasi Sudut Kampuh Terhadap Kekuatan Tarik Aluminium 6061 Dengan Gas Pelindung Argon Grade A dan Grade C Pada Pengelasan GTAW. *Jurnal Teknik Perkapalan*, *9*(1), 130–138.

Malik, M., Setiawan, I. C., & Rahmalina, D. (2022). Sifat Mekanis Paduan Aluminium A356 dengan Penambahan Unsur Tembaga Hasil Proses Gravity Casting. *Jurnal Teknologi Rekayasa*, *7*(2), 201–208.

Naufal, A., Jokosisworo, S., & Samuel. (2016). Pengaruh Kuat Arus Listik Dan Sudut Kampuh V Terhadap Kekuatan Tarik Dan Tekuk Alumunium 5083 Pengelasan GTAW. *Jurnal Teknik Perkapalan*, 256–264.

Rahmatika, A., Ibrahim, S., Hersaputri, M., & Aprilia, E. (n.d.). Studi Pengaruh Variasi Kuat Arus Terhadap Sifat Mekanik Hasil Pengelasan GTAW Alumunium 1050 Dengan Filler ER 4043. *Jurnal Polimesin*, 47–54.

Ramadhan, F., Irawan, A., & Kurniawan, F. A. (2020). Arus Pengelasan Terhadap Tarik Las SMAW Elektroda E6013 Pada Baja Karbon Rendah. *Jurnal SiMeTRi Rekayasa*, *2*(2), 116–122.

Wang, Y., & Zhang, Z. (2018). Numerical simulation and experimental validation of groove angle effects on aluminum welding. *International Journal of Advanced Manufacturing Technology*, *97*, 5–8.

Yang, P., Song, Y., Wang, J., Hu, F., & Xie, L. (2021). Semiconductor laser cladding of an Fe-based alloy on nodular cast iron. *Welding in the World*, *65*(5), 785–792. https://doi.org/10.1007/s40194-021-01078-3

Zhang, X., Li, Y., & Wang, H. (2020). Optimization of groove angle in aluminum welding for improved tensile strength and reduced porosity. *Journal of Materials Processing Technology*, 116–125.

Zhou, Q., Zhang, F., & Huang, X. (2017). Aggregate multiple radial basis function models for identifying promising process parameters in magnetic field assisted laser welding. *Journal of Manufacturing Processes*, *28*, 21–32. https://doi.org/10.1016/j.jmapro.2017.05.012