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Energy absorption and toughness analysis on FSW butt joint of AA 5052 and AA 5083

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Abstract

Friction Stir Welding (FSW) is an efficient and effective welding method with good-quality welds. Aluminum Alloy (AA) has been widely used for various automotive needs, including in vehicle manufacturing. AA series 5XXX is a type of material used for vehicle manufacturing because it has good strength properties even after the joining process. A similar butt joint using the FSW method was carried out on material AA 5052 and AA 5083. The results of the welding were then given radiographic testing to determine the general condition of the welds. The impact test was carried out according to the procedures standard of ASTM on the welding results to analyze the energy absorption and toughness properties of welds by getting the impact value of the welded joint, and then looking for the quantity ratio to the impact value of the base material. After that, the results and discussion were obtained that the welded areas showed different impact strength and absorbed energy value, which is compared to the base material the range is below with a decrease in value of between 34% and 68% of the initial toughness strength of the parent material. The reduction in toughness strength can be attributed to the influence of mechanical properties during the welding process. Nevertheless, the welds demonstrated good quality and integrity, highlighting FSW's efficacy in joining aluminum alloys. This research significantly contributes to comprehending the energy absorption and toughness analysis of FSW butt joints in aluminum alloys, crucial for vehicle body technology applications.

Keywords:
Energy absorption, toughness, friction stir welding, aluminum alloy, vehicle technology.

1 Introduction

Welding is a joining process that uses heat energy between two or more parts of similar or dissimilar materials. Welding generally plays an important role in the construction and repair of metal-type materials. Calculation of heat input is very important when establishing the Welding Procedure Specification (WPS) of a production process. In Friction Stir Welding (FSW) the heat input components are purely mechanical and are replaced by forces, friction, and rotation. As a result, the FSW process forms joints at about 80-90° of the metal's melting temperature, resulting in most cases producing joints that are superior to conventional fusion welded joints. FSW is ideal for mechanical welding because only four main parameters need to be mastered. Of the four variables, the most important is downforce which allows you to control higher welding speeds. When the downward force increases, frictional heat is generated, and even if there is a tolerance error in the material to be joined, the material will be softer and can ensure good quality. The FSW process model is given in Fig. 1.

Welding is a widely employed joining process used in the construction and repair of metal-type materials, involving the application of heat energy between two or more parts of similar or dissimilar materials. In the context of vehicle body technology, welding plays a crucial role in ensuring the structural integrity and durability of the vehicle components. The selection of an appropriate welding method and understanding its effects on the material properties are of paramount importance.

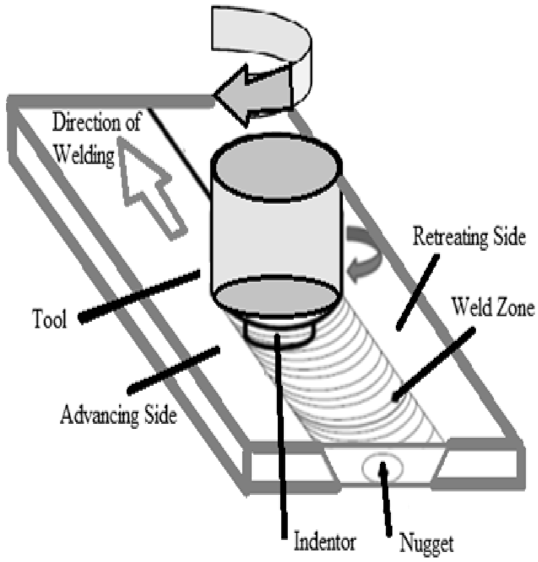

Fig. 1. Friction stir welding process.

FSW has a good performance in terms of significant cost savings, good mechanical strength, and increased production capacity because of increasing welding speed and minimizing welding distortion compared to traditional fusion welding processes such as GTAW which is given in Fig. 2. To generate more heat or achieve efficient mixing has two main advantages. Better dissolution and mixing of the workpiece oxide layer and more efficient heat generation for faster welding speeds and better quality.

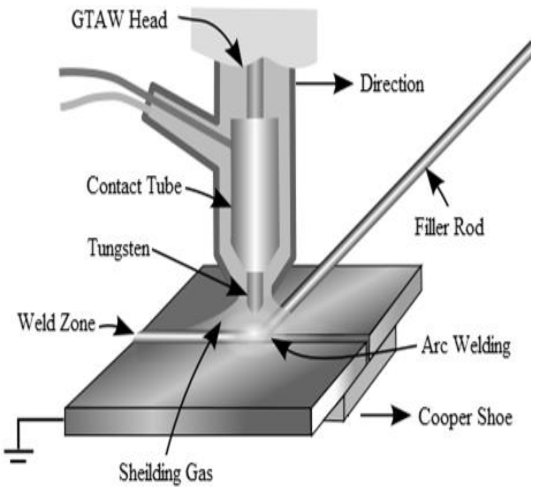

Fig. 2. Arc fusion welding process.

Welding is one of the powers of the industry, especially those that use metal as their main product material. The vehicle manufacturing industry is one of the manufacturers that uses a lot of aluminum metal or its alloys (aluminum alloys) as their production material. Until now aluminum alloy itself has many types of series with different properties and applications. One of them is serie 5 aluminum alloy which has been widely used in the vehicle industry. The 5xxx serie aluminum alloys have different properties from other aluminum alloy series. Its formability properties with relative light mass make this aluminum alloy to be an important material that suitable for various parts of the vehicle body. Although this kind of aluminum alloy cannot be strengthened by heat treatment, it has good corrosion resistance, strength, and welding performance for use in vehicle body technology.

Two of many types of the 5xxx series that are commonly used as materials for vehicle bodies are aluminum alloy type 5052 and 5083. Both are known to have good formability and welding performance, as well as good strength and corrosion resistance. So, it makes AA 5052 and AA 5083 can be used in the process of making bodies for various land and sea vehicles such as cars, trucks, ships, boats, etc. The manufacture is mainly for making vehicle bodies in structural parts, chassis, fuel tanks, engine outer panels, trunks, doors, hoods, and roofs of vehicles, etc. Which is, of course, this use can improve the quality performance of the vehicle so that it has an impact on saving energy in fuel use.

Furthermore, AA 5052 is aluminum with magnesium as the main alloying element, which has smooth surface properties with good forming and welding abilities as well as excellent hardenability. Aluminum alloy 5052 has a higher strength-to-weight ratio than low-carbon steel. Therefore AA 5052 is often applied to vehicles that are not only for safety but also improve performance by reducing vehicle weight so that fuel energy efficiency can be achieved. In addition for certain materials, when comparing the strength-to-weight ratio of the metal, 5052 aluminum alloy can absorb twice the impact energy of low carbon steel [1]–[4]. Therefore, it can be said that AA 5052 can absorb impact energy while helping to further ensure the safety factor of passengers. While 5083 aluminum alloy is aluminum with magnesium element as its main alloy. This metal is corrosion-resistant, durable and the most widely used by industries, including in vehicle manufacturing. It has high strength, fatigue resistance, high plasticity, and good welding performance.

Welding is required in the manufacturing industry itself. The FSW welding method is widely used for welding in the vehicle manufacturing industry because it is eco-friendly and relatively better than other welding methods. Friction Stir Welding (FSW) research on aluminum alloy has been widely studied, including studies about the effect of tool rotation speed and welding speed in the FSW process on the mechanical properties of welded aluminum alloy [5]. Research on the effect of tool parameters on mechanical properties, temperature, and force application during FSW [6]. Study of the mechanical properties of AA 5083 at different temper at low temperatures [7]. In this study, the results of welding AA 5083 and AA 6061 with the FSW process were evaluated, which is aimed to determine the effect of the FSW process parameters and their optimization on weld quality and the ability to form welds after the FSW process [8]. In addition, there is also research [9] that has conducted experimental research on FSW between AA 6061 and AA 5083 using the Taguchi technique. Then, the research [10] conducted an experimental FSW study on AA 5058 and AA 6061 by measuring the relationship between tool rotation speed, welding speed, and tilt angle to analyze the effect of FSW process parameters on test response.

Investigations on the welding of two different aluminum alloys AA 6063 and AA 5083 [11]. Effect of FSW pin tool on mechanical and microstructural properties of AA 5083 [12]. Investigation of friction stir welding of aluminum alloy 5083-H116 [13]. Experimental study of the hardness and fatigue behavior of welding AA 5083 and AA 6063 using the FSW method [14]. The mechanical properties analysis of FSW welding results on aluminum alloys that are applied to the marine industry such as AA 5052, AA 5083, AA 6061, and AA 6063 [15]. This study investigates the weldability of aluminum alloy 5052 by underwater FSW welding [16]. Study of the mechanical properties of the welded joints AA 7075-AA 5182 using the FSW welding method [17]. Investigation of the mechanical properties of FSW AA 5083-AA 6061 [18]. Method for increasing the strength of FSW of AA 5083 joints [19]. Study of the effect of process parameters on the impact strength of FSW AA 5083 and AA 6061 welding [20]. Effect of welding design on fracture toughness of 5052 aluminum alloy welds [21]. The damage and toughness characteristics of AA 5052 are based on continuum damage mechanics [22]. Investigation of the toughness properties of AA 5083 fabricated joints by the FSW process [23].

The effects of welding parameters on mechanical properties of the results of friction stir welding AA 5052 and AA 6061 [24]. Characteristics and optimization of FSW AA 5052 and AA 606 using the Response Surface Methodology (RSM) technique [25]. Formability and failure response of AA 5052-H32 sheet by spot friction stir welding [26]. Comparative study of mechanical and corrosion behavior of TIG and FSW AA 5083-H321 welds [27]. Characterization of friction stir welded joint of aluminum alloy 5083 [28]. Optimizations of friction stir welding process parameters for AA 5052-H32 using the Taguchi method [29]. Mechanical properties of FSW results of AA 5052 and AA 2024 [30]. The effect of tool pin and FSW parameters on tensile strength of AA 5052 [31]. Mechanical and corrosive properties in friction stir welding aluminum alloy 5083 that is used for marine applications [32]. Investigation of the mechanical properties on the welded joints of FSW AA 6063 and AA 5083 [33]. Effect of FSW tool rotational speed on the mechanical properties of AA 5083 [34]. Comparative investigation of mechanical properties of friction stir welding and fusion welding of aluminum alloys 6061-T6 and 5083-O [35]. Mechanical behavior of FSW welded joints AA 6063 and AA 5083 [36]. Microstructural and mechanical characterization of AA 5083-AA 7804 butt joint using FSW method [37].

The problem was found related to the impact strength of the parts on the vehicle body. This is, related to the toughness strength and ductility of the friction stir welding results on aluminum alloys 5052 and 5083, when there is an impact load in a short time interval that acts on the material. This is based on the reality in the field that at any time the vehicle body structure can face extreme stress during its use. The material in the structure must be tested for toughness and fracture failure to find out how the material changes shape so that it may eventually be damaged under these dynamic conditions, for example during collisions or rapid loading which can be in the form of falling to the ground and vehicle collisions.

For this reason, research must be carried out to further analyze the impact strength properties of the material resulting from FSW welding on both aluminum alloys. Therefore, the purpose of this research is to analyze the impact strength properties of similar joint welding results on aluminum alloys which are widely used in the vehicle manufacturing industry, then compare the results of each and compare the quantity ratio of the impact strength properties of the weld results to the base material. The research also includes the calculation of the required energy absorption after impact testing. Toughness or impact strength is the primary property considered in the analysis to describe the quality of the welding process specification or Welding Procedure Specification (WPS). In addition, this research is also to provide analysis and justification for the results obtained to become one of the research and development references for future quality improvement.

2 Materials and Methods

The materials used in this research are AA 5052 and AA 5083 with a thickness of 5 mm. In the FSW welding process, the parameters used were a feed rate of 21 mm/min, a tool rotation of 910 rpm, and a milling machine with a tilt angle of 0°. The tool pins used are AISI H13 steel, with a shoulder diameter of 20 mm and depth of 5 mm, reaching an indent depth of 4.6 mm. FSW welding was performed using the AWS D17.3/D17.3 M:200X standard. The results of the welding are then carried out by visual and radiographic testing with the procedure standard of ASTM E1032 to determine the general condition of the weld results. Besides, the main thing is to do impact testing to know the value of the toughness or impact strength and also absorbed energy of the welded material that is given a load with a fast time (rapid loading). This impact testing process uses the charpy impact test V-notch method that follows the ASTM E23 procedure standard.

After several welding and testing has been carried out, the data of test value is obtained. This data is then processed for further analysis and discussion. Finally, in closing, a conclusion is given to the results and discussion that has been given before. In summary, the process flow of this research is as shown in the flowchart of Fig. 3.

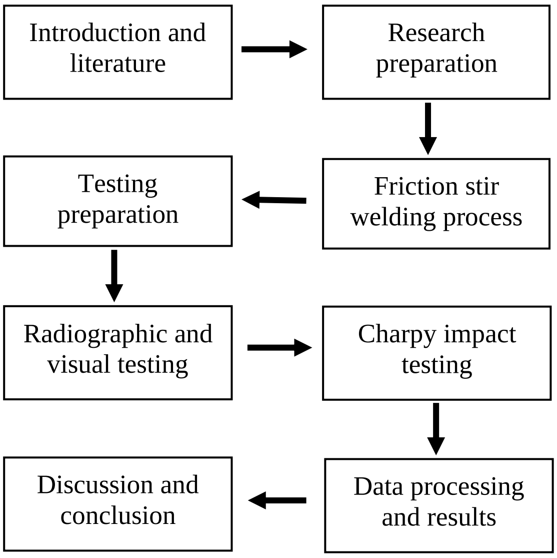

Fig. 3. Flowchart of research methods.

3 Results and Discussion

3.1 Friction Stir Welding

After running the FSW welding process, the following results of the weld sample were obtained. In addition, before producing samples for mechanical testing under the applicable standard testing rules/SOP, these samples were first analyzed to determine whether there was significant damage on the outside or inside of the weld. For AA 5052 welding results are given in Fig. 4 which visually can be ascertained that the weld results obtained are very good and no major damage is visible from the outside.

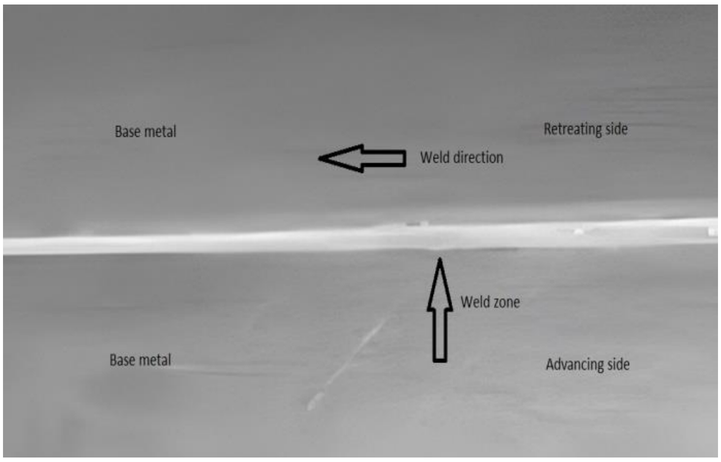

Fig. 4. Welding results of AA 5052.

Likewise the welding results of AA 5083 in Fig. 5, the results are very good and can be classified as welds without significant damage. The welding results obtained in this way can be followed up with radiological testing to check the condition of the weld seam which is not visible to the naked eye. If the X-ray results are good enough, we can proceed to the impact testing. If not, the welding will have to be repeated.

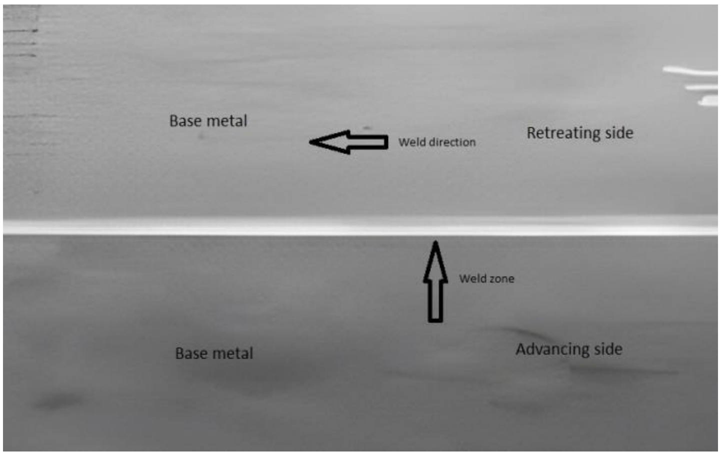

Fig. 5. Welding results of AA 5083.

3.2 Radiography

A radiographic inspection is required to detect possible weld defects in the weld, and absolutely this test is a kind of non-destructive test. Table 1 is the results of the Radiography Test.

Table 1. Radiography results

Type	5052	5083
Incomplete penetration	-	-
Crack	-	-
Root defect	-	-
Defect	-	-
Reject	-	-

From Table 1 there is no evidence of significant damage or defects in the welds during the FSW process of AA 5052 and AA 5083, so the welding results can be still accepted although there is an indication of incomplete fusion. The existing weld samples can be used for further impact mechanical testing.

3.3 Impact

Impact testing was carried out to determine the toughness properties of the AA 5052 and AA 5083 aluminum alloy materials which had undergone a similar joint FSW welding process. The toughness characteristics of base metal and the weld results from AA 5052 and AA 5083 can be determined by carrying out an impact test which is measured in the impact value. In the context of this research, toughness can be defined as the ability of the welded specimen and base material to absorb the absorbed energy. The impact test is carried out using a Charpy impact test tool, the result is in the form of absorbed energy by the test object and can be read directly on the test tool that has been calibrated first. In the Charpy impact test, the specimen is mounted transversely to a cantilever beam and is struck by the swing of a pendulum released from the fixed span to the specimen clamp.

The test is carried out with various temperature variations on specimens that have been previously conditioned to reach the desired temperature. Temperature can show changes in the fracture of a material when it is impact tested at different temperatures, especially if it is quite extreme. From Fig. 6 the graph of the impact values obtained, it shows aluminum alloy 5052 and 5083 have a large transition temperature because the impact strength at various temperatures tends not to differ much. This matter of transition temperature can be important if the material is used for applications with a large temperature range, such as from low temperatures (below 273 K) to high temperatures (up to 373 K or above). And also in both of these materials there is an element of magnesium inside which is sufficient to cause material toughness both in the welding results and in the base material against temperature changes.

The test results are expressed in terms of the energy absorbed by the weight to break the specimen. Energy is required to cause cracks or even direct damage to allow fracture propagation in the test specimen. The fracture itself is a total fracture which can generally be divided into fibrous and granular fractures. Fibrous fracture involves a mechanism of shifting of crystal planes in a ductile material. Meanwhile, granular fracture is produced by the cleavage mechanism of the grains of brittle material. The impact value for the material tested by the Charpy method is obtained by the equation E_{abs}/A, where E_{abs} is the absorbed energy in the specimen and A is its cross-sectional area. The data results were obtained from the impact testing values of the FSW welded specimens and base material of AA 5052 and AA 5083, which were then processed for display. Fig. 6 is the results of the impact test have been processed in such a way that they become the impact value expressed in the international system of units, converted from Joules per square millimeter, as Joules per square meter [38] and then displayed in graphical form.

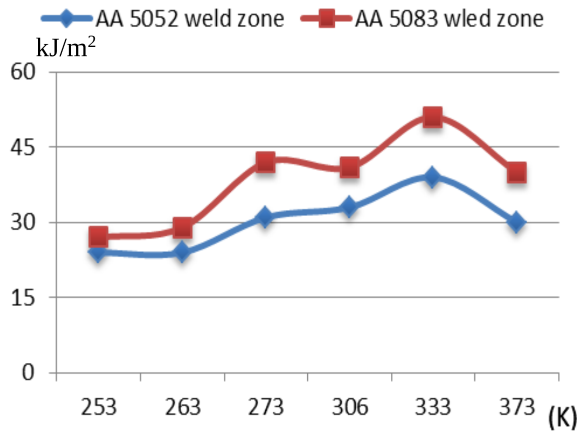

Fig. 6. Impact value on weld zone AA 5052 and AA 5083 for various temperatures.

The second is the impact value on the results of welding aluminum alloy 5083 material. It can be seen that for temperatures of 253 K and 263 K, the impact values are 27 kJ/m^2 and 29 kJ/m^2, respectively. Next, at 273 K the impact value obtained is 42 kJ/m^2. Then at room temperature which is 306 K, the impact value is 41 kJ/m^2. Furthermore, the value at a temperature of 333 K gives the result of an impact value of 51 kJ/m^2. And finally, when the temperature is 373 K, the graph shows an impact value of 40 kJ/m^2.

Based on the data graph and explanation, we can analyze that the impact value at low-temperature T = 253 K, both AA 5052 and AA 5083 tend to have the lowest relatively impact value, which is 24 kJ/m^2 for AA 5052 and 27 kJ/m^2 for AA 5083. While the relatively highest impact value occurs at a temperature of 333 K, the magnitudes of AA 5052 and AA 5083 are 39 kJ/m^2 and 51 kJ/m^2, respectively. We all know that AA 5052 and AA 5083 materials are aluminum alloys with a more dominant mixture of magnesium elements so that these materials can work well at low temperatures. It can be seen from the previous discussion that at low temperatures the energy required for fracture to occur is relatively small. This occurs because at low temperatures crack propagation occurs faster than plastic deformation occurs. Whereas at higher temperatures, the energy required for cracking to occur is greater because it is preceded by plastic deformation.

Furthermore, based on the data graph and descriptions that have been given, the average impact value on the AA 5052 welding results for various temperatures can be calculated and the magnitude is 30.17 kJ/m^2. While the impact value of AA 5052 welding results for various temperatures when averaged is obtained as a value of 38.33 kJ/m^2. In addition, impact testing was also carried out on the base material as was done on the welding results, and the impact values obtained on the base materials AA 5052 and AA 5083 were 74.88 kJ/m^2 and 78.08 kJ/m^2, respectively. The results of these impact values are visualized in Fig. 7.

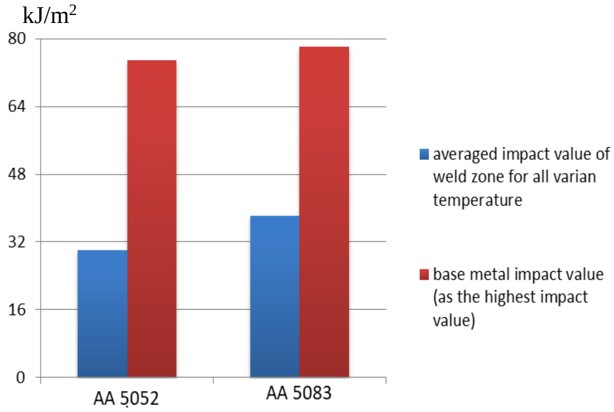

Fig. 7. Comparison of weld zone averaged impact value with base metal impact value.

Fig. 8 shows that the impact value of the welding results tends to be below the base material impact value. If we compare the results of the average impact area of the welding area with the base metal, we will get a ratio of 40.28% for the AA 5052 material. It means the impact area of the weld results has decreased from the base material impact value, which is around 40.29% of the base material impact value. The same thing happened with the AA 5083 material. The comparison ratio between the results of the average impact value of the welding area of AA 5083 and the base metal was 49.10%. It means the value of the impact area of the weld also decreases from the impact value of the base metal.

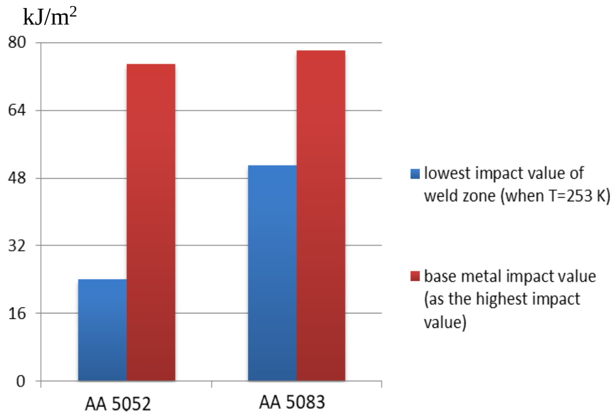

Fig. 8. Comparison of weld zone lowest impact value with base metal impact value.

Fig. 8 shows that the impact value on the results of welding AA 5052 when the temperature equal to 253 K is 24 kJ/m^2. This is also the lowest value among the impact values of other welding results from AA 5052 and AA 5083 for various temperatures, and we obtained it's a comparative ratio to the base metal equals to 32.05%. Then the result of welding AA 5083 when the temperature is 253 K, the impact value is 51 kJ/m^2. This value is the highest value among the impact values of other AA 5052 and AA 5083 welding results for various temperatures, with a comparison ratio of 65.32% of the base metal.

Thus, after the discussion that has been given regarding the ratio of the impact value or material toughness of the welding results of FSW AA 5052 and AA 5083 to their respective base metals. It can be stated that all ratio values are varied, but if generalized within a range of values for the overall impact value results obtained, the ratio is between 32% and 66%. Further research on the impact test results on the references in this study revealed that in general, the impact values of all aluminum alloy samples differed between the weld area and the base material, but did not exceed the base material values. This can be caused by an imperfect agitation process, resulting in poor heat input and uneven distribution, as well as signs of imperfect bonding/coupling. Therefore, the impact value of the weld area is lower than that of the base metal.

The strength and toughness properties of a welded material expressed by the impact value obtained from the tests in this research are also in line with other researches. Among them is research related to type aluminum alloy 5052 [22], [21], [23], [39], [40], [41] and type aluminum alloy 5083 [9], [14], [20], [42], [43], [44]. Which is, generally states that the material impact strength value in the welding area is below the value of the base metal. The results and discussion of the research show that the results of welding on AA 5052 and AA 5083 materials have varying impact values at various temperature conditions when impact testing is carried out. However, if we generalize the impact values, the range is below of the base metal, with a decrease in value of between 34% and 68% of the initial toughness strength of the parent material.

Hardness and toughness are material properties that sound similar to common people but are actually two different scientific quantities. Many materials have impact resistance due to their very hard nature, even though we know that the two properties are different from one another. Hardness is the property of a material's resistance to any kind of deformation such as scratching, bending, compression, etc. In this case, for example, the treatment of scratches, where the higher the hardness value of a material, the greater the load required to scratch its surface. It also includes bending or breaking, which mainly refers to the resistance to impact caused by external loads or sharp objects. Hardness is also a measure of how much (or not) a material or object undergoes plastic (permanent) deformation. If a material is not scratched or bent, it is relatively brittle. Hardness is measured with a hardness tester, usually on the Brinell, Rockwell, or Vickers scale. The hardness tester measures how deep a stylus with a certain profile can penetrate the surface of a material.

Toughness is the ability of the elastic and plastic ranges to absorb energy, while elasticity is the ability of a material to absorb energy within the elastic range. Toughness is required for components that are subjected to bending, torsional, or impact loads. Toughness is defined as the ability of a solid material to absorb energy until it breaks. The modulus of elasticity is a measure of the energy per unit volume required to deform a given solid material to its elastic limit. Toughness is an important property to consider when high elastic deflection is required. Toughness is an important consideration in forming (forging, bending, sheeting, etc.) and metal joining processes.

While the toughness property of the material is the material's ability to absorb energy and change it to be plastically deformed without breaking. Toughness also determines how brittle an object is or will break with force. A material can be said to have low toughness if it is relatively easily broken or crushed. The Charpy test is used to measure the toughness of a material. The Charpy test measures the amount of energy that can be absorbed by the test object before it fractures. On the other hand, there is strength which is a material property that states how much load the material can bear to withstand deformation when given a load.

In addition to its hardness properties, very hard materials must also have good strength and toughness to be hard enough. Call it an example is ceramic which breaks easily because it is not too hard. However, breaking metal plates such as aluminum alloy will require a lot of energy because it has a much harder characteristic. Alloys have a very high impact resistance but are still formed only elastically. Although materials such as aluminum alloys have relatively high impact strength and hardness values, there is little discernible pattern of relationship between these material properties.

In the mechanism of material failure, temperature also plays a role in determining the occurrence of fracture or destruction. It can affect impact testing in diffusion welding [45]. In addition effect of process parameters on the impact strength of FSW joint [20]. Tool rotational speed affects the temperature and impact strength of friction stir welded joints of aluminum alloys [46]. Besides the effect of welding design on fracture toughness of aluminum alloy welds [21]. The failure and toughness characteristics of are based on continuum damage mechanics [22]. In the impact test, the loading is given in a very fast time and the crack propagation energy is measured by finding the energy lost by the collider when it hits the test material. The impact test is also useful for determining the transition temperature of the ductile phase to the fracture phase with a fracture type under different conditions. The ductile phase is the phase in which the material is resistant to fracture, as measured by the amount of fracture energy it can withstand. We can look at other inline research about fatigue or failure in [47], [48], [49]. [50].

4 Conclusion

Based on the results and discussion of the research that has been done, it can be stated that the welding results of FSW AA 5052 and AA 5083 are quite good and acceptable. The impact value on the welding results of aluminum alloy 5052 and 5083, in six different temperature conditions, shows that the tendency for the impact value of all samples is different. Where the average impact value for all of these conditions is 30.17 kJ/m^2 and nothing exceeds the impact value of the base material of the aluminum alloy itself.

The average ratio of the impact value or material toughness of friction stir welding AA 5052 results at various temperatures is 40.28% of the base material impact value. Meanwhile, for AA 5083, the ratio is 49.10%. Although the ratio of the impact value of the welded material to the base metal varies for each temperature condition, if it is generalized within a range of values for the overall results of the impact value obtained, it can be stated that the range is below of the base metal, with a decrease in value of between 34% and 68% of the initial toughness strength of the parent material.

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