Indonesian Journal of Physics
Vol. 27. No.1, July, 2016
Journal homepage: http://ijphysics.com

Effect of Tool Rotation Speed on Mechanical Properties and Microstructure as the Results of Friction Stir Welding Method on Aluminium 5083-7075

Maryati[1*], Bambang Soegijono[2], M. Yudi Masduky[3], Tarmizi[4]
[1,2,3]*Department of Physics, Faculty of Mathematics and Natural Science, University of Indonesia, Jl.* Salemba *Raya No.4 Jakarta, 10430, Indonesia*

[4]*Laboratory Division of Welding and Machinery, Metal Industries Development Center, Jl. Sangkuriang No. 12 Bandung, 40135, Indonesia*

Received: 15 March 2016, Revised: 31 June 2016, Accepted: 29 July 2016

Abstract

Friction Stir Welding (FSW) is a new method of welding process which is affordable and provide good quality. Aluminium 5083-7075 has been connected successfully by using friction stir welding (FSW) method into butt joint connection form. Tool rotation speed is one of the important parameters in FSW. The changes of rotation speed will affect the characteristics of mechanical properties and microstructure. The parameters of welding being used are welding speed of 29 mm/minutes by varying the speed rotation of 525 rpm, 680 rpm, 910 rpm, and 1555 rpm. In order to find out the mechanical strength of welds, tensile strength and hardness testing is done while finding out the microstructure will be done by using optical microscope and Scanning Electron Microscope (SEM). The result of the research showed that the highest tensile strength obtained at 910 rpm speed rotation about 244.85 MPa and the greatest hardness values was found on aluminium 5083 around the wheel zone area about 96 HV with rotary speed of 525 rpm. Then, the result of testing the macro and microstructure on all samples indicated defect which is seen as incomplete fusion and penetration causing the formation of onion rings. In other words, it is which showed that the result of stirring and tacking in the welding area is less than perfect.

Keywords: *FSW, Aluminium 5083-7075, Tensile Strength, Hardness Values, Microstructure.*

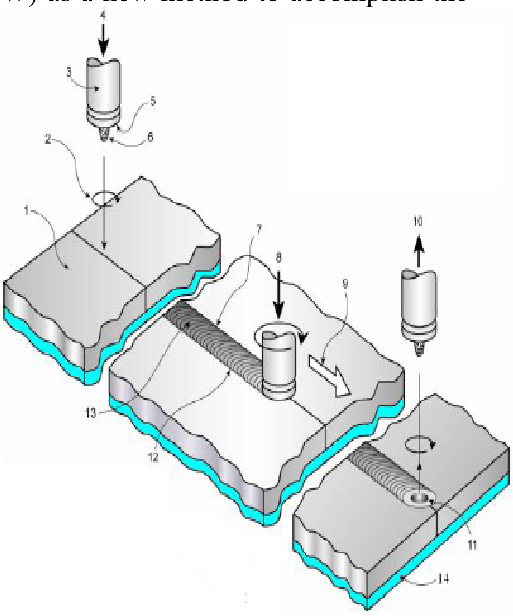
INTRODUCTION

Welding is a process of switching between two local metal parts or more by utilizing the energy of the heat. Welding plays an important role in the industrial growth especially in modification and reparation of metal production. One metal which is often used in welding process is Aluminium. Recently, aluminium is being used commonly in the fields of electricity, buildings, storage equipment, and transportation such as airplanes, cars, and electric boats. Aluminium has excellent quality such as mild, anti-corrosive, malleable, and flexible [5]. However, pure aluminium has lower quality so that in order to fix its weakness, aluminium should be combined with other composition. The aluminium, which has been combined with other elements, has a very good mechanical quality. Thus, it caused aluminium is being widely used in industrial aspects. As an example, the type of aluminium which is commonly used as a combination are aluminium 5xxx series such as 5083 series and aluminium 7xxx series such as 7075 seres. The combined 5083 aluminium series is the type of combined aluminium which its mechanical quality cannot be fixed by heat treatment. This nature is called as non-heat treatable alloy and its primary blend is Magnesium (Mg). The combined 7075 aluminium series is the type of aluminium combination which can be treated under the heat and its primary blend is Zinc (Zn). Both types of aluminium alloys are the type of aluminium which

* Corresponding author.
E-mail address: yatimar48@gmail.com

is widely and commonly used in industrial fields because it has good quality in mechanical properties such as moderate strength of tensile values, anti-corrosive, and widely used for the application of some construction such as the constructions of airplanes and automotive structures.

Generally, the process of welding on aluminium is using GTAW or GMAW method. However, in the welding process, the formation of porosity could exist during the solidification of weld metal and prone to deformation. Along with the development of welding technology, in 1991, Wayne Thomas who worked at The Welding Institutes (TWI), in The United States of America has discovered and developed the Friction Stir Welding (FSW) as a new method to accomplish the connection of metals including Aluminium. FSW is one method of welding that has the principles of utilizing the friction of rotating and idle working object so it could melt the idle working object and connect it become one. The FSW welding process occurs in the solid condition (solid state joining), in which the temperature of welding process is below the temperature of melting materials being weld so there will be little possibility for the occurence of microstructural changes. As the result of welding temperature which is not too high, then the created residual tense and distortion caused by the heat are low. Some examples of this type of welding are the manufacturing of the fuselage, car body, and cooking equipment. [11].



(1) Base material
(2) Direction of tool rotation
(3) Welding tool
(4) Downward movement of the tool
(5) Tool shoulder
(6) Pin
(7) Advancing side of the weld
(8) Vertical (axial) force
(9) Welding direction
(10) Upward movement of the tool
(11) Exit hole
(12) Retreating side of the weld
(13) Weld face
(14) Backing plate

Figure 1. The Components of FSW [1]

EXPERIMENTAL METHOD

In this research, the material used are aluminium series 5083 and 7075. Both sizes of the aluminium are (280x160x6) mm with composition as shown in Table 1.

Table 1. The Chemical Composition of Aluminium series 5083 and 7075

Chemical Composition (wt %)		
Unsure	Aluminium 5083	Aluminium 7075
Al	91.19	85.68
Mg	6.24	5.40
Mn	0.91	0.02
S	0.10	0.09
Si	0.54	0.53
Ti	0.08	0.08
Zn	0.11	5.90
Fe	0.39	0.24
V	0.02	0.00
Cu	0.03	1.41

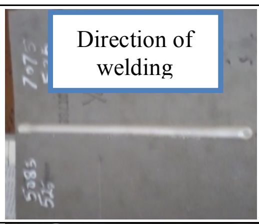
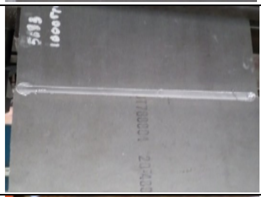
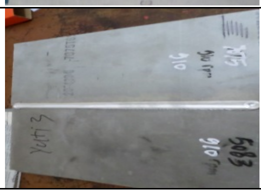
The welding process applying FSW method uses a tool called Frais Machine. The parameters will be used is the change in tool rotation speed of 525 rpm, 680 rpm, 910 rpm, and 1555 rpm and the welding speed which is constantly kept at 29 mm / minute, and also the tilt angle around 0^o. The tool that is used is AISI H13 steel with shoulder diameter around 20 mm, pin diameter 5 mm, pin length around 5 mm, and plunge depth around 4.87 mm. The cutting process of sample resulted from the FSW welding method is using the standard AWS D17.3/D17.3 M:200 X. Furthermore, the result of cutting process will be tested in radiography, tensile strength test using Zwick / Roell tensile test machine with a maximum capacity of 25 tons. Hardness testing will use tool of Microhardness Vickers in Buehler brand with load around 100 grams and 10 seconds limitation according to the standard of ASTM E 384-69. The other test is testing macro and microstructures by using optical microscope of Olympus brand which etching materials used is etching color that suits the reagent keller's solution. The micro structure testing is also done by using Scanning Electron Microscope-Energy Dispersive X-Ray (SEM-EDX) in order to find out the composition around the weld area.

RESULTS AND DISCUSSION

THE RESULTS OF FRICTION STIR WELDING

The results from welding applying friction stir welding are shown in Table 2.

Table 2. The Result of FSW Welding Process

Name of Sample	Top View	Bottom View
525 rpm		
680 rpm		
910 rpm		
1555 rpm		

THE RESULTS OF RADIOGRAPHY TESTING

Radiography is one way of testing to detect defects in metal or weld witout damaging the material being tested. The result of radiography is able to produce a permanent record of the components shown in the film. The results of radiography testing can be seen in Table 3.

Table 3. The Result of Radiograpghy Testing on Aluminium 5083-7075

Type of Defect	525 rpm	680 rpm	910 rpm	1555 rpm
Root defect	-	-	-	-
Crack	-	-	-	-
Incomplete penetration	-	-	-	-
Incomplete fusion	√	-	√	√
Others	-	-	-	-
No defect	-	√	-	-
Acceptable	-	-	-	-
Reject	-	-	-	-
Remarks	IF : 8 mm	-	IF: 235 mm	IF: 35 mm

THE RESULTS OF MACRO AND MICROSTRUCTURES TESTING

The macro and microstructure testing is conducted to determine the defects inside the macroscopic and microscopic cross-section of the welding area covering the main area, HAZ, TMAZ, and stir zone. The result of macro and micro testing in the main area of 7075 is shown in symbol a. The result in HAZ area is shown in symbol b, the result in stir zone is shown in symbol c, the result in HAZ area on the sides of aluminium series 5083 is shown in symbol d, and the result of metal in main metal of 5083 is shown in symbol e.

1. Sample with rotation speed of 525 rpm

Macrosturctures

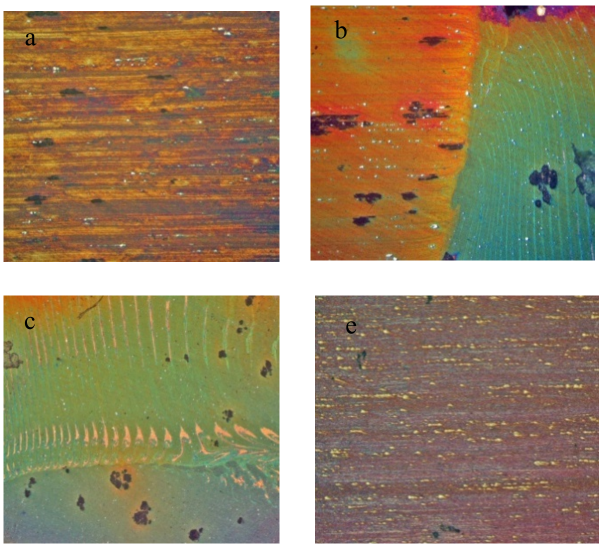


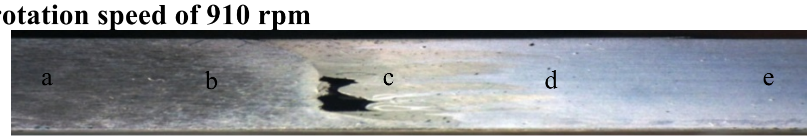
Figure 2. Macro and microstructures in rotation speed of 525 rpm with 200x optical zoom.

2. Sample with rotation speed of 680 rpm

Macrosturctures

Figure 3. Macro and microstructures in rotation speed of 680 rpm with 200x optical zoom.

3. Sample with rotation speed of 910 rpm



Macrosturctures

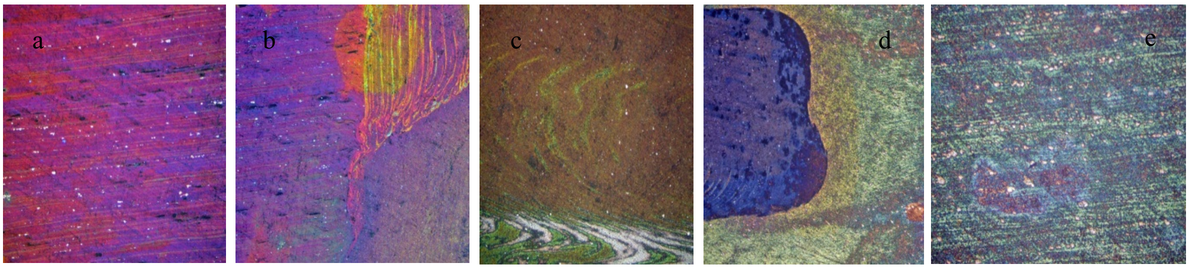
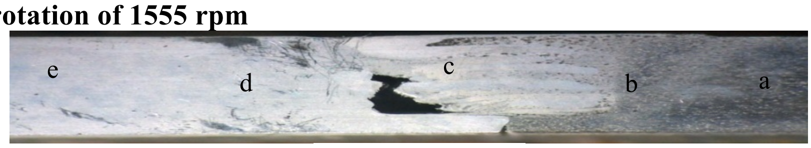
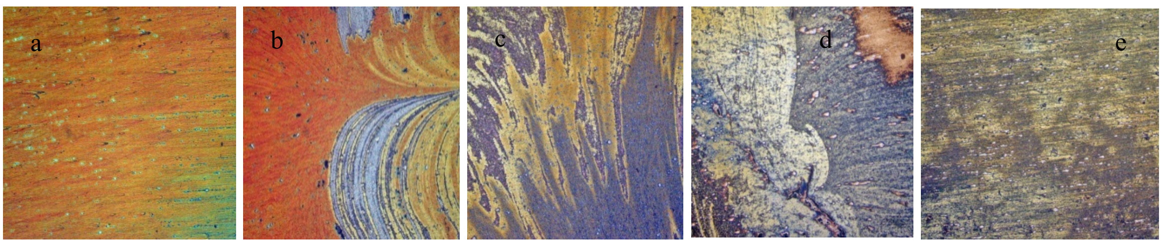


Figure 4. Macro and microstructures in rotation speed of 910 rpm with 200x optical zoom.

4. Sample with rotation of 1555 rpm



Macrosturctures



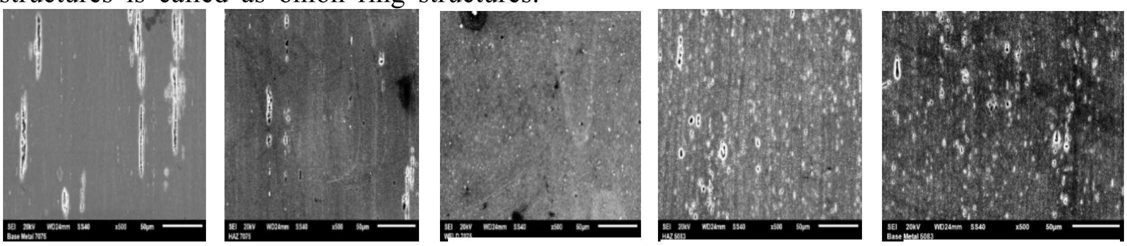
Gambar 5. Macro and microstructures in rotation speed of 1555 rpm with 200x optical zoom.

The results of macro and microstructures in main area according to figure 2 until figure 5 shows that in every result of welding with tool rotation speed variation of 525 rpm, 680 rpm, 910 rpm, and 1555 rpm occured defect in form of a big hole (incomplete fusion) and seen a little less perfect penetration so that the welding process could not reach into the bottom root of the materials (bottom view of the samples). In visual observation from the macrostructure test, the biggest hole occurs in speed rotation 1555 rpm and the smallest hole occurs in rotation speed 680 rpm. The results is different with the result of radiography because before the sample is being macro tested, it was being subjected to techniques such as being prepared through sanding and etching time. In other words, the defect became obvious after the material being tested. Then, from the result of microstructures with 200x optical zoom, the changes of the form of microstructures between the main area of the metal and the area of welding such as stir zone and HAZ area is seen for every changes in tool speed rotation. The microstructural changes occur due to movement of the rotation and welding speed from tool pin so that the the grain shapes of stir zone area become smoother than the metal grain in main materials. The HAZ and TMAZ area have no difference in the shape of the structures. The HAZ area is located in the middle of main metal and TMAZ while the TMAZ area is located between HAZ area and stir zone. In HAZ area which is shown in letter b, it has lower temperature from the stir zone so that the effect of welding through the microstructure is less then the effect on the mechanical properties are also small, usually, in HAZ area, the hardness values is lower than those in metal base area.

The characteristics of steering area at the weld zone is that the presence of concenric circles like onion structures is called as onion ring structures. The structure shows that the stirring process is not perfect so its mechanical properties fall down if it is compared to the main metal. The factors which affects the process was the insertion of the heat that happened less maximum because of the distribution of temperature done uneven and low. There is also a presence of 1 mm gap between the length of tool pin and the materials being tested. From several speed rotation, there were some good result of welding in tool rotation speed of 910 rpm and 520 rpm. It is seen from the stirring process which showed good values so that the number of mechanical properties can be seen higher.

THE RESULT OF SEM-DEX TESTING

The characterization of SEM-DEX is conducted to analyze the morphology of the material surface and semi-quantitative material compossitions. The testing of SEM-DEX is performed at tool rotation speed of 900 rpm because it can be seen that in speed 900 rpm, the grain of the microstructure and the stirring process look good. The result of SEM testing can be seen in Figure 6.



Base metal 7075 HAZ area of 7075 Stir Zone Area Haz area of 5083 *Base metal* 5083

Figure 6. The result of SEM Testing in 500x optical zoom

The result of SEM testing in Figure 6 shows that the formed grains are smooth on metal base of series 7075. It is indicated by the existence of white color of grain in the materials so that it makes the mechanical properties of main metal of series 7075 higher than the metal base of aluminium series 5083 because in aluminium series 5083 the size of the grain is big enough, then in HAZ area, both sides of the aluminium showed that the micro structure experiences a few changes but it does not change the main form of the main metal, while the stir zone area which is the area of welding process, the result shows that the structure has smaller grain than the one in main metal. Besides, in this area, it is seen that the process of composing looks imperfect because the spreading of the particles looks uneven that eventually it makes the mechanical properties value less than the one in main metal. To find out the elements composing in the area of metal base and stir zone, consider Figure 7.

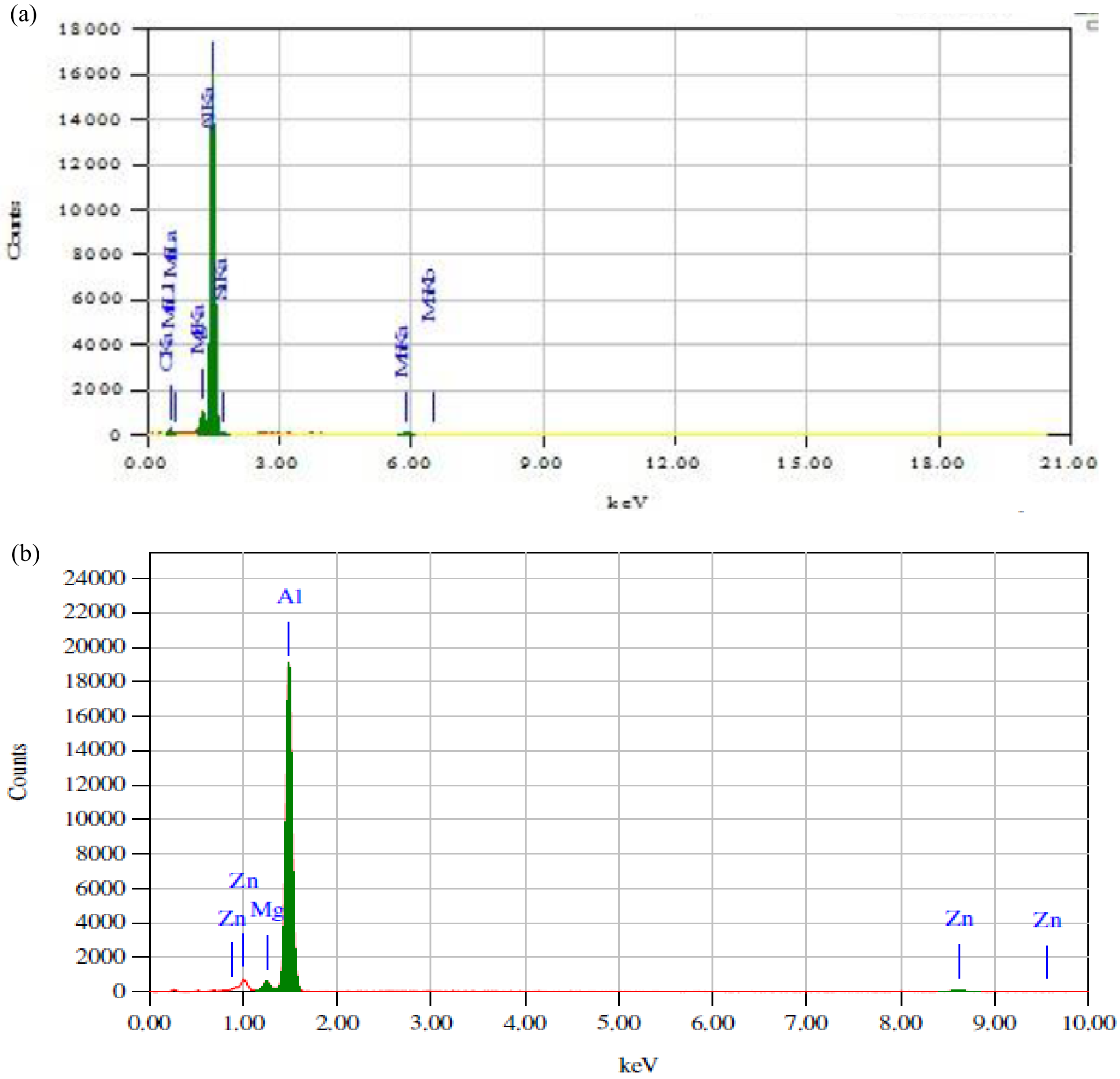


Figure 7. The result of EDX testing in 500x optical zoom, a) in base metal area of 5083 b) in stir zone area of 900 rpm

The result of EDX testing shows that the components in this sample which is located in metal base area of 5083 are Al, Mg, Si, Mn, and O. On the other hand, the components that is located in stir zone area are Al, Zn, and Mg. The result of EDX testing can be seen in Table 4.

Table 4 The result of EDX Testing

EDX Testing Result in area of Base Metal 5083		EDX Testing Result in Stir Zone area	
Element	Massa (%)	Element	Massa (%)
O	5,75	Mg	0,61
Mg	6,74	Al	93,21
Al	81,19	Zn	6,180
Si	3,64	-	-
Mn	2,68	-	-
Total	100	Total	100

The main percentage of the combination elements from the result of EDX testing is used to find out the phase which is formed in each aluminium by means of the percentage of the element obtained in the welding process is inserted into phase diagrams of Al-Mg-Si, Al-Mg-Mn, and Al-Zn-Mg. Before identifying phase in diagram, the temperature from the welding process is needed to be known. Based on the research conducted by Mishra and Z.Y. Ma in 2004, the temperature which is resulted in the welding area especially in the stir zone area ranges from 255°C–475°C. According to the result of SEM-EDX testing and phase diagrams of Al-Mg-Si, Al-Mg-Mn, dan Al-Mg-Zn, then the forming of the phase can be found. In the area of base metal 5083, the phases which is formed are Mg_2Si dan $MnAl_6$. In stir zone area, the phases which is formed are Al + $MgZn_5$. Then, in base metal 7075 area and the result of chemical composition contains 5,40% Mg, 85,68% Al, so the phase which is formed are Al + $Mg_3Zn_3Al_2$.

THE RESULT OF TENSILE STRENGTH TESTING

Tensile strength testing is done to find out the strength of the material around the welding area towards the tensile force. Based on the testing of tensile strength, it can be seen that the fracture occurs in all area of welding on all samples. The fractures shows that the absence of necking will cause the material being tested become ductile. Around the area of welding is the area which suffered some technical treatments so that around the area of welding has different mechanical strength of material with the main metal. Moreover, it is supported by the difference of characteristics between both main metals such as the difference of hardness value of aluminium series 5083 and series 7075. The result of tensile strength in every changes of tool rotation speed can be seen in figure 8.

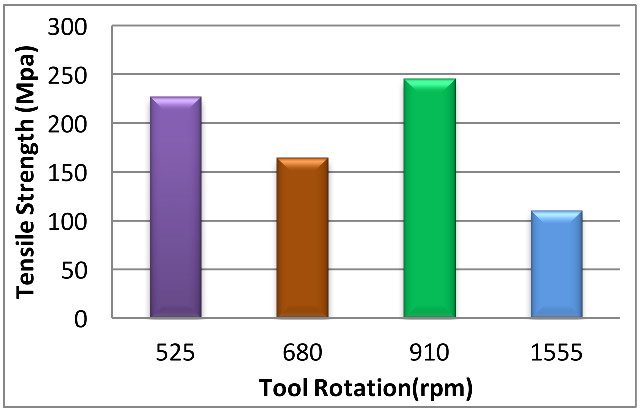


Figure 8. The result of tensile strength testing with the changes of tool rotation

Figure 8 shows that the tensile strength around the area of welding have significant difference for every speed of tool rotation. The highest values occurs in rotation speed of 910 rpm and the lowest one occurs in rotation speed of 680 rpm. However, if all results being compared to the base materials for the standard value of tensile strength, the results are decreasing. It can be happened because there is difference in the speed of tool rotation so the insertion of the heat would be different to all samples that resulted in the soften process of aluminium become not entirely softened. The process of softening plays an important role in welding process because if the material fail to melt, the pin which function as the composer and connector of the material would not compose it perfectly. The bigger the speed of tool rotation is, the bigger the insertion of the heat occurs, nevertheless in the process of welding applying FSW method, the speed of tool rotation should not be set too high because it can loose the nature of welding which happened because the difference of the characteristics of base metal. It can be seen towards the result of welding in speed of tool rotation aroung 1555 rpm that has decreasing value of tensile strength. Based on the observation of the welding result on each sample, the defects occured are the incomplete fusion and incomplete penetration. Both defects occured because there are gaps around 1 mm between the length of tool pin and the thickness of material being tested so that the process of penetration occurs imperfectly and resulting in the imperfect of the process of composing and molding. It can be seen in the result of testing in micro structures that the forming of onion ring around the stir zone area for all samples that caused deficiency in the value of tensile strength. On the other hand, the process of welding with the speed of tool rotation around 910 and 525 rpm, the result of connecting look quite good so that on both samples the value of tensile strength increasing better. In the *Aluminium Welding Second Edition*, it showed that the value of tensile strength in FSW welding method would increase three times bigger than the one in the main metal if the process of connecting run perfect.

THE RESULT OF HARDNESS TESTING

The process of hardness testing is done to find out how big the effect of welding is in different rotation speed toward the hardness value around the welding zone which included the main metal, HAZ, and stir zone. Figure 9 is the chart of the result of hardness value testing of the welding result that having changes in rotation speed.

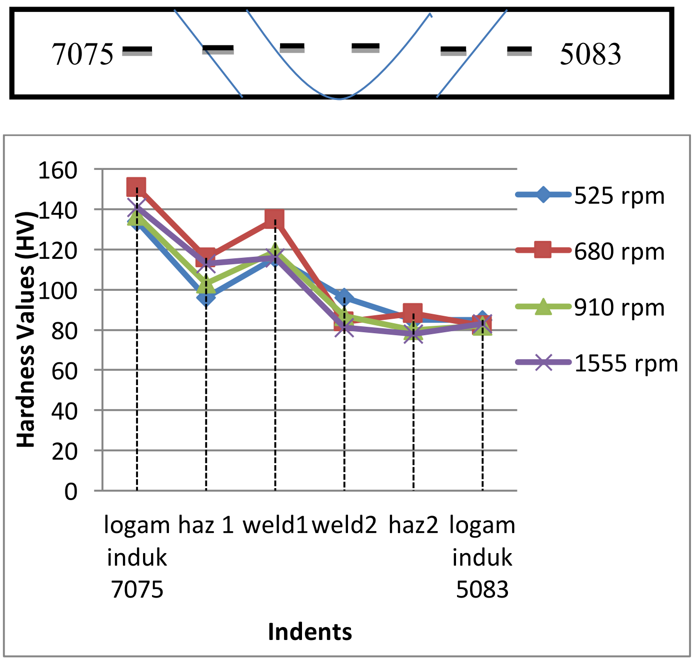


Figure 9. The result of hardness value testing around the area of welding and main metal

According chart in Figure 9, it is seen that the result of hardness value testing on welding area which is stir zone at the sides of aluminium series 7075 suffered a decreasing point for all variation of changes in rotation speed, but at the sides of aluminium series 5083 the value is increasing with the variation of rotation speed around 525 rpm, 680 rpm, and 910 rpm while the value is decreasing in rotation speed around 1555 rpm. Then, around the HAZ area, the value of hardness is decreasing if it is compared to the value in the main metal both in the sides of aluminium series 7075 or 5083. The difference of hardness between main metal of aluminium series 7075 and 5083 occured significantly so that the connection between both materials is considered complicated if there is not enough insertion of heat that could make both materials unable to joint well. The decreasing value of hardness around the welding area of the sides of aluminium series 7075 caused by the process of hardening is unable to occur when the process of welding is in progress. Accoring to journal written by Jarot Wijanto, the process of hardening around the welding area would be attained if the sedimentation of the second phase happened below temperature 160-185^{o}C in 6 to 20 hours.

In this welding process, the highest hardness value around the stir zone occured along the sides of aluminium series 7075 with the speed of rotation 680 rpm around 135 HV while the lowest value occured along the sides of aluminium series of 5083 with the speed of rotation 1555 rpm around 81 HV. If it is seen overall on all samples, the hardness value on the stir zone area of the sides of aluminium series 7075 and 5083, the value is volatile. It can be happened because the imperfect process of stirring which is caused by the uneven and low distribution of temperature so that the insertion of the heat is considered too low and also the existence of defects on all samples is caused by the gap between the length of tool pin and the thickness of the material being tested. As the result to that, the hardness value around the welding area is less than equal from the main metal. In this study, the hardness value should be able to be affected by the high or low of the speed of the tool rotation being used. The bigger the speed of tool rotation is, the bigger also the insertion of the heat produced and it will caused the small grain of welds so that the hardness value could be set high.

CONCLUSION

Based on the result of research about welding process using friction stir welding method done towards the aluminium series 7075 and series 5083 with some variations of tool rotation, the conclusions are as follows:

1. The welding process of aluminium series 7075 and 5083 with the variations of tool rotation by applying FSW method could be done in a good way.
2. Based on the observation of the macrostructures on all samples with some variations in tool rotation, there were some defects such as incomplete fusion and incomplete penetration that makes the process of stirring and molding become imperfect.
3. Based on the observation of the microstructures with some variations in tool rotation, the process of stirring and molding resulting in good quality of weld happen in tool rotation speed on 525 rpm and 910 rpm.
4. The result of the highest tensile strength happen in the result of welding with the tool rotation speed on 910 rpm around 244.85 MPa and the lowest tensile strength happen in tool rotation speed on 1555 rpm aroung 109.5 MPa.
5. The result of hardness value testing around the area of welding stir zone has lower value on the sides of aluminium series 7075 if it is compared to the one in main metal for all variations of tool rotation, while on the sides of aluminium 5083 the value is increaasing better than the one in the main metal.

ACKNOWLEDGMENT

The writers would like to thank all parties who have helped the writers in accomplishing the research and writing this paper.

REFERENCES

[1] American Welding Society (AWS) D17. (2009). *Specification for Friction Stir Welding of Aluminium Alloys for Aerospace Applications*. Published by American National Standards Institute.

[2] ASM *Handbook*. (1998). *Volume 3 Alloy Phase Diagram*. Published by ASM International

[3] ASM *Handbook*. (2004). *Volume 9 Metallography and Microstructures*. Published by ASM International

[4] Mishra, R. S, Z. Y.Ma. (2005). *Friction Stir Welding and Processing*. Journal of Materials Science and Engineering R 50 (2005) 1-78.

[5] Wijayanto, Jarot. (2012). *Pengaruh Feed Rate Terhadap Sifat Mekanik Pada Friction Stir Welding Aluminium*, Prosiding Seminar Nasional Aplikasi Sains & Teknologi (SNAST) Periode III, ISSN: 1979-911X, 2012.

[6] Wijayanto, Jarot, Aghda Anelis. (2010). *Pengaruh Feed Rate Terhadap Sifat Mekanik Pada Pengelasan Friction Stir Welding Aluminium 6110*, Jurnal Kompetensi Teknik Vo.2, No.1, Nov 2010.

[7] S, M. Ilangovan, and Rajendra Boopathy, V. Balasubramanian. (2015). *Effect of Tool Pin Profile on Microstructure and Tensile Properties of Friction Stir Welded Dissimilar AA 6061 – AA 5058 Aluminium Alloy Joints*. Journal of Defence Technology 11 (2015) 17-184.

[8] Dwi Afandi, Rahmad, Ahmad Zubaydi, 2012, *Analisis Sudut Kerja Tool Terhadap Sifat Mekanik Hasil Pengelasan Friction Stir Welding Aluminium 5083 Kapal Katamaran.* Jurnal Teknik Pomits,Vo.1 No.2, 2012, ISSN: 2301-9271.

[9] R. Hariharan, R. J. Golden Renjith Nimal. (2014). *Friction Stir Welding of Dissimilar Alloys (6061&7075) By Using Computerized Numerical Control Machine*. Middle-East Journal of Scientific Research 20 (5): 601-605 2014.

[10] Ravikumar, S, and V. Seshagiri Rao, R. V. Pranesh. (2014). *Effect of Process Parameters on Mechanical Properties of Friction Stir Welded Dissimilar Materials Between AA6061-T651 and AA7075-T651 Alloys*, International Journal of Advanced Mechanical Engineering ISSN 2250-3234 Vol.4, No. 1 (2014)

[11] W. M., Nicholas, Thomas, E. D., et al. (1995). Patent Application No. 9125978.8, December 1991 and US Patent No. 5460317, October 1995.