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Hartono Yudo[1], Razin Hilmy Baihaqi [2], Untung Budiarto [3]

***Abstract*— aluminium 5052 on ships can be used in LNG tanks, heat exchangers, bulkheads, and superstructures. Its characteristics that can be used in various types of construction in ships cause aluminium 5052 to meet various temperature conditions. The purpose of this research is to find out the strength of the FSW and TIG aluminium 5052 welded joints due to the effect of working temperature. The methods used are impact test and bending test of aluminium 5052 specimens immersed in liquid nitrogen at -160^{0}C and heated in oven at 166^{0}C. The average impact value of raw materials, FSW specimens, and TIG specimens immersed in liquid nitrogen at -160^{0}C are 1.22 J/mm^2, 0.2195 J/mm^2, and 0.0663 J/mm^2, respectively. The average impact value of raw materials, FSW specimens, and TIG specimens heated in an oven at 166^{0}C are 1.3403 J/mm^2, 0.1395 J/mm^2, and 0.0870 J/mm^2, respectively. The average bending stress of raw materials, FSW specimens, and TIG specimens immersed in liquid nitrogen at -160^{0}C are 394.70 MPa, 85.82 MPa, and 299.49 MPa, respectively. The average bending stress of raw materials, FSW specimens, and TIG specimens heated in an oven at 166^{0}C are 400.45 MPa, 148.58 MPa, and 318.55 MPa, respectively. Weld discontinuity observations shows that all raw material specimens do not have open discontinuities exceeding 3 mm, all FSW specimens have open discontinuities exceeding 3 mm, and TIG specimens shows varied results. The conclusion of this study shows that aluminium 5052 is a material that is resistant to temperature changes and is able to maintain its strength at various temperature conditions because aluminium is an FCC (Face Centred Cubic) material.**

Keywords—aluminium 5052, bending stress, FSW, impact value, temperature, TIG , weld discontinuity.

I. INTRODUCTION

Aluminium is the most widely used non-ferrous metal in the industrial world and has been widely used in aerospace, machinery manufacturing, automobiles, and shipping. Aluminium 5052 on ships can be used in LNG tanks, heat exchangers, bulkheads, and superstructures. Its characteristics that can be used in various types of construction on ships cause aluminium 5052 will meet various temperature conditions and temperature is a factor that affects the toughness of the material.

Referring to the book entitled *Standard Welding Terms and Definitions* published by the *American Welding Society*, welding is a joining process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure or with the application of pressure only, and with or without the use of a filler metal. *Gas Tungsten Inert Welding* (GTAW) is an arc welding process that uses tungsten electrodes and *filler rods.* This process uses a shield gas and without the application of pressure. *Friction Stir Welding* (FSW) is a welding variation that produces welds by friction heating caused by a tool in the form of a *tool pin* that rotates rapidly across the weld joint**.**[1]

Tests on the results of welded joints such as impact tests and bending tests are important things to do with the aim of ensuring the quality and reliability of the welded joints.

A material can experience the effect of *ductile* to brittle *transition* or *Ductile to Brittle Transition Temperature* (DBTT). This effect describes a change in the behaviour of a material from being ductile at or above room temperature to being brittle at low temperatures. The ductile-brittle transition effect occurs

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due to the development of the plastic zone in the material and a temperature dependent effect. Materials with a *face centred cubic* (FCC) structure such as aluminium tend not to undergo this transition and are able to maintain their strength at low temperatures.[2]

A research entitled the effect of temperature differences on the impact strength of aluminium 5083 *tungsten inert gas* results obtained an average impact strength that was not too far away, materials given a temperature of -20^{0}C had an average impact value of 0.03 J/mm^2, materials at -10^{0}C has an average impact value of 0.03 J/mm^2, materials at 0^{0}C has an average impact value of 0.04 J/mm^2, materials at room temperature (34^{0}C) has an impact value an average of 0.04 J/mm^2, materials at 50^{0}C has an average impact value of 0.05 J/mm^2, materials at 150^{0}C has an average impact value of 0.03 J/mm^2. These results indicate that aluminium 5083 is a material that is resistant to temperature changes because the structure of this material is FCC (*Face Centred Cubic*).[3]

A research entitled analysis of the effect of argon shielding gasses grade A and grade C on the impact strength and bending of the butt joint on aluminium 5083 showed different impact strength test results. The highest impact strength was obtained for argon shielding gas grade A at 0.22 J/mm^2 and the lowest impact strength is 0.11 J/mm^2 for argon shielding gas grade C. The bending test also showed different results. The highest bending strength was obtained in argon shielding gas grade A at 1458 N/mm^2 while the lowest bending strength is 900 N/mm^2 on materials with argon shielding gas grade C. Impact strength tests showed the most optimal results on materials with argon shielding gas grade A with a value of 0.22 J/mm^2 and the optimal bending strength test on a material with argon shielding gas grade A with a value of 1458 N/mm^2.[4]

A research that investigates the effect of electric current, temperature, and variations of weld angle on the impact strength of 5083 aluminium GTAW welding with helium shielding gas using variations in weld angle of 60^0 and 80^0, temperature variations are -20^{0}C, 0^{0}C, 20^{0}C, and variations of current are 130 A, 150 A, 170 A, 200 A. The results showed that the material with a weld angle of 60^0 given -20^{0}C had an average impact value of 0.078 J/mm^2, materials at 0^{0}C had an average impact value of 0.11675 J/ mm^2, and materials at 20^{0}C has an average impact value of 0.078 J/mm^2. This research found that the highest impact strength is 0.156 J/mm^2 which is obtained by the material at 20^{0}C with a current of 130 A and the lowest impact strength is 0.048 J/mm^2 which is obtained by the material at -20^{0}C with a current of 200 A. This research found that the highest strength occurred at a current of 130 A with weld angle of 80^0 at 20^{0}C.[5]

Research that investigates the effect of electric current and temperature on the tensile and impact strength of aluminium 5083 GMAW welding (*Gas Metal Arc Welding*) using temperature variations of -20^{0}C, 0^{0}C, 20^{0}C and variations in current strength of 130 A, 150 A, 170 A, 200 A shows that materials given a temperature of 20^{0}C has the highest impact value at a current of 130 A with a value of 0.17 J/mm^2, a temperature of 0^{0}C has the highest impact value at a current of 130 A with a value of 0.116 J/mm^2, and a temperature of -20^{0}C has the highest impact value at 130 A with a value of 0.11 J/mm^2.[6]

A study conducted to determine the comparison of the impact, tensile, bending, and micrographic strengths of aluminium 6061 during Tungsten Inert Gas (TIG) welding with seawater, fresh water, and air cooling media shows that materials use seawater as cooling medium have an average impact value of 0.261 J/mm^2, materials use air as cooling medium have an average impact value of 0.085 J/mm^2, and materials use freshwater as cooling medium have an average impact value of 0.237 J/mm^2. Meanwhile, bending test materials use seawater as cooling medium had an average bending stress value of 43.88 MPa, the bending test material use air as cooling medium had an average bending stress value of 34.11 MPa, and the bending test material use fresh water as cooling medium has an average bending stress value of 44.31 MPa. The test results show that the most optimal cooling is specimens treated with fresh water and sea water cooling medium.[7]

A study entitled the effect of heat treatment normalizing on the impact strength of aluminium 6061 MIG welding with variations in the position and shape of the groove got the results that the highest impact value was on the raw material heat treatment normalizing with the value of 0.457 J/mm^2. The raw material without normalizing has an impact value of 0.445 J/mm^2. Thus, the raw material heat treatment normalizing has a greater impact value than the specimen without heat treatment.[8]

A research conducted to determine the effect of the *feed rate* and rotational speed of the friction stir welding (FSW) pin tool on the tensile strength and hardness of aluminium 5052 with variations in the feed rate of 20, 60, 120, and 180 mm/minute and the rotation the tool pin of 1500, 2500, and 3600 rpm. The results showed that the tensile strength at a feed rate of 20 mm/minute is 193.33 MPa, a feed rate 60 mm/minute and 120 mm/minute are 183.33 MPa and 182 MPa, respectively, but the tensile strength at a feed rate 180 mm/minutes decreased drastically to 93.33 MPa. This shows that increasing the feed rate will reduce the tensile strength of the FSW welding results. The results also show that the modulus of elasticity with 1500 rpm pin tool rotation is 48.5 GPa, pin tool rotation 2500 rpm and 3600 rpm are 67.8 GPa and 68.1 GPa, respectively. This shows that an increase in tool pin rotation will increase the value of the modulus of elasticity of FSW welding results. These two parameters indicate that the tool pin rotation and feed rate play an important role in the FSW welding process.[9]

A research conducted to investigate the effect of different feed rates on the tensile and impact strength of aluminium 6061 using the friction stir welding (FSW) welding method using feed rate of 30 mm/minute, 50 mm/minute, 100 mm/minute, and 200 mm/minute. The value of the impact strength test on FSW materials decreased compared to the base metal. The highest average impact value is 0.21 J/mm^2 obtained by materials with a given feed rate of 30 mm/minute while the lowest average impact value is 0.1 J/mm^2 obtained by materials with a given feed rate of 200 mm/minute. The value of tensile strength and strain test significantly decreased compared to the base metal. The highest average tensile strength produced by a feed rate of 70 mm/minute, which is 150.06 MPa and the smallest average tensile strength value produced by a feed rate of 200 mm/minute, which is 128.19 MPa. The largest average strain produced at a feed rate 200 mm/min, which was 4% and the smallest average strain produced at a feed rate 30 mm/min, which is 2.56%.[10]

A review of the existing literature can be summarized that there are several researches that examine the strength of aluminium, but only one study that examines aluminium 5052, and that research examines tensile strength and hardness. There have been no researches examining the impact and bending strength of aluminium 5052. Several researchers also researched TIG welding but no one has examined the strength of aluminium 5052 with TIG welding. There are also no other researches that have examined the effect of temperature treatment in accordance with the working temperature on ships on FSW and TIG welding.

This research aims to investigate the strength of the welded joints of FSW and TIG aluminium 5052 due to the effect of working temperature and to investigate the suitability of the test results with ASTM E-23 and ASME Section IX standards. The temperature used is in accordance with the actual temperature of use on ships, that are -160^{0}C (used on material in LNG tanks) and 166^{0}C (used on material in heat exchangers heat treatment systems ballast water).

II. METHOD

A. Object of Research

Material used in this research is Aluminium 5052. Aluminium 5052 is the majority alloy between aluminium and magnesium (Al-Mg)

B. Research Parameters

1. Material : Aluminium 5052
2. Welding Type : FSW and TIG
3. Groove : Single-V (TIG) and Square (FSW)
4. TIG Weld Angle : 45^0
5. Dimensions of impact test specimens based on ASTM E-23:
   - Length of specimen : 55 mm
   - Width of specimen : 10 mm
   - Thickness of specimen : 10 mm
6. Dimensions of bending test specimens based ASME *Section* IX:
   - Length of specimen : 150 mm
   - Width of specimen : 38 mm
   - Thickness of specimen : 10 mm
7. Dimension of bending test equipment based on ASME Section IX:
   - Thickness of *bending plunger* : 67 mm
   - Distance between pillars : 90 mm
8. The temperature used to be given to the specimens, that are -160^{0}C dan 166^{0}C.

C. Plate Cutting

The first thing to do in the specimen preparation process is cutting plates. There are 2 plates sized 180x60x10 mm, 1 plate sized 120x60x10 mm, 2 plates sized 600x155x10 mm, and 1 plate sized 460x155x10 mm.

Plates that will be welded by tungsten inert gas (TIG) given single-V groove with weld angle of 45^0 while plates that will be welded by friction stir welding (FSW) and raw material are not given special groove shape so they have I-groove or square groove. The plate that has been cut and given weld groove is polished to make it smoother.

D. Tungsten Inert Gas (TIG)

This welding uses a non-consumable electrode in the form of tungsten to create an electric arc and filler rod ER4043 which enters the electric arc area to melts and carried to the base metal. The filler rod's feeding system is manual by hand so that the feeding speed set by the welded. The chemical composition of filler rod ER4043 can be seen in **Table 1**. The TIG welding uses argon as shielding gas. Argon capacity is 15 liters/minute, voltage of 22 volt, current of 165 A, and weld speed of 10 cm/minute.

TABLE 1.
CHEMICAL COMPOSITION ER4043

No	*Element*	*Value*
1	Si	5,2
2	Fe	0,8
3	Cu	0,2
4	Mn	0,05
5	Mg	0,05
6	Cr	0,05-0,2
7	Zn	0,1
8	Ti	0,2
9	Al	*Balance*

E. Friction Stir Welding (FSW)

FSW welding producing a welded material because of friction between base material and rotating cylindrical tool pin probe which trigger local heating to soften the material, then the tool pin probe with 58 HRC hardness pressed into the material and the workbench run manually by hand with a feed rate of 50 mm/minute until the material connects as a whole.

Tool pin probe uses a cylindrical KNL 110 Extra bohler iron with a diameter of 20 mm and then being lathed to get a diameter of 6 mm and a depth of 9 mm. Tool pin probe that has been lathed, is being hardened by heating the workpiece into an oven with specified temperatures for a certain period of time then being cooled in air at room temperature followed by cooling it with oil. The hardening process aims to increase the strength of the tool pin probe.

F. Forming Impact Test Specimens

The impact test specimens as shown in **Figure 1**, consist 30 specimens. There are 10 raw material specimens, 10 TIG specimens, and 10 FSW specimens which will be given temperatures of -160^{0}C and 166^{0}C.

G. Forming Bending Test Specimens

The bending test specimens as shown in **Figure 2,** consist 28 specimens. There are 10 raw material specimens, 10 TIG specimens, and 8 FSW specimens which will be given temperatures of -160^{0}C and 166^{0}C.

Figure. 1. Impact Test Specimens

Figure. 2. Bending Test Specimens

H. Hot Temperature Treatment

Hot temperature treatment as shown in **Figure 3**, given to 15 impact test specimens that has been welded and in the form of raw material and 14 bending test specimens that has been welded and in the form of material by heating them in an oven at 166^{0}C for 30 minutes. The specimens are taken out one by one for being tested on impact and bending test equipment immediately.

I. Cold Temperature Treatment

Cold temperature treatment as shown in **Figure 4**, given to 15 impact test specimens that has been welded and in the form of raw material and 14 bending test specimens that has been welded and in the form of material by immersing them into liquid nitrogen at -160^{0}C. The specimens are taken out one by one for being tested on impact and bending test equipment immediately.

Figure. 3. Hot Temperature Treatment Process

Figure. 4. Cold Temperature Treatment Process

J. Impact Test

Impact test is an attempt to simulate the conditions of the use of material that often encountered which is sudden loads. This research uses the charpy method. This method is used to determine the brittleness or ductility of the test specimen at the weld joint with the position of test specimen placed horizontally on the test equipment.

K. Bending Test

The load process in bending test uses a bending plunger whose dimensions have been determined according to standard. The bending plunger uses to press the test specimen until it bends between two pillars separated by a predetermined distance. This research uses face transversal bending which the weld base is having bending stress and the weld surface is having tensile stress.

L. Tools

Tools used in this research are:

1. Aluminum 5052 plate
2. FSW and TIG welding machines
3. Filler rod ER4043
4. Lathe machine
5. Liquid nitrogen and the container
6. Oven or furnace
7. Impact test equipment and bending test equipment
8. Clamp
9. 58 specimens of impact test specimens and bending test specimens

M. Research Location

Aluminum 5052 plate obtained at PT. Mita Jaya Mandiri. The process of cutting aluminum 5052 plate and tungsten inert gas (TIG) welding at Inlastek-Welding Institute, Surakarta.

Friction-stir welding (FSW) and the lathing process of cylindrical KNL 110 Extra bohler iron at SMKN Jawa Tengah (BPM Dikjur), Semarang. Cylindrical KNL 110 Extra bohler iron obtained at PT. Bhinneka Bajanas, Semarang.

The process of impact test and bending test is being done at mechanical engineering laboratory, UGM Vocational School.

III. Results and Discussion

A. Impact Test Result of Specimens Immersed in Nitrogen at -160^{0}C

The impact value of specimens immersed in nitrogen at -160^{0}C and has complied the calculation of standard deviation shown in **Table 2**. 4 raw material specimens have an average impact value of 1.22 J/mm^2, 4 FSW specimens have an average impact value of 0.2195 J/mm^2, and 4 TIG specimens have an average impact value of 0.06625 J/mm^2.

These data indicate that the raw material have a higher impact value than specimens treated with FSW and TIG welding with a difference of about ±1 J/mm^2 but FSW specimens have a better average impact value compared to TIG specimens.

B. Impact Test Result of Specimens Heated in an Oven at 166^{0}C

The impact value of specimens heated in an oven at 166^{0}C and has complied the calculation of standard deviation shown in **Table 3**. 3 raw material specimens have an average impact value of 1.3403 J/mm^2, 4 FSW specimens have an average impact value of 0.1395 J/mm^2, and 4 TIG specimens have an average impact value of 0.0870 J/mm^2.

These data indicate that the raw material have a higher impact value than specimens treated with FSW and TIG welding with a difference of about ±1 J/mm^2 but FSW specimens have a better average impact value compared to TIG specimens.

TABLE 2.
DATA OF IMPACT TEST RESULT OF SPECIMENS IMMERSED IN NITROGEN AT -160^{0}C

Welding Type	Impact Value (J/mm^2)	Standard Deviation
Raw Material	1.22	0.0221
FSW	0.2195	0.0698
TIG	0.06625	0.0044

TABLE 3.
DATA OF IMPACT TEST RESULT OF SPECIMENS HEATED IN AN OVEN AT 166^{0}C

Welding Type	Impact Value (J/mm^2)	Standard Deviation
Raw Material	1.3403	0.0411
FSW	0.1395	0.0212
TIG	0.0870	0.0128

C. Comparison of Impact Test Results with ASTM E-23 Standard

The comparison of the impact values of *raw material*, FSW, and TIG specimens that have been given various temperature treatments shown in **Figure 5**. The ASTM E-23 standard regulates that non-welded materials must have a minimum standard impact value of 0.40 J/mm^2 while welded materials must have a minimum impact value of 0.10 J/mm^2.

The average impact value of *raw material* immersed in liquid nitrogen at -160^{0}C is 1.22 J/mm^2 and specimens heated in an oven at a temperature of 166^{0}C is 1.34 J/mm^2 so that based on this value, the impact value of the *raw material* has complied the impact value standard set by ASTM E-23.

The impact test on FSW specimens shows that specimens immersed in liquid nitrogen at -160^{0}C has an average impact value of 0,22 J/mm^2 while specimens heated in an oven at 166^{0}C has an average impact value of 0,14 J/mm^2. The majority of FSW specimens have impact values that complied ASTM E-23 standard.

The impact test on TIG specimens shows that specimens immersed in liquid nitrogen at -160^{0}C has an average impact value of 0,07 J/mm^2 while specimens heated in an oven at 166^{0}C has an average impact value of 0,09 J/mm^2 so that TIG specimens have impact values that do not complied ASTM E-23 standard. Based on discussion with the laboratory assistant from the Inlastek-Welding Institute, TIG specimens do not comply ASTM E-23 standard are thought due to the use of an inappropriate filler rod.

In the impact test process, the pendulum strikes the center of the specimen that has been given 2 mm deep-notch so that in the FSW and TIG specimen, the pendulum strikes the weld joint. The average impact value of TIG specimens is lower than the average impact value of raw material specimens is thought to occur due to the difference in the value of material strength in form of tensile strength between aluminum 5052 and filler rod ER 4043. Tensile strength of aluminum 5052 is 290 MPa, while the filler rod ER4043 is 186 MPa.

The average impact value of FSW specimens is lower than raw material specimen and the average impact value of FSW specimens at -160^{0}C is higher than 166^{0}C, which is different with the trend of raw material specimen and TIG specimen which values at -160^{0}C is higher than 166^{0}C, is thought to occur due to the chemical composition of KNL 110 Extra Bohler Iron does not contain aluminum so that the FSW specimen does not blend perfectly.

The general trends of ductile-brittle transition effect for different groups of metals shown **in Figure 6.** Aluminium as face centred cubic (FCC) metals tends not to undergo this effect. This theory proved by the result of impact test of raw material, FSW, and TIG specimens given temperature variations of -160^{0}C and 166^0 showed in Figure 5. The result of this research indicates that aluminium 5052 is able to maintain its strength in various temperature conditions.

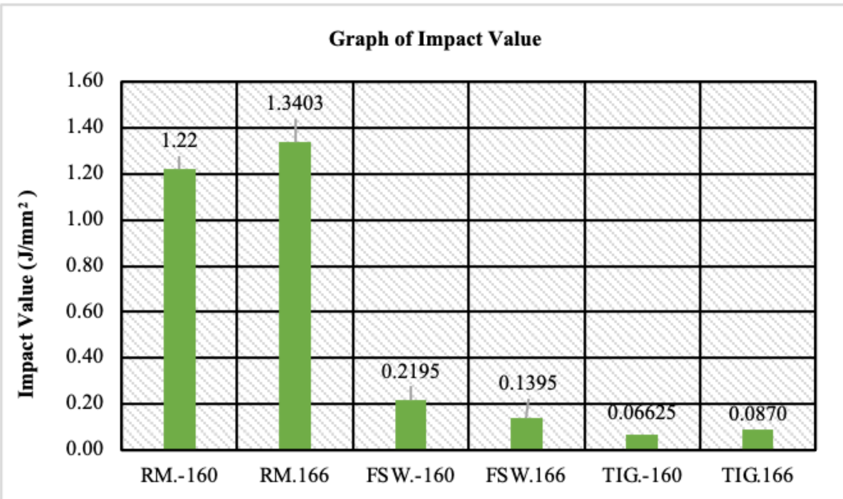

Figure. 5. Graph of Impact Value

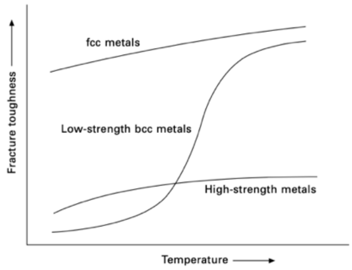

Figure. 6. General Trends Graph Of The Ductile-Brittle Transition Effect For Different Groups Of Metals

D. Bending Test Result of Specimens Immersed in Nitrogen at -160^{0}C

The bending value of specimens immersed in liquid nitrogen at -160^{0}C and has complied the calculation of standard deviation shown in **Table 4**. 3 raw material specimens have an average bending stress value of 394.70 MPa, 4 FSW specimens have an average bending stress value of 85.82 MPa, and 2 TIG specimens have an average bending stress value of 299.49 MPa.

These data indicate that the raw material have a higher average bending stress value than specimens treated with FSW and TIG welding but TIG specimens have a better average bending value compared to FSW specimens.

TABLE 4.
DATA OF BENDING TEST RESULT OF SPECIMENS IMMERSED IN NITROGEN AT -160^{0}C

Welding Type	Bending Stress Value (MPa)	Standard Deviation
Raw Material	394.70	9.45
FSW	85.82	30.6341
TIG	299.49	36,29

ASME Section IX regulates that welded joint specimen tested transversal-bending must not have an open discontinuity exceeding 1/8 inches (3 mm) measured at the convex surface of the welded joint specimen after being tested by transversal-bending test.

The raw material bending test specimens immersed in liquid nitrogen at -160^0 C shown in **Figure 7.** They bended without experiencing an open discontinuity so that this specimen complied with the standard set by ASME Section IX, which is not experiencing an open discontinuity exceeding 3 mm.

The FSW bending test specimens immersed in liquid nitrogen at -160^{0}C shown in **Figure 8(a)**. They undergo an open discontinuity exceeding 3 mm so FSW specimens do not comply the standard set by ASME Section X. The test results do not comply the standard are thought due to the poor quality of the weld joint with indication that there are weld defects in the form of incomplete penetration

The TIG bending test specimens immersed in liquid nitrogen at -160^{0}C shown in **Figure 8(b)**. Specimen with code 1T3, 1T4, and 1T5 do not undergo an open discontinuity exceeding 3 mm so they complied with the standard set by ASME Section IX, while specimens coded 1T1 and 1T4 experiencing a fracture so they do not comply ASME Section IX. There are specimens do not comply the standard estimated because of the use of an inappropriate filler rod. This research uses a ER4043 filler rod while based on discussion with laboratory assistant from Inlastek-Welding Institute, if the aluminum used is 5000-series aluminum, the filler rod used should also be 5000-series filler rod.

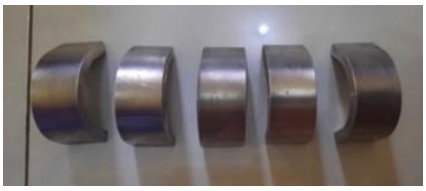

Figure. 7. Raw Material Specimens After Being Given Bending Test

(a) **(b)**

Figure. 8. ***(a)*** FSW Specimen After Being Given Bending Test. ***(b)*** TIG Specimen After Being Given Bending Test.

E. Bending Test Result of Specimens Heated in an Oven at 166^{0}C.

The bending value of specimens immersed in liquid nitrogen at 166^{0}C and has complied the calculation of standard deviation shown in **Table 5**. 4 raw material specimens have an average bending stress value of 400.45 MPa, 4 FSW specimens have an average bending stress value of 148.58 MPa, and 2 TIG specimens have an average bending stress value of 318.55 MPa.

These data indicate that the raw material have a higher average bending stress value than specimens treated with FSW and TIG welding but TIG specimens have a better average bending value compared to FSW specimens.

TABLE 5.
DATA OF BENDING TEST RESULT OF SPECIMENS HEATED IN AN OVEN AT 166^{0}C

Welding Type	Bending Stress Value (MPa)	Standard Deviation
Raw Material	400.45	12.81
FSW	148.58	120.20
TIG	318.55	39.13

ASME Section IX regulates that welded joint specimen tested transversal-bending must not have an open discontinuity exceeding 1/8 inches (3 mm) measured at the convex surface of the welded joint specimen after being tested by transversal-bending test.

The raw material bending test specimens immersed in liquid nitrogen at 166^0 C shown in **Figure 9**. They bended without experiencing an open discontinuity so that this specimen complied with the standard set by ASME Section IX, which is not experiencing an open discontinuity exceeding 3 mm.

The FSW bending test specimens heated in an oven at 166^{0}C shown in **Figure 10(a)**. They undergo an open discontinuity exceeding 3 mm so FSW specimens do not comply the standard set by ASME Section X. The test results do not comply the standard are thought due to the poor quality of the weld joint with indication that there are weld defects in the form of incomplete penetration.

The TIG bending test specimens heated in an oven at 166^{0}C shown in **Figure 10(a)**. Specimen with code 3T5 do not undergo an open discontinuity exceeding 3 mm so they complied with the standard set by ASME Section IX, while specimens coded 3T1, 3T2, 3T3, and 3T4 experiencing a fracture so they do not comply ASME Section IX. There are specimens do not comply the standard estimated because of the use of an inappropriate filler rod. This research uses a ER4043 filler rod while based on discussion with laboratory assistant from Inlastek-Welding Institute, if the aluminum used is 5000-series aluminum, the filler rod used should also be 5000-series filler rod.

Figure. 9. Raw Material Specimens After Being Given Bending Test

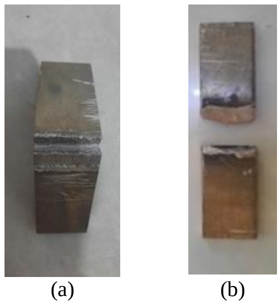

Figure. 10. ***(a)*** FSW Specimens After Being Given Bending Test. ***(b)*** TIG Specimens After Being Given Bending Test

F. Comparison of Bending Stress Value

A graph of the comparison of the bending stress values of *raw material*, FSW, and TIG specimens that have been given various temperature treatments shown in **Figure 11**. Average bending stress value of raw material specimens immersed in in liquid nitrogen at -160^{0}C is 394.70 MPa and specimens heated in an oven at a temperature of 166^{0}C is 400.4475 MPa.

The bending test on FSW specimens shows that specimens immersed in liquid nitrogen at -160^{0}C has an average bending stress value of 85.82 MPa while specimens heated in an oven at 166^{0}C has an average bending stress value of 148.5775 MPa.

The bending test on TIG specimens shows that specimens immersed in liquid nitrogen at -160^{0}C has an average bending stress value of 299.485 MPa while specimens heated in an oven at 166^{0}C has an average bending stress value of 318.5475 MPa.

In the bending test process, the bending plunger bend the center of the specimen that has been given 2 mm deep-notch so that in the FSW and TIG specimen, the bending plunger bend the weld joint. The average bending stress value on the raw material specimen which is greater than the TIG specimen is thought to occur due to the difference in the value of material strength in form of tensile strength between aluminum 5052 and filler rod ER 4043. Tensile strength of aluminum 5052 is 290 MPa, while the filler rod ER4043 is 186 MPa. The average bending stress value on the raw material is greater than the FSW specimen, it is estimated that the chemical composition of KNL 110 Extra Bohler Iron does not contain aluminum so that the FSW specimens does not blend perfectly.

The general trends of ductile-brittle transition effect for different groups of metals shown in **Figure 6**. Aluminium as face centred cubic (FCC) metals tends not to undergo this effect. This theory proved by the result of bending test of raw material, FSW, and TIG specimens given temperature variations of -160^{0}C and 166^0 showed in Figure 11. The result of this research indicates that aluminium 5052 is able to maintain its strength in various temperature conditions.

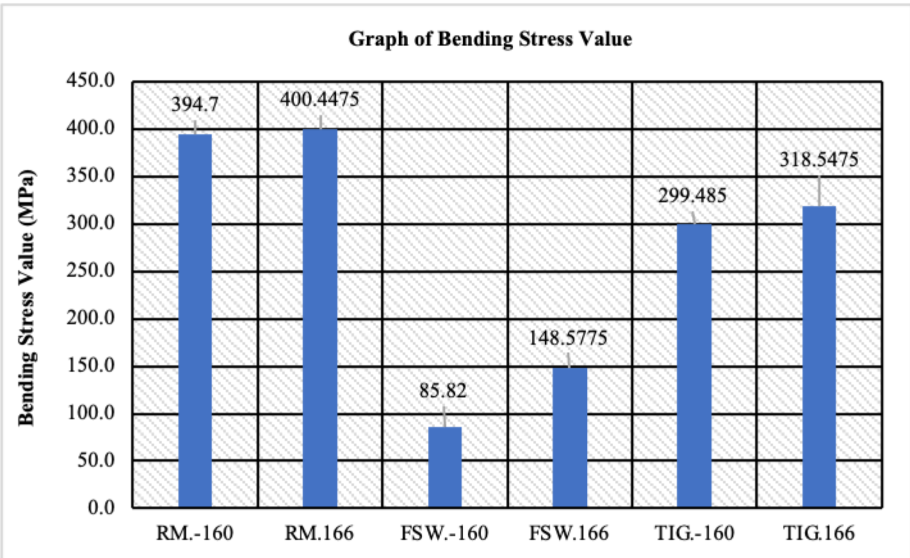

Figure. 11. Graph of Bending Stress Value

IV. Conclusion

Conclusion resulted from the research that investigate the strength of the welded joints of FSW and TIG aluminium 5052 due to the effect of working temperature are:

The average impact value of raw material specimens immersed in liquid nitrogen at -160^{0}C is 1.22 J/mm^2 while raw material specimens being heated in an oven at 166^{0}C is 1.3403 J/mm^2. The average impact value of FSW specimens immersed in liquid nitrogen at -160^0 C is 0.2195 J/mm^2 while FSW specimens being heated in an oven at 166^{0}C is 0.1395 J/mm^2. The average impact value of TIG specimens immersed in liquid nitrogen at -160^0 C is 0.06625 J/mm^2 while FSW specimens being heated in an oven at 166^0C is 0.0870 J/mm^2.

The average bending stress value of raw material specimens immersed in liquid nitrogen at -160^0C is 394.70 MPa while raw material specimens being heated in an oven at 166^0C is 400.45 MPa. The average bending stress value of FSW specimens immersed in liquid nitrogen at -160^0C is 85.82 MPa while FSW specimens being heated in an oven at 166^0C is 148.5775 MPa. The average bending stress value of TIG specimens immersed in liquid nitrogen at -160^0C is 299.485 MPa while TIG specimens being heated in an oven at 166^0C is 318.5475 MPa.

The results of the impact test and bending test of *raw material*, FSW, and TIG specimens given temperature variations of -160^0C and 166^0C indicate that aluminium 5052 is a material that is resistant to temperature changes and is able to maintain its strength in various temperature conditions because aluminum is an FCC (*face centered cubic*).

Visual open discontinuity observation made on bending test specimens shows that all raw material specimens do not undergo an open discontinuity exceeding 3 mm, all FSW specimens experienced an open discontinuity exceeding 3 mm, and TIG specimens shows varied visual open discontinuity observation result, there are specimens which are undergo and do not undergo open discontinuity exceeding 3 mm.

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Analysis of FSW and TIG Aluminium 5052 Welded Joint Strength Due to The Effect of Working Temperature

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***Abstract*— aluminium 5052 on ships can be used in LNG tanks, heat exchangers, bulkheads, and superstructures. Its characteristics that can be used in various types of construction in ships cause aluminium 5052 to meet various temperature conditions. The purpose of this research is to find out the strength of the FSW and TIG aluminium 5052 welded joints due to the effect of working temperature. The methods used are impact test and bending test of aluminium 5052 specimens immersed in liquid nitrogen at -160^{0}C and heated in oven at 166^{0}C. The average impact value of raw materials, FSW specimens, and TIG specimens immersed in liquid nitrogen at -160^{0}C are 1.22 J/mm^2, 0.2195 J/mm^2, and 0.0663 J/mm^2, respectively. The average impact value of raw materials, FSW specimens, and TIG specimens heated in an oven at 166^{0}C are 1.3403 J/mm^2, 0.1395 J/mm^2, and 0.0870 J/mm^2, respectively. The average bending stress of raw materials, FSW specimens, and TIG specimens immersed in liquid nitrogen at -160^{0}C are 394.70 MPa, 85.82 MPa, and 299.49 MPa, respectively. The average bending stress of raw materials, FSW specimens, and TIG specimens heated in an oven at 166^{0}C are 400.45 MPa, 148.58 MPa, and 318.55 MPa, respectively. Weld discontinuity observations shows that all raw material specimens do not have open discontinuities exceeding 3 mm, all FSW specimens have open discontinuities exceeding 3 mm, and TIG specimens shows varied results. The conclusion of this study shows that aluminium 5052 is a material that is resistant to temperature changes and is able to maintain its strength at various temperature conditions because aluminium is an FCC (Face Centered Cubic) material.**

Keywords—aluminium 5052, bending stress, FSW, impact value, temperature, TIG , weld discontinuity.

I. Introduction

Aluminium is the most widely used non-ferrous metal in the industrial world and has been widely used in aerospace, machinery manufacturing, automobiles, and shipping. Aluminium 5052 on ships can be used in LNG tanks, heat exchangers, bulkheads, and superstructures. Its characteristics that can be used in various types of construction on ships cause aluminium 5052 will meet various temperature conditions and temperature is a factor that affects the toughness of the material.

Referring to the book entitled *Standard Welding Terms and Definitions* published by the *American Welding Society*, welding is a joining process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure or with the application of pressure only, and with or without the use of a filler metal. *Gas Tungsten Inert Welding* (GTAW) is an arc welding process that uses tungsten electrodes and *filler rods.* This process uses a shield gas and without the application of pressure. *Friction Stir Welding* (FSW) is a welding variation that produces welds by friction heating caused by a tool in the form of a *tool pin* that rotates rapidly across the weld joint**.**[1]

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Tests on the results of welded joints such as impact tests and bending tests are important things to do with the aim of ensuring the quality and reliability of the welded joints.

A material can experience the effect of *ductile* to brittle *transition* or *Ductile to Brittle Transition Temperature* (DBTT). This effect describes a change in the behaviour of a material from being ductile at or above room temperature to being brittle at low temperatures. The ductile-brittle transition effect occurs due to the development of the plastic zone in the material and a temperature dependent effect. Materials with a *face centred cubic* (FCC) structure such as aluminium tend not to undergo this transition and are able to maintain their strength at low temperatures.[2]

A research entitled the effect of temperature differences on the impact strength of aluminium 5083 *tungsten inert gas* results obtained an average impact strength that was not too far away, materials given a temperature of -20^{0}C had an average impact value of 0.03 J/mm^2, materials at -10^{0}C has an average impact value of 0.03 J/mm^2, materials at 0^{0}C has an average impact value of 0.04 J/mm^2, materials at room temperature (34^{0}C) has an impact value an average of 0.04 J/mm^2, materials at 50^{0}C has an average impact value of 0.05 J/mm^2, materials at 150^{0}C has an average impact value of 0.03 J/mm^2. These results indicate that aluminium 5083 is a material that is resistant to temperature changes because the structure of this material is FCC (*Face Centred Cubic*).[3]

A research entitled analysis of the effect of argon shielding gasses grade A and grade C on the impact strength and bending of the butt joint on aluminium 5083 showed different impact strength test results. The highest impact strength was obtained for argon shielding gas grade A at 0.22 J/mm^2 and the lowest impact strength is

0.11 J/mm^2 for argon shielding gas grade C. The bending test also showed different results. The highest bending strength was obtained in argon shielding gas grade A at 1458 N/mm^2 while the lowest bending strength is 900 N/mm^2 on materials with argon shielding gas grade C. Impact strength tests showed the most optimal results on materials with argon shielding gas grade A with a value of 0.22 J/mm^2 and the optimal bending strength test on a material with argon shielding gas grade A with a value of 1458 N/mm^2.[4]

A research that investigates the effect of electric current, temperature, and variations of weld angle on the impact strength of 5083 aluminium GTAW welding with helium shielding gas using variations in weld angle of 60^0 and 80^0, temperature variations are -20^{0}C, 0^{0}C, 20^{0}C, and variations of current are 130 A, 150 A, 170 A, 200 A. The results showed that the material with a weld angle of 60^0 given -20^{0}C had an average impact value of 0.078 J/mm^2, materials at 0^{0}C had an average impact value of 0.11675 J/ mm^2, and materials at 20^{0}C has an average impact value of 0.078 J/mm^2. This research found that the highest impact strength is 0.156 J/mm^2 which is obtained by the material at 20^{0}C with a current of 130 A and the lowest impact strength is 0.048 J/mm^2 which is obtained by the material at -20^{0}C with a current of 200 A. This research found that the highest strength occurred at a current of 130 A with weld angle of 80^0 at 20^{0}C.[5]

Research that investigates the effect of electric current and temperature on the tensile and impact strength of aluminium 5083 GMAW welding (*Gas Metal Arc Welding*) using temperature variations of -20^{0}C, 0^{0}C, 20^{0}C and variations in current strength of 130 A, 150 A, 170 A, 200 A shows that materials given a temperature of 20^{0}C has the highest impact value at a current of 130 A with a value of 0.17 J/mm^2, a temperature of 0^{0}C has the highest impact value at a current of 130 A with a value of 0.116 J/mm^2, and a temperature of -20^{0}C has the highest impact value at 130 A with a value of 0.11 J/mm^2.[6]

A study conducted to determine the comparison of the impact, tensile, bending, and micrographic strengths of aluminium 6061 during Tungsten Inert Gas (TIG) welding with seawater, fresh water, and air cooling media shows that materials use seawater as cooling medium have an average impact value of 0.261 J/mm^2, materials use air as cooling medium have an average impact value of 0.085 J/mm^2, and materials use freshwater as cooling medium have an average impact value of 0.237 J/mm^2. Meanwhile, bending test materials use seawater as cooling medium had an average bending stress value of 43.88 MPa, the bending test material use air as cooling medium had an average bending stress value of 34.11 MPa, and the bending test material use fresh water as cooling medium has an average bending stress value of 44.31 MPa. The test results show that the most optimal cooling is specimens treated with fresh water and sea water cooling medium.[7]

A study entitled the effect of heat treatment normalizing on the impact strength of aluminium 6061 MIG welding with variations in the position and shape of the groove got the results that the highest impact value was on the raw material heat treatment normalizing with the value of 0.457 J/mm^2. The raw material without normalizing has an impact value of 0.445 J/mm^2. Thus, the raw material heat treatment normalizing has a greater impact value than the specimen without heat treatment. [8]

A research conducted to determine the effect of the *feed rate* and rotational speed of the friction stir welding (FSW) pin tool on the tensile strength and hardness of aluminium 5052 with variations in the feed rate of 20, 60, 120, and 180 mm/minute and the rotation the tool pin of 1500, 2500, and 3600 rpm. The results showed that the tensile strength at a feed rate of 20 mm/minute is 193.33 MPa, a feed rate 60 mm/minute and 120 mm/minute are 183.33 MPa and 182 MPa, respectively, but the tensile strength at a feed rate 180 mm/minutes decreased drastically to 93.33 MPa. This shows that increasing the feed rate will reduce the tensile strength of the FSW welding results. The results also show that the modulus of elasticity with 1500 rpm pin tool rotation is 48.5 GPa, pin tool rotation 2500 rpm and 3600 rpm are 67.8 GPa and 68.1 GPa, respectively. This shows that an increase in tool pin rotation will increase the value of the modulus of elasticity of FSW welding results. These two parameters indicate that the tool pin rotation and feed rate play an important role in the FSW welding process.[9]

A research conducted to investigate the effect of different feed rates on the tensile and impact strength of aluminium 6061 using the friction stir welding (FSW) welding method using feed rate of 30 mm/minute, 50 mm/minute, 100 mm/minute, and 200 mm/minute. The value of the impact strength test on FSW materials decreased compared to the base metal. The highest average impact value is 0.21 J/mm^2 obtained by materials with a given feed rate of 30 mm/minute while the lowest average impact value is 0.1 J/mm^2 obtained by materials with a given feed rate of 200 mm/minute. The value of tensile strength and strain test significantly decreased compared to the base metal. The highest average tensile strength produced by a feed rate of 70 mm/minute, which is 150.06 MPa and the smallest average tensile strength value produced by a feed rate of 200 mm/minute, which is 128.19 MPa. The largest average strain produced at a feed rate 200 mm/min, which was 4% and the smallest average strain produced at a feed rate 30 mm/min, which is 2.56%.[10]

A review of the existing literature can be summarized that there are several researches that examine the strength of aluminium, but only one study that examines aluminium 5052, and that research examines tensile strength and hardness. There have been no researches examining the impact and bending strength of aluminium 5052. Several researchers also researched TIG welding but no one has examined the strength of aluminium 5052 with TIG welding. There are also no other researches that have examined the effect of temperature treatment in accordance with the working temperature on ships on FSW and TIG welding.

This research aims to investigate the strength of the welded joints of FSW and TIG aluminium 5052 due to the effect of working temperature and to investigate the suitability of the test results with ASTM E-23 and ASME Section IX standards. The temperature used is in accordance with the actual temperature of use on ships, that are -160^{0}C (used on material in LNG tanks) and 166^{0}C (used on material in heat exchangers heat treatment systems ballast water).

II. METHOD

A. Object of Research

Material used in this research is Aluminium 5052. Aluminium 5052 is the majority alloy between aluminium and magnesium (Al-Mg)

B. Research Parameters

1. Material : Aluminium 5052
2. Welding Type : FSW and TIG
3. Groove : Single-V (TIG) and Square (FSW)
4. TIG Weld Angle : 45^0
5. Dimensions of impact test specimens based on ASTM E-23:
   - Length of specimen : 55 mm
   - Width of specimen : 10 mm
   - Thickness of specimen : 10 mm
6. Dimensions of bending test specimens based ASME *Section* IX:
   - Length of specimen : 150 mm
   - Width of specimen : 38 mm
   - Thickness of specimen : 10 mm
7. Dimension of bending test equipment based on ASME Section IX:
   - Thickness of *bending plunger* : 67 mm
   - Distance between pillars : 90 mm
8. The temperature used to be given to the specimens, that are -160^{0}C dan 166^{0}C.

C. Plate Cutting

The first thing to do in the specimen preparation process is cutting plates. There are 2 plates sized 180x60x10 mm, 1 plate sized 120x60x10 mm, 2 plates sized 600x155x10 mm, and 1 plate sized 460x155x10 mm.

Plates that will be welded by tungsten inert gas (TIG) given single-V groove with weld angle of 45^0 while plates that will be welded by friction stir welding (FSW) and raw material are not given special groove shape so they have I-groove or square groove. The plate that has been cut and given weld groove is polished to make it smoother.

D. Tungsten Inert Gas (TIG)

This welding uses a non-consumable electrode in the form of tungsten to create an electric arc and filler rod ER4043 which enters the electric arc area to melts and carried to the base metal. The filler rod's feeding system is manual by hand so that the feeding speed set by the welded. The chemical composition of filler rod ER4043 can be seen in **Table 1**. The TIG welding uses argon as shielding gas. Argon capacity is 15 liters/minute, voltage of 22 volt, current of 165 A, and weld speed of 10 cm/minute.

TABLE 1.
CHEMICAL COMPOSITION ER4043

No	*Element*	*Value*
1	Si	5,2
2	Fe	0,8
3	Cu	0,2
4	Mn	0,05
5	Mg	0,05
6	Cr	0,05-0,2
7	Zn	0,1
8	Ti	0,2
9	Al	*Balance*

E. Friction Stir Welding (FSW)

FSW welding producing a welded material because of friction between base material and rotating cylindrical tool pin probe which trigger local heating to soften the material, then the tool pin probe with 58 HRC hardness pressed into the material and the workbench run manually by hand with a feed rate of 50 mm/minute until the material connects as a whole.

Tool pin probe uses a cylindrical KNL 110 Extra bohler iron with a diameter of 20 mm and then being lathed to get a diameter of 6 mm and a depth of 9 mm. Tool pin probe that has been lathed, is being hardened by heating the workpiece into an oven with specified temperatures for a certain period of time then being cooled in air at room temperature followed by cooling it with oil. The hardening process aims to increase the strength of the tool pin probe.

F. Forming Impact Test Specimens

The impact test specimens as shown in **Figure 1**, consist 30 specimens. There are 10 raw material specimens, 10 TIG specimens, and 10 FSW specimens which will be given temperatures of -160^{0}C and 166^{0}C.

G. Forming Bending Test Specimens

The bending test specimens as shown in **Figure 2,** consist 28 specimens. There are 10 raw material specimens, 10 TIG specimens, and 8 FSW specimens which will be given temperatures of -160^{0}C and 166^{0}C.

Figure. 1. Impact Test Specimens

Figure. 2. Bending Test Specimens

H. Hot Temperature Treatment

Hot temperature treatment as shown in **Figure 3**, given to 15 impact test specimens that has been welded and in the form of raw material and 14 bending test specimens that has been welded and in the form of material by heating them in an oven at 166^0C for 30 minutes. The specimens are taken out one by one for being tested on impact and bending test equipment immediately.

I. Cold Temperature Treatment

Cold temperature treatment as shown in **Figure 4**, given to 15 impact test specimens that has been welded and in the form of raw material and 14 bending test specimens that has been welded and in the form of material by immersing them into liquid nitrogen at -160^0C. The specimens are taken out one by one for being tested on impact and bending test equipment immediately.

Figure. 3. Hot Temperature Treatment Process

Figure. 4. Cold Temperature Treatment Process

J. Impact Test

Impact test is an attempt to simulate the conditions of the use of material that often encountered which is sudden loads. This research uses the charpy method. This method is used to determine the brittleness or ductility of the test specimen at the weld joint with the position of test specimen placed horizontally on the test equipment.

K. Bending Test

The load process in bending test uses a bending plunger whose dimensions have been determined according to standard. The bending plunger uses to press the test specimen until it bends between two pillars separated by a predetermined distance. This research uses face transversal bending which the weld base is having bending stress and the weld surface is having tensile stress.

L. Tools

Tools used in this research are:

1. Aluminum 5052 plate
2. FSW and TIG welding machines
3. Filler rod ER4043
4. Lathe machine
5. Liquid nitrogen and the container
6. Oven or furnace
7. Impact test equipment and bending test equipment
8. Clamp
9. 58 specimens of impact test specimens and bending test specimens

M. Research Location

Aluminum 5052 plate obtained at PT. Mita Jaya Mandiri. The process of cutting aluminum 5052 plate and tungsten inert gas (TIG) welding at Inlastek-Welding Institute, Surakarta.

Friction-stir welding (FSW) and the lathing process of cylindrical KNL 110 Extra bohler iron at SMKN Jawa Tengah (BPM Dikjur), Semarang. Cylindrical KNL 110 Extra bohler iron obtained at PT. Bhinneka Bajanas, Semarang.

The process of impact test and bending test is being done at mechanical engineering laboratory, UGM Vocational School.

III. RESULTS AND DISCUSSION

A. Impact Test Result of Specimens Immersed in Nitrogen at -160^{0}C

The impact value of specimens immersed in nitrogen at -160^{0}C and has complied the calculation of standard deviation shown in **Table 2**. 4 raw material specimens have an average impact value of 1.22 J/mm^2, 4 FSW specimens have an average impact value of 0.2195 J/mm^2, and 4 TIG specimens have an average impact value of 0.06625 J/mm^2.

These data indicate that the raw material have a higher impact value than specimens treated with FSW and TIG welding with a difference of about ±1 J/mm^2 but FSW specimens have a better average impact value compared to TIG specimens.

B. Impact Test Result of Specimens Heated in an Oven at 166^{0}C

The impact value of specimens heated in an oven at 166^{0}C and has complied the calculation of standard deviation shown in **Table 3**. 3 raw material specimens have an average impact value of 1.3403 J/mm^2, 4 FSW specimens have an average impact value of 0.1395 J/mm^2, and 4 TIG specimens have an average impact value of 0.0870 J/mm^2.

These data indicate that the raw material have a higher impact value than specimens treated with FSW and TIG welding with a difference of about ±1 J/mm^2 but FSW specimens have a better average impact value compared to TIG specimens.

TABLE 2.
DATA OF IMPACT TEST RESULT OF SPECIMENS IMMERSED IN NITROGEN AT -160^{0}C

Welding Type	Impact Value (J/mm^2)	Standard Deviation
Raw Material	1.22	0.0221
FSW	0.2195	0.0698
TIG	0.06625	0.0044

TABLE 3.
DATA OF IMPACT TEST RESULT OF SPECIMENS HEATED IN AN OVEN AT 166^{0}C

Welding Type	Impact Value (J/mm^2)	Standard Deviation
Raw Material	1.3403	0.0411
FSW	0.1395	0.0212
TIG	0.0870	0.0128

C. Comparison of Impact Test Results with ASTM E-23 Standard

The comparison of the impact values of *raw material*, FSW, and TIG specimens that have been given various temperature treatments shown in **Figure 5**. The ASTM E-23 standard regulates that non-welded materials must have a minimum standard impact value of 0.40 J/mm^2 while welded materials must have a minimum impact value of 0.10 J/mm^2.

The average impact value of *raw material* immersed in liquid nitrogen at -160^{0}C is 1.22 J/mm^2 and specimens heated in an oven at a temperature of 166^{0}C is 1.34 J/mm^2 so that based on this value, the impact value of the *raw material* has complied the impact value standard set by ASTM E-23.

The impact test on FSW specimens shows that specimens immersed in liquid nitrogen at -160^{0}C has an average impact value of 0,22 J/mm^2 while specimens heated in an oven at 166^{0}C has an average impact value of 0,14 J/mm^2. The majority of FSW specimens have impact values that complied ASTM E-23 standard.

The impact test on TIG specimens shows that specimens immersed in liquid nitrogen at -160^{0}C has an average impact value of 0,07 J/mm^2 while specimens heated in an oven at 166^{0}C has an average impact value of 0,09 J/mm^2 so that TIG specimens have impact values that do not complied ASTM E-23 standard. Based on discussion with the laboratory assistant from the Inlastek-Welding Institute, TIG specimens do not comply ASTM E-23 standard are thought due to the use of an inappropriate filler rod.

In the impact test process, the pendulum strikes the center of the specimen that has been given 2 mm deep-notch so that in the FSW and TIG specimen, the pendulum strikes the weld joint. The average impact value of TIG specimens is lower than the average impact value of raw material specimens is thought to occur due to the difference in the value of material strength in form of tensile strength between aluminum 5052 and filler rod ER 4043. Tensile strength of aluminum 5052 is 290 MPa, while the filler rod ER4043 is 186 MPa.

The average impact value of FSW specimens is lower than raw material specimen and the average impact value of FSW specimens at -160^{0}C is higher than 166^{0}C, which is different with the trend of raw material specimen and TIG specimen which values at -160^{0}C is higher than 166^{0}C, is thought to occur due to the chemical composition of KNL 110 Extra Bohler Iron does not contain aluminum so that the FSW specimen does not blend perfectly.

The general trends of ductile-brittle transition effect for different groups of metals shown **in Figure 6.** Aluminium as face centred cubic (FCC) metals tends not to undergo this effect. This theory proved by the result of impact test of raw material, FSW, and TIG specimens given temperature variations of -160^{0}C and 166^0 showed in Figure 5. The result of this research indicates that aluminium 5052 is able to maintain its strength in various temperature conditions.

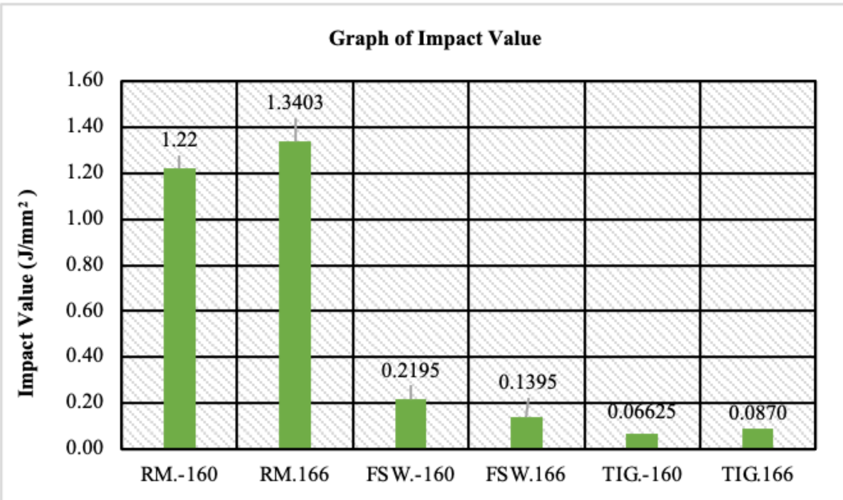

Figure. 5. Graph of Impact Value

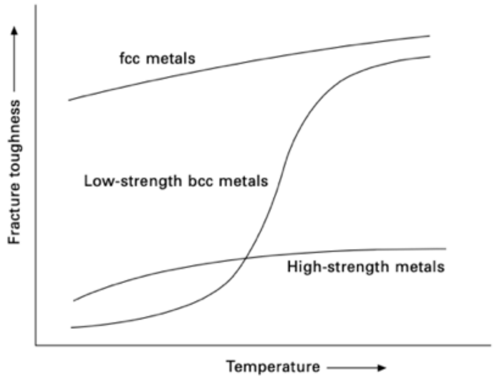

Figure. 6. General Trends Graph of The Ductile-Brittle Transition Effect For Different Groups of Metals

D. Bending Test Result of Specimens Immersed in Nitrogen at -160^{0}C

The bending value of specimens immersed in liquid nitrogen at -160^{0}C and has complied the calculation of standard deviation shown in **Table 4**. 3 raw material specimens have an average bending stress value of 394.70 MPa, 4 FSW specimens have an average bending stress value of 85.82 MPa, and 2 TIG specimens have an average bending stress value of 299.49 MPa.

These data indicate that the raw material have a higher average bending stress value than specimens treated with FSW and TIG welding but TIG specimens have a better average bending value compared to FSW specimens.

TABLE 4.
DATA OF BENDING TEST RESULT OF SPECIMENS IMMERSED IN NITROGEN AT -160^{0}C

Welding Type	Bending Stress Value (MPa)	Standard Deviation
Raw Material	394.70	9.45
FSW	85.82	30.6341
TIG	299.49	36,29

ASME Section IX regulates that welded joint specimen tested transversal-bending must not have an open discontinuity exceeding 1/8 inches (3 mm) measured at the convex surface of the welded joint specimen after being tested by transversal-bending test.

The raw material bending test specimens immersed in liquid nitrogen at -160^0 C shown in **Figure 7.** They bended without experiencing an open discontinuity so that this specimen complied with the standard set by ASME Section IX, which is not experiencing an open discontinuity exceeding 3 mm.

The FSW bending test specimens immersed in liquid nitrogen at -160^{0}C shown in **Figure 8(a)**. They undergo an open discontinuity exceeding 3 mm so FSW specimens do not comply the standard set by ASME Section X. The test results do not comply the standard are thought due to the poor quality of the weld joint with indication that there are weld defects in the form of incomplete penetration

The TIG bending test specimens immersed in liquid nitrogen at -160^{0}C shown in **Figure 8(b)**. Specimen with code 1T3, 1T4, and 1T5 do not undergo an open discontinuity exceeding 3 mm so they complied with the standard set by ASME Section IX, while specimens coded 1T1 and 1T4 experiencing a fracture so they do not comply ASME Section IX. There are specimens do not comply the standard estimated because of the use of an inappropriate filler rod. This research uses a ER4043 filler rod while based on discussion with laboratory assistant from Inlastek-Welding Institute, if the aluminum used is 5000-series aluminum, the filler rod used should also be 5000-series filler rod.

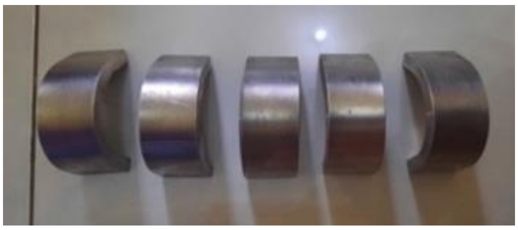

Figure. 7. Raw Material Specimens After Being Given Bending Test

(a) **(b)**

Figure. 8. ***(a)*** FSW Specimen After Being Given Bending Test. ***(b)*** TIG Specimen After Being Given Bending Test.

E. Bending Test Result of Specimens Heated in an Oven at 166^{0}C.

The bending value of specimens immersed in liquid nitrogen at 166^{0}C and has complied the calculation of standard deviation shown in **Table 5**. 4 raw material specimens have an average bending stress value of 400.45 MPa, 4 FSW specimens have an average bending stress value of 148.58 MPa, and 2 TIG specimens have an average bending stress value of 318.55 MPa.

These data indicate that the raw material have a higher average bending stress value than specimens treated with FSW and TIG welding but TIG specimens have a better average bending value compared to FSW specimens.

TABLE 5.
DATA OF BENDING TEST RESULT OF SPECIMENS HEATED IN AN OVEN AT 166^{0}C

Welding Type	Bending Stress Value (MPa)	Standard Deviation
Raw Material	400.45	12.81
FSW	148.58	120.20
TIG	318.55	39.13

ASME Section IX regulates that welded joint specimen tested transversal-bending must not have an open discontinuity exceeding 1/8 inches (3 mm) measured at the convex surface of the welded joint specimen after being tested by transversal-bending test.

The raw material bending test specimens immersed in liquid nitrogen at 166^0 C shown in **Figure 9**. They bended without experiencing an open discontinuity so that this specimen complied with the standard set by ASME Section IX, which is not experiencing an open discontinuity exceeding 3 mm.

The FSW bending test specimens heated in an oven at 166^{0}C shown in **Figure 10(a)**. They undergo an open discontinuity exceeding 3 mm so FSW specimens do not comply the standard set by ASME Section X. The test results do not comply the standard are thought due to the poor quality of the weld joint with indication that there are weld defects in the form of incomplete penetration.

The TIG bending test specimens heated in an oven at 166^{0}C shown in **Figure 10(a)**. Specimen with code 3T5 do not undergo an open discontinuity exceeding 3 mm so they complied with the standard set by ASME Section IX, while specimens coded 3T1, 3T2, 3T3, and 3T4 experiencing a fracture so they do not comply ASME Section IX. There are specimens do not comply the standard estimated because of the use of an inappropriate filler rod. This research uses a ER4043 filler rod while based on discussion with laboratory assistant from Inlastek-Welding Institute, if the aluminum used is 5000-series aluminum, the filler rod used should also be 5000-series filler rod.

Figure. 9. Raw Material Specimens After Being Given Bending Test

Figure. 10. ***(a)*** FSW Specimens After Being Given Bending Test. ***(b)*** TIG Specimens After Being Given Bending Test

F. Comparison of Bending Stress Value

A graph of the comparison of the bending stress values of *raw material*, FSW, and TIG specimens that have been given various temperature treatments shown in **Figure 11**. Average bending stress value of raw material specimens immersed in in liquid nitrogen at -160^{0}C is 394.70 MPa and specimens heated in an oven at a temperature of 166^{0}C is 400.4475 MPa.

The bending test on FSW specimens shows that specimens immersed in liquid nitrogen at -160^{0}C has an average bending stress value of 85.82 MPa while specimens heated in an oven at 166^{0}C has an average bending stress value of 148.5775 MPa.

The bending test on TIG specimens shows that specimens immersed in liquid nitrogen at -160^{0}C has an average bending stress value of 299.485 MPa while specimens heated in an oven at 166^{0}C has an average bending stress value of 318.5475 MPa.

In the bending test process, the bending plunger bend the center of the specimen that has been given 2 mm deep-notch so that in the FSW and TIG specimen, the bending plunger bend the weld joint. The average bending stress value on the raw material specimen which is greater than the TIG specimen is thought to occur due to the difference in the value of material strength in form of tensile strength between aluminum 5052 and filler rod ER 4043. Tensile strength of aluminum 5052 is 290 MPa, while the filler rod ER4043 is 186 MPa. The average bending stress value on the raw material is greater than the FSW specimen, it is estimated that the chemical composition of KNL 110 Extra Bohler Iron does not contain aluminum so that the FSW specimens does not blend perfectly.

The general trends of ductile-brittle transition effect for different groups of metals shown in **Figure 6**. Aluminium as face centred cubic (FCC) metals tends not to undergo this effect. This theory proved by the result of bending test of raw material, FSW, and TIG specimens given temperature variations of -160^{0}C and 166^0 showed in Figure 11. The result of this research indicates that aluminium 5052 is able to maintain its strength in various temperature conditions.

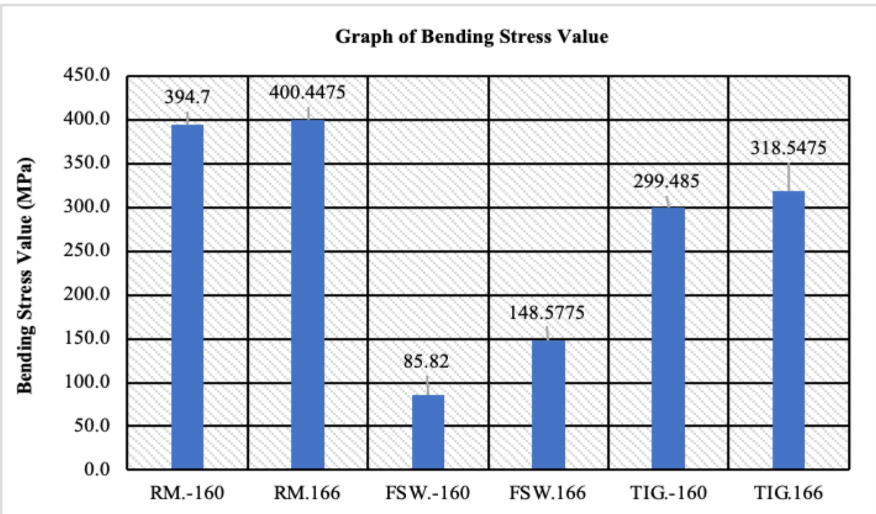

Figure. 11. Graph of Bending Stress Value

IV. CONCLUSION

Conclusion resulted from the research that investigate the strength of the welded joints of FSW and TIG aluminium 5052 due to the effect of working temperature are:

The average impact value of raw material specimens immersed in liquid nitrogen at -160^{0}C is 1.22 J/mm^2 while raw material specimens being heated in an oven at 166^{0}C is 1.3403 J/mm^2. The average impact value of FSW specimens immersed in liquid nitrogen at -160^0 C is 0.2195 J/mm^2 while FSW specimens being heated in an oven at 166^{0}C is 0.1395 J/mm^2. The average impact value of TIG specimens immersed in liquid nitrogen at -160^0 C is 0.06625 J/mm^2 while FSW specimens being heated in an oven at 166^{0}C is 0.0870 J/mm^2.

The average bending stress value of raw material specimens immersed in liquid nitrogen at -160^{0}C is 394.70 MPa while raw material specimens being heated in an oven at 166^{0}C is 400.45 MPa. The average bending stress value of FSW specimens immersed in liquid nitrogen at -160^{0}C is 85.82 MPa while FSW specimens being heated in an oven at 166^{0}C is 148.5775 MPa. The average bending stress value of TIG specimens immersed in liquid nitrogen at -160^{0}C is 299.485 MPa while TIG specimens being heated in an oven at 166^{0}C is 318.5475 MPa.

The results of the impact test and bending test of *raw material*, FSW, and TIG specimens given temperature variations of -160^{0}C and 166^{0}C indicate that aluminium 5052 is a material that is resistant to temperature changes and is able to maintain its strength in various temperature conditions because aluminum is an FCC (*face centered cubic*).

Visual open discontinuity observation made on bending test specimens shows that all raw material specimens do not undergo an open discontinuity exceeding 3 mm, all FSW specimens experienced an open discontinuity exceeding 3 mm, and TIG specimens shows varied visual open discontinuity observation result, there are specimens which are undergo and do not undergo open discontinuity exceeding 3 mm.

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