Journal of Engineering and Applied Sciences 12 (6): 1649-1656, 2017
ISSN: 1816-949X

Effect of Chamfer Angle on Torsion and Impact Strength of Continuous Drive Friction Weld Joint of Round Aluminum A6061

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Abstract: This study presents the using of chamfer angle could increase torsion and impact strength of the CDFW joint. Torsion and impact strength tests were conducted by using the specimens from round aluminum A6061 CDFW specimens that have chamfer angles of 15°, 30°, 45°, 60, 75° and no chamfer angle in both side of friction contact area. The testing results were discussed using results of macrostructure, microstructure and micro-hardness testing. It was found that chamfer angle influenced torsion and impact strength of the weld joint. Specimens with chamfer angle of 30° had maximum torsion strength due to minimum porosity and maximum area of fully plasticized Zone 1 (Zpl1) at the center of weld joint that had the highest hardness. Maximum impact strength found on the specimens that had chamfer angle of 15° due to minimum porosity and broader area of fully plasticized Zone 2 (Zpl2) that has lower hardness, more coarse grains and higher ductility than that of Zpl1.

Key words: Continuous drive friction welding, aluminum, chamfer angle, torsion strength, impact strength

INTRODUCTION

Continuous Drive Friction Welding (CDFW) is one of friction welding method which is a solid state welding process. This method is able to join round metals using heat generated from rubbing at contact surfaces. One specimen is rotated at constant angular speed while the other in the same alignment under an applied pressure. In the certain period, rotation and pressure is maintained to gain adequate heat and mechanical state of the interface region. After the joint is made and the flash is occurred, the rotated specimen is stopped then higher pressure applied to forge specimens together (Sathiya *et al*., 2007). This method usually apply to join round similar or dissimilar metal to produced round bulk or pipe components such as tie rod, shaft and pipe.

Aluminum alloy A6061 is one of aluminum alloys that has good corrosion resistance, good formability and good weldability (Budinski, 1996). This aluminum alloy has found wide application in engineering products such as components of machines, heavy vehicles, ships, aircraft and rail transportations (Bauccio, 2005).

There are many efforts to increase strength of round aluminum weld joint from welding parameters view and welding method. Lin *et al*. (1999) used 60° chamfer angle towards contact surface of aluminum alloy Al-Mg-Si to make friction weld joint with composite of Al-Mg-Si and SiC. It was found that the tensile strength of CDFW joint using chamfer angle was higher than that of specimen without chamfer angle. Irawan *et al*. (2012, 2016) studied effect of various chamfer angle of tensile strength of weld joint produced by CDFW or spinning friction welding. They also found that chamfer angle of 30° on the both side of contact surface gave maximum tensile strength of the weld joint. However, effect of chamfer angle on the both side of contact surfaces on torsion and impact strength are not investigated yet. This study discussed about chamfer angle that affected torsion and impact strength of weld joint based on mechanical tests, macrostructure and microstructure and hardness distribution of CDFW joint.

MATERIALS AND METHODS

Experimental method: Material used in this study was round aluminum alloy A6061. This aluminum has chemical composition as shown in Table 1. Friction welding specimens were prepared by cutting using a saw machines with cooling media of water. The friction surfaces were polished and machined by a lathe machine to shape a CDFW specimen as shown in Fig. 1.

During CDFW specimen preparation, aluminum alloy A6061 round bar was cut using a saw machine with water as coolant. Machined surfaces as contact surface of CDFW were polished using sand study with grid of 600. Geometry of CDFW specimens is shown in Fig. 1 and were produced by turning process using a lathe machine.

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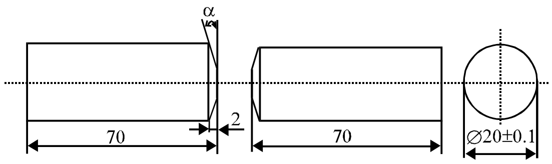

Chamfer angle, α : 0, 15, 30, 45, 60 and 75°

Fig. 1: Geometry of CDFW specimen (dimensions in mm). Left side is rotated part and the right side is stationary part that subjected with compression force

Table 1: Chemical composition of aluminum A6061

Components	Weight (%)	Components	Weight (%)
Al	99.384	Mn	0.094
Mg	0.907	Cr	0.036
Si	0.694	Pb	0.021
Fe	0.435	Ti	0.021
Cu	0.209	Ni	0.008
Zn	0.190	Sn	0.004

The specimens had various chamfer angles of 15°, 30°, 45°, 60°, 75° and without chamfer angle (0°) to vertical line or contact surface. Figure 1 shows two parts of CDFW specimens.

In the CDFW process, a rotated part or left side of the rod as shown in Fig. 1 was gripped by the chuck of the lathe machine that connected to an electrical motor. The right part of specimen was set in a gripping tools that can give compression force by a spring mechanism. Both contact surface of specimens were cleaned by acetone, before friction welding started. The left part of specimen was rotated with rotation speed of 1600 rpm, then a right part of specimen was engaged to the left part of specimen by subjecting compression force of 1230 N for 2 min. After the machine was shut down, the right specimen continued to be given by compression force of 1570 N for 2 min before cooled in air.

For torsion and impact strength testing of friction welding joints, welded specimens were machined with the coolant to shape torsion strength and impact strength testing specimens as shown in Fig. 2 and 3. CDFW joint was located in the center of torsion and impact strength specimen. The notch of impact strength specimen was located in the center of CDFW joint.

Torsion and impact strength test were performed using a torsion test machine and charpy impact test machine, respectively. Three specimens of each variation of chamfer angle were prepared and tested to find torsion and impact strength of CDFW joints.

To find hardness distribution on CDFW joints, welded specimens were machined with the coolant to shape specimen as illustrated in Fig. 4. Micro-Vickers hardness testing was conducted on the CDFW joint specimen, after surface was polished. Indentations were performed with load of 50 gf and indentation time of 6 sec. Locations of micro-vickers hardness testing were

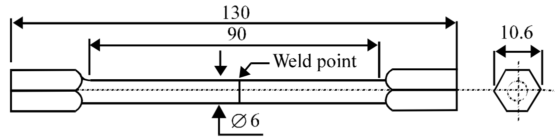

Fig. 2: Shape and dimensions of torsion strength test spesimen (mm)

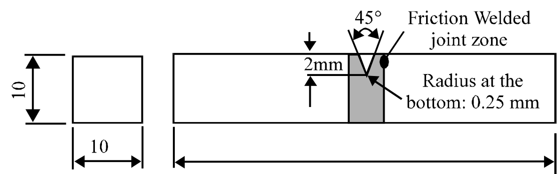

Fig. 3: Shape and dimensions of Charpy impact strength test spesimen (mm)

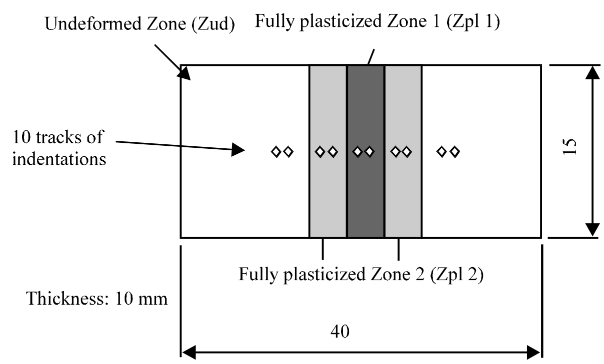

Fig. 4: Indentation locations of micro-Vickers hardness testing on CDFW joint

10 points in the middle of CDFW joint that represent the hardness of fully plasticized zone of heat affected Zone 1 (Zpl1) fully plasticized Zone 2 (Zpl2) and Undeformed Zone (Zud). It is known that the CDFW joint contains Zpl, Partly Deformed Zone (Zpd) and Zud4. However, in this study, it found that in the Zpl contains 2 zones of Zpl1 and Zpl2 in the macrostructures so that discussion is based on these zones.

Macro-structure and micro-structures observation of the weld joint were also conducted to find areas of fully plasticized Zone 1 and 2 (Zpl1 and 2) and porosity zone using a graphic analysis software. The area of these zones can be used to explain the behavior of torsion and impact strength of friction welding joint of A6061 since each area has its specific mechanical properties such as hardness.

RESULTS AND DISCUSSION

Figure 5 shows the representative photographs of CDFW joints for specimen without chamfer angle or

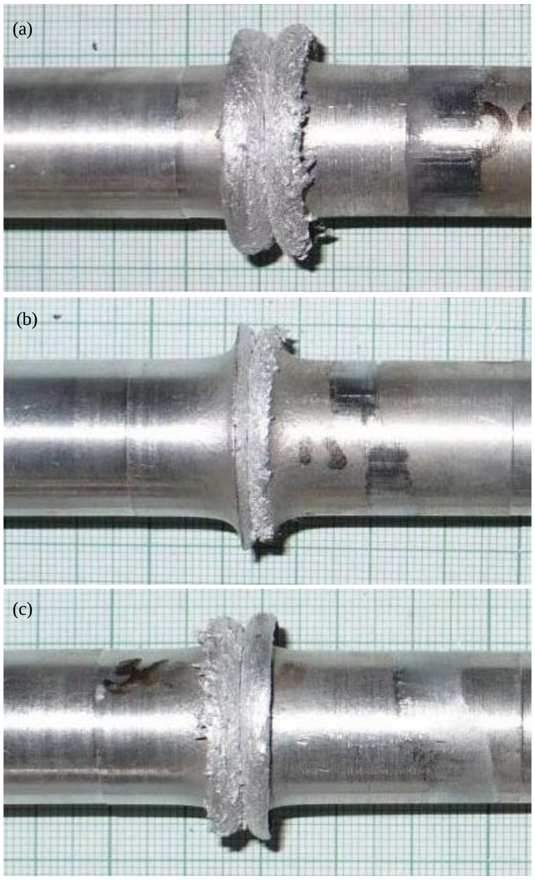

Fig. 5: Representative photographs of CDFW joints: a) Chamfer angle of 0° (without chamfer); b) Chamfer angle of 15° and c) Chamfer angle of 30°

chamfer angle of 0°, chamfer angle of 15° and chamfer angle of 30° on the millimeter block study. The flash was formed at the center of the specimen or the outer side of interface of two rods of the specimens.

It can be seen that chamfer angle influenced the formation and geometry of the CFDW flash. The size and geometry of flash for specimen without chamfer angle is the biggest of other flash of CDFW joints. Meanwhile, the flash geometry for specimen with the smallest chamfer angle (chamfer angle of 15°) is the smallest of other flash of CDFW joints. It may occur because different chamfer angle makes different area of initial friction area.

Based on Fig. 1, the smaller chamfer angle with the same height of chamfer (2 mm) gives smaller friction area. In the same time of CDFW process in 2 min, the generated initial heat from rubbing of smaller friction area will be lower than that of specimen with bigger friction area as result of bigger chamfer angle. Meanwhile, specimen without chamfer angle has the biggest area of friction. Therefore, the generated heat input during CDFW process for specimen without chamfer angle is the biggest so that yields the biggest geometry of flash compared to that of other specimens. In addition, specimen with the smallest chamfer angle (15°) has the smallest friction area and yields lower heat input so that the smallest flash formed as shown in Fig. 5b.

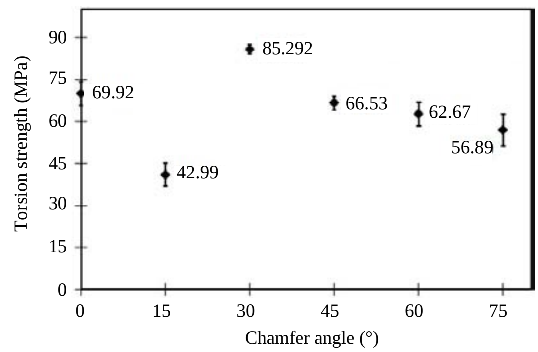

Fig. 6: Relationship of chamfer angle and torsion strength of A6061 CDFW joint (ASTM International, 2002a, b)

Torsion strength: Figure 6 shows relationship of chamfer angle and torsion strength of CDFW joint. It can be seen that chamfer angle of friction area affected the torsion strength. The highest torsion strength occurred in the specimen with chamfer angle of 30° and the torsion strength is around 23% higher than that of specimen without chamfer angle or with chamfer angle of 0° as shown in Fig. 6. Meanwhile, the lowest torsion strength occurred in the specimen with chamfer angle of 15° and the higher chamfer angle >30°, the lower torsion strength of CDFW joint. Figure 7 shows some macrostructures of CDFW joint in longitudinal section for specimen without chamfer angle (0°), chamfer angle of 15°, chamfer angle 30° that has the highest torsion strength and other chamfer angle. As shown in Fig. 7, CDFW joints contain fully plasticized Zone 1 (Zpl1) in the middle of the joint and Zpl2 where are located beside of Zpl1 area. These zones formed during friction process and upset stage of CDFW process. Each area has properties such us microstructures, hardness that affect to mechanical properties of CDFW joints such us tensile, torsion and impact strength. Zpl1 usually has higher hardness than Zpl2 (Sathiya *et al*., 2007; Irawan *et al*., 2012; Sahin *et al*., 2007). Some specimens have porosity in the CDFW joint and measured as zone of porosity (Zpr) as shown in Fig. 7b-f.

Table 2 shows areas of zones in the CDFW joint that measured using a graphic analyzer software by drawing curve line around each zone and measuring the area of

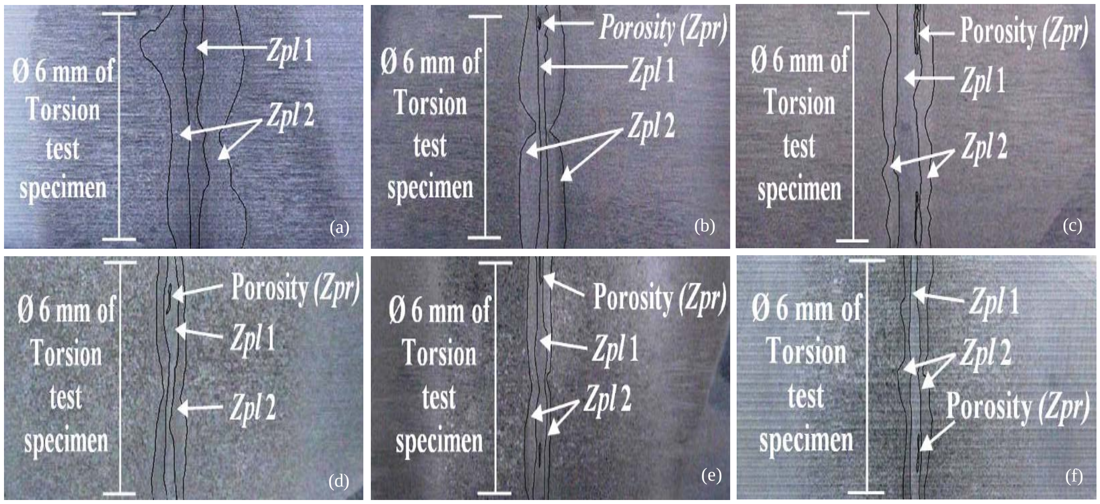

Fig. 7: Macro-structures of CDFW joints in longitudinal section (ASTM International, 2002b): a) Without chamfer, torsion strength = 69.92 MPa; b) α = 15°, the lowest torsion strength = 40.99 MPa; c) α = 30°, the highest torsion strength = 85.82 MPa; d) α = 45°, torsion strength = 66.53 MPa; e) α = 60°, torsion strength = 62.67 MPa; f) α = 75°, torsion strength of 56.89 MPa' a) Without chamfer (chamfer angle, α = 0°); b) Chamfer angle of 15°; c) Chamfer angle of 30°; d) Chamfer angle of 45°; e) Chamfer angle of 60° and f) Chamfer angle of 75°)

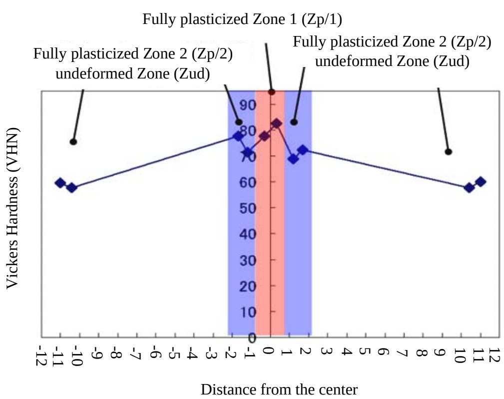

Fig. 8: Hardness distribution of CDFW joint with chamfer angle of 0°

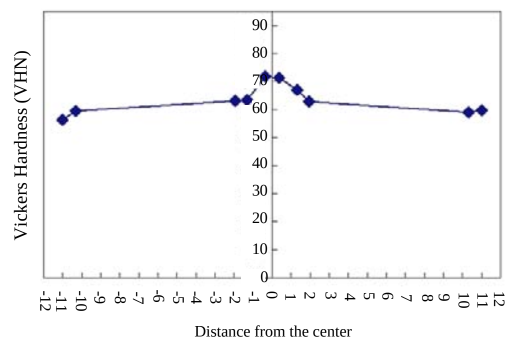

Fig. 9: Hardness distribution of CDFW joint with chamfer angle of 30° that has the highest torsion strength

each zone. Figure 8 and 9 shows hardness distribution of some CDFW joint on Zpl1, Zpl2 areas of specimen with no chamfer angle and the highest torsion strength. It can be seen that hardness of Zpl1 is higher than that of Zpl2. It is confirmed that microstructure grains of Zpl1 is finer than that of Zpl2 as shown in Fig. 10 and 11 which are microstructure photograph of Zpl1 and Zpl2 for specimen without chamfer angle and that with chamfer angle of 30° that has the highest torsion strength, respectively. This state is also reported by Sathiya *et al*. (2007) in ferritic stainless steel (Sahin *et al*., 2007) in AISI 1040 steel, Kimura *et al*. (2006) in A5052 and Irawan *et al*. (2016) in A6061 (Irawan *et al*., 2012, 2016). This state

Table 2: Area of zone in the middle of CDFW joint, Zpr: Zone of porosity, Zpl1: Zone of fully plasticized 1, Zpl2: Zone of fully plasticized 2

Chamfer angle (α)	Zpr (mm^2)	Zpl1 (mm^2)	Zpl2 (mm^2)
0°	0.00	8.41	28.20
15°	0.09	4.51	18.54
30°	0.49	12.55	13.34
45°	0.13	6.46	10.03
60°	0.21	6.22	10.62
75°	0.17	6.11	13.80

is thought as result of upset loading in the final stage of CDFW process that yields plastic deformation that increased density of dislocation as represented by finer grains. Besides, the area of Zpl1 which has higher hardness for specimen with chamfer angle of 30° as shown in Table 2 is the broadest among other

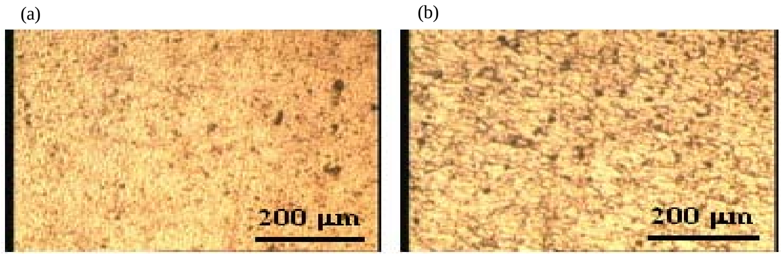

Fig. 10: Micro-structures of CDFW joint with chamfer angle of 0°: a) Zpl1 and b) Zpl2

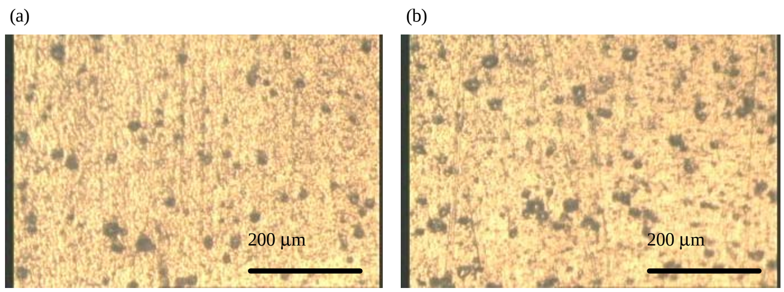

Fig. 11: Micro-structures of CDFW joint with chamfer angle of 30°: a) Zpl1 and b) Zpl2

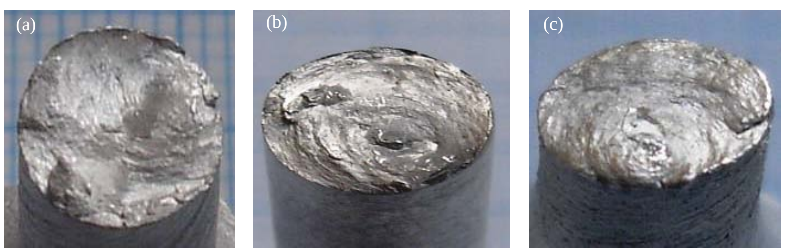

Fig. 12: Fracture surface of torsion test specimen: a) No chamfer (0°) with torsion strength of 69.92 MPa; b) Chamfer angle of 15° with the lowest torsion strength = 40.99 MPa and c) Chamfer angle of 30° with the highest torsion strength = 85.82 MPa

specimens. This condition is thought to yield the highest torsion strength on the specimen with chamfer angle of 30°.

Figure 12 shows typical fracture surface of the torsion test specimen. All specimens were fractured in shear mode with fracture surface perpendicular to longitudinal direction of specimen. Specimen with the highest torsion strength fractured in undeformed zone not in Zpl area. Meanwhile, specimen with the lowest torsion strength fractured in the Zpl2 area. It is thought to be occurred due to the smallest zone of Zpl1 (Table 2) that represent the metallurgical bonding between friction surface during CDFW process. It can be found that the smaller area of metallurgical bonding in the interface of friction welded rod (Zpl1), the lower torsion strength of the CDFW joint.

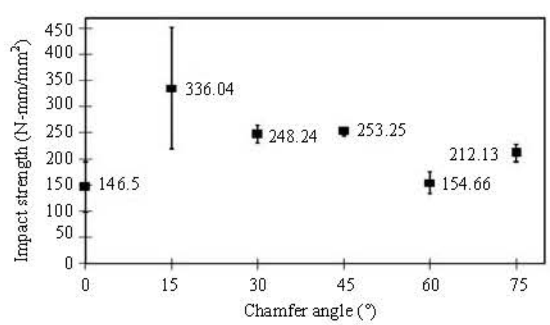

Fig. 13: Relationship of chamfer angle and impact strength of A6061 CDFW joint

Impact strength: Figure 13 shows results of impact strength testing to variations of chamfer angle. It is found

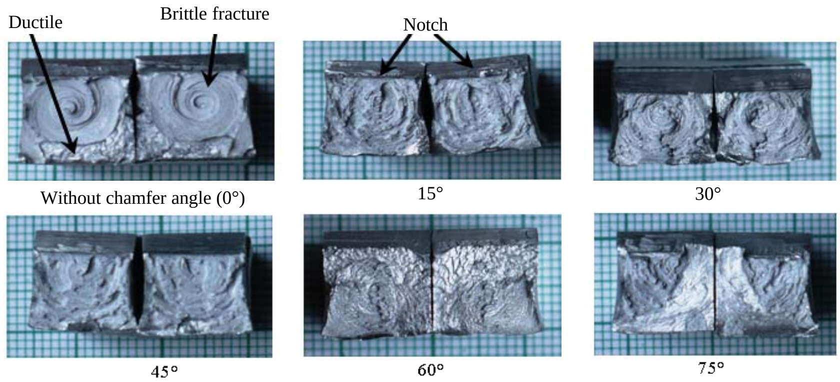

Fig. 14: Fracture surfaces of impact strength specimens of A6061 CDFW joint with various chamfer angles

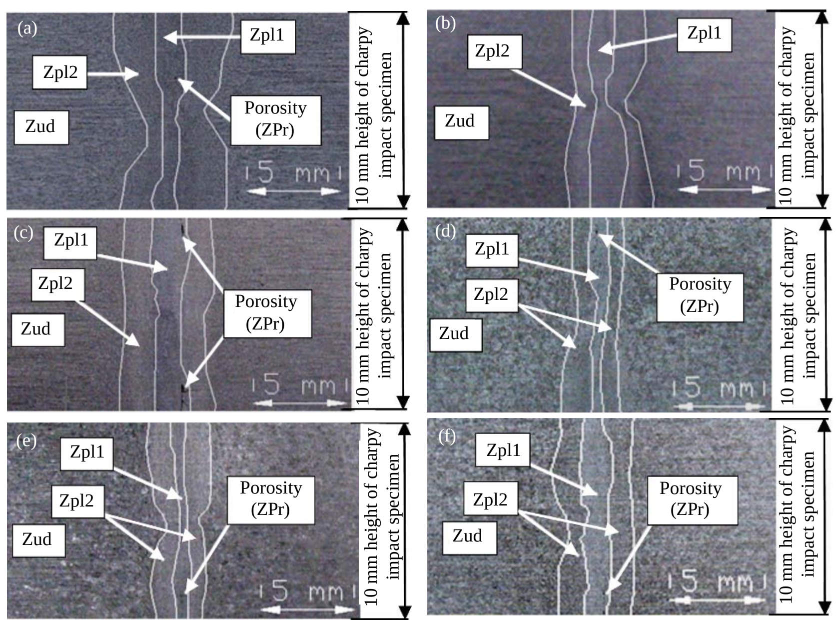

Fig. 15: Macro-structures of CDFW joints in longitudinal section of impact specimens: a) No chamfer, impact strength = 69.92 MPa; b) α = 15°, the lowest impact strength = 40.99 MPa; c) α = 30°, the highest impact strength = 85.82 MPa; d) α = 45°, impact strength = 66.53 MPa; e) α = 60°, impact strength = 62.67 MPa; f) α = 75°, impact strength = 56.89 MPa; a) Without chamfer (chamfer angle, α = 0°); b) Chamfer angle of 15°; c) Chamfer angle of 30°; d) Chamfer angle of 45°; e) Chamfer angle of 60°; f) Chamfer angle of 75°

that chamfer angle on two contact surfaces increases impact strength of CDFW joint. Maximum impact strength was obtained from the specimens with chamfer angle of 15°.

Figure 14 is the photos of fracture surfaces of Charpy impact testing specimens. It can be seen that ductile fracture area which has fibrous area or deformed zone in specimen with chamfer angle of 15° are the largest. It shows that specimen with chamfer angle of 15° gives the most ductile weld joint, so that it was able to absorb more impact energy during Charpy impact test.

Figure 15 shows macrostructures of CDFW joint in longitudinal section for Charpy impact test specimens. without chamfer angle (0°), chamfer angle of 15° chamfer angle 30° that has the highest torsion strength and other chamfer angle. As shown in Fig. 7 and 15, CDFW joints of the specimen contain fully plasticized Zone 1 (Zpl1) in the middle of the joint and Zpl2 where are located beside of Zpl1 area. Figure 15 also show small porosity area Zpr in the CDFW joints.

Table 3 shows the area of zones (Zpl1, Zpl2 and porosity, Zpr) in the CDFW joint of Charpy impact

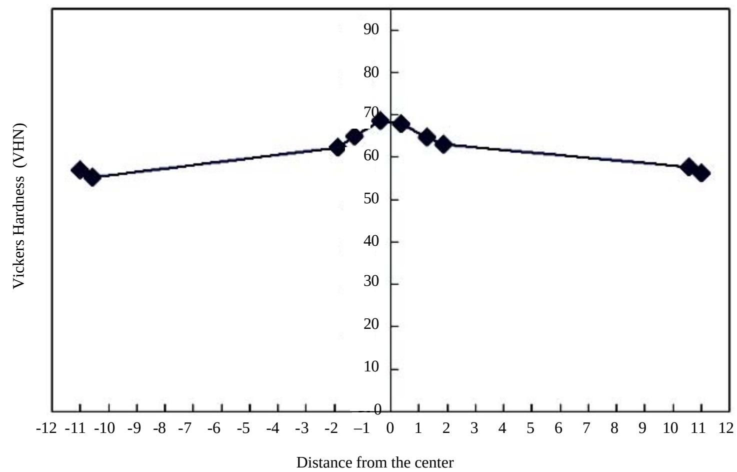

Fig. 16: Hardness distribution of CDFW joint with chamfer angle of 15° that has the highest impact strength

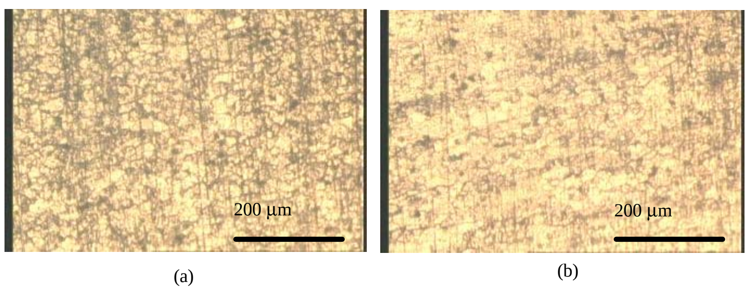

Fig. 17: Micro-structures of CDFW joint with chamfer angle of 15°: a) Zpl1 and b) Zpl2

Table 3: Area of zone in the middle of CDFW joint in the Charpy test specimen with the width of 10 mm, Zpr: Zone of porosity, Zpl1, and Zpl2

Chamfer angle (°)	Zpr (mm^2)	Zpl1 (mm^2)	Zpl2 (mm^2)
0	0.01	11.63	38.91
15	0.00	14.33	23.73
30	0.36	16.36	30.56
45	0.43	7.57	19.85
60	0.22	6.21	22.23
75	0.17	13.95	24.79

specimens using the same method in Fig. 7 and Table 2. It is found that almost all the Charpy impact specimens contains porosity, except specimen with chamfer angle of 15°. It is also found in Table 2 and 3. It is known that porosity has negative effect to impact strength because when specimen receives impact load, porosity will act as stress concentrators and makes the crack that initiated from charpy impact notch initiated and propagates faster until the specimen fractured. Namely, the larger area of porosity, the higher the brittleness of specimen and the lower impact strength will be. Besides, it is thought that the area of Zpl2 that has the lower hardness as shown in Fig. 8 and 9 also absorbs impact energy due to its higher ductility.

Figure 16 shown micro vickers hardness distribution along center line of longitudinal section of CDFW joints. It is also confirmed that ZPl1 has higher hardness than Zpl2. Microstructures photographs in Fig. 17 also shows that Zpl1 in the specimen that has finer grains than that of Zpl2. It is thought that due to this condition, the Charpy impact specimen with chamfer angle of 15° has the maximum impact strength.

CONCLUSION

From this study, it can be concluded as follows: Chamfer angle influenced torsion and impact strength of CDFW weld joint of round Aluminum alloys A6061. The specimens with chamfer angle of 30° had maximum torsion strength due to minimum porosity and maximum area of fully plasticized Zone 1 (Zpl1) at the center of weld joint that had the highest hardness compared to that of other zone such us Zpl2 and undeformed Zone (Zud). Maximum impact strength found on the specimens that had chamfer angle of 15° due to minimum porosity and broader area of fully plasticized Zone 2 (Zpl2) that has lower hardness, more coarse grains and higher ductility than that of

Zpl1. Porosity, area of fully plasticized Zone 1 and 2 have a role to affect the torsion and impact strength of CDFW joint.

ACKNOWLEDGEMENTS

This research was supported in part by Directorate Higher Education of Indonesian Ministry of Education, Institute of Research and Community Services and Faculty of Engineering, Brawijaya University, Indonesia.

REFERENCES

ASTM International, 2002a. Standard test method for shear modulus at room temperature. ASTM E143. http://www.astm.org/DATABASE.CART/HISTORICAL/E143-02.htm.

ASTM International, 2002b. Standard test methods for notched bar impact testing of metallic materials. ASTM E23-02. http://www.astm.org/DATABASE.CART/HISTORICAL/E23-02.htm.

Bauccio, M., 2005. ASM Metals Reference Book. 3rd Edn., ASM International, USA., ISBN: 9780871704788, Pages: 614.

Budinski, K.G., 1996. Engineering Materials: Properties and Selection. 5th Edn., Prentice Hall, New Jersey.

Irawan, Y.S., M. Amirullah, G.B.D. Gumilang, T. Oerbandono and W. Suprapto, 2016. Torsion strength of continuous drive friction weld joint of round bar aluminum A6061 affected by single cone geometry of friction area. AIP Conf. Proc., Vol. 1717. 10.1063/1.4943453

Irawan, Y.S., M. Wirohardjo and M.S. Ma'arif, 2012. Tensile strength of weld joint produced by spinning friction welding of round aluminum A6061 with various chamfer angles. Adv. Mater. Res., 576: 761-765.

Kimura, M., M. Choji, M. Kusaka, K. Seo and A. Fuji, 2006. Effect of friction welding conditions on mechanical properties of A5052 aluminium alloy friction welded joint. Sci. Technol. Welding Joining, 11: 209-215.

Lin, C.B., C.K. Mu, W.W. Wu and C.H. Hung, 1999. Effect of joint design and volume fraction on friction welding properties of A360/SiC (p) composites. Welding J., 78: 100-s-108-s.

Sahin, M., H.E. Akata and T. Gulmez, 2007. Characterization of mechanical properties in AISI 1040 parts welded by friction welding. Mater. Characterization, 58: 1033-1038.

Sathiya, P., S. Aravindan and A. Noorul Haq, 2007. Effect of friction welding parameters on mechanical and metallurgical properties of ferritic stainless steel. Int. J. Adv. Manuf. Technol., 31: 1076-1082.