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Influence of Cooling Methods in Friction Stir Welding of 7075 Aluminum Alloy

[1] Paisan Saeyang, [2] Amarin Chanpariyavatevong, [3] Kodcharawit Lamkham, [4] Somsak Siwadamrongpong, [5] Suradet Tantrairatn

[1] [2] [4] School of Manufacturing Engineering, Suranaree University of Technology, Thailand,
[3] School of Manufacturing Engineering, Rajamangala University of Technology Lanna, Thailand,
[5] School of Mechanical Engineering, Suranaree University of Technology, Thailand
Corresponding Author Email: [1] paisan0573@gmail.com, [2] amarin_chan@outlook.com, [3] Kodcharawit2538@gmail.com, [4] somsaksi@sut.ac.th, [5] suradetj@sut.ac.th

Abstract— Regarding various part manufacturing in industrial scale, one of the most popular processes was welding, especially in automotive and aircraft industries. It was well known that these industries have an increasing rate of aluminum consumption every year. There was due to aluminum has many outstanding properties such as light weight, high strength to weight ratio and very good elongation. One of the most used aluminum alloys was AL7075, which is suitable for highly stressed structural applications in aircraft structural parts. However, fusion welding techniques were usually yielded poor strength for such grade of aluminum. Friction stir welding is a solid-state welding technique that joins two workpieces without melting the workpiece material. Heat was generated by friction between the shoulder of the stirring tool and the workpiece. The probe was to stir and mix two metals parts together. However, the Thermo Mechanical Affect Zone (TMAZ) and Heat Affect Zone (HAZ) were reported as the weakest area of welded parts. Therefore, this study aims to improve the joints by cooling processes during welding using cutting fluid and cryogenic cooling with different parameters such as welding speed and shoulder size. The results of these experiment indicated that the cooling process influenced the mechanical properties of the joints. The micro-vicker hardness showed a significant increase in TMAZ and HAZ area.

Index Terms— AL7075, Friction stir welding, Cutting Fluid, Cryogenic.

I. INTRODUCTION

Al 7XXX series alloys were widely used, such as airframes, sports equipment, member in bridge and rail transport system, safety equipment and parts in automotive sector. There was due to aluminum has outstanding properties such as high strength-to-weight ratio and good corrosion resistance [1]. In the production process, it was necessary to assemble or increment materials together. The assembly can be divided into 2 types: temporary and permanent assembly. Permanent assembly by welding was one of the most popular permanent assembly methods. However, fusion welding techniques often yield low strength for Al7xxx and Al2xxx aluminum, as they were susceptible to hot cracking during solidification [2]. Hot cracking of welded metal could occur in the fusion zone during solidification of molten metal. There causes uneven flow of aluminum which leads to cause defects and affects the strength of the weldment as well.

Over 20 years of development, Friction Stir Welding (FSW) has become a key welding and manufacturing technology [3]. Friction stir welding is a solid-state welding technique that joins two facing workpieces without melting the workpiece material. Heat was generated by friction between the shoulder of the stirring tool and the workpiece material. This weakens the area near the FSW instrument. While the tool moves along the butt joint of the workpiece, the probe was to stir and mix two metals together. Fine grain size in stirred zone was reported and resulting in high strength of weldment [4]. Friction stir welding causes serious plastic deformation and frictional heating during the process. This was an effect of recrystallized grain structure in the nugget zone (NZ) [5]. The recrystallization was reported because of strain gradient, strain rate and temperature of NZ. Some works were aimed to enhance the mechanical properties of the weldment, friction stir welding was performed on Al1050 alloy and a significant increase in hardness (37%) and tensile strength (46%) compared to the starting material. Friction stir welding was a promising technique to increase the mechanical properties resulting from grain size control during the friction stir welding process [6]. Many researchers have also reported that parameter optimization can effectively control the grain size and consequently improve the mechanical properties of the weldment [7-9]. The sludge forming after processing was also studied and it was concluded that the adverse event of sludge dissolution or coarse grain size during friction stir welding might be the main reason for showing inferior properties. Although it developed a fine-grained microstructure[10]. In addition, it was found that the grain size developed during friction stir welding exhibited a rapid expansion of the grain size due to the slow cooling rate after welding [11].

Many techniques were used to improve the properties of weldment. It has been made by using heat treatment method [12, 13]. It was concluded that heat-treated weldments had increased tensile strength. Not only this, but there has also been research on the use of Cryogenic treatment to increase the efficiency of the weld by bringing the weldment to Deep Cryogenic treatment[14]. There were showed that the cold treatment was able to increase the strength of the weldment. Submerged friction welding was used to control the expansion of the grain[15, 16], by submerging under cooling media such as air, water, dry ice and gas. [17-19].

Therefore, in the present research work, was aimed to investigate friction stir welding on Al7075. 3 Friction stir welding parameters, shoulder size of tool, welding speed and cooling methods (using cutting fluid and cryogenic cooling) were investigated. Mechanical properties of the weldment have been evaluated and compared with based material.

II. EXPERIMENTAL DETAILS

The 4 mm thick rolled sheet of Al7075 alloy was used as the base metal in this study. The density was 2.81 g/cm³ and percentage composition was shown in Table I. Mechanical properties of the alloy were shown in Table II. The base metal is cut into 100 × 50 × 4 mm sheet for friction stir welding process.

Table I. Chemical composition of Al7075

Composition (wt%)						
Al	Zn	Mg	Cu	Si	Fe	Mn
Bal.	5.1	2.1	1.2	0.58	0.35	0.12

Table II. Mechanical properties of Al7075

Mechanical properties			
Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Vicker Hardness (HV)
498	566	9	164

The strength of the FSW joint was greatly affected by shoulder size and welding speed, Angkarn et al. There was achieved in the welding speed range of 36-63 mm/min and tool rotation at *1,580 – 2,220* rpm[20]. In this study, Full Factorial Design technique was employed with two levels of welding speed (*40* and 60 mm/min), two levels of shoulder (*9* and *15*mm) and three levels of cooling (No cooling, Cutting Fluid, Cryogenic) were carried out and indicated in Table III. The stir tool with cylindrical pin 3 mm in diameter was made by SKD11 hot-work tool steel and hardened to 51-55 HRC, which is displayed in Fig. 1. The friction stir welding (FSW) operation was operated with tool tilt onward angle of 3° for all the FSW experiments.

Regarding the cryogenic cooling process, compressed air at a pressure of 5 bar was poured into a liquid nitrogen tank. After that, the coolant was supplied through an insulated 5.5 mm diameter copper tube. Flow rate of approximately 0.25 l/min was applied to the weldment [21], the measured temperature at the spray point was -130°C. For the cutting fluid cooling process, HIKUT W10 was selected with mixing ratio 5%, flow rate approximately 1.5 l/min, coolant spray distance around 15 mm behind the stirrer, as shown in Fig 2. The FSW machine in this study was a modified 3 axis milling machine (Lagun GUM 152) with a welding fixture assembled on it.

Fig. 1 Tool used for friction stir welding

Table III. FSW process parameters

Parameters	**levels**			**Unit**
	1	**2**	**3**	
Welding speed	40	60		mm/min
Shoulder diameter	9	15		mm
cooling	No cooling	Cutting Fluid	Cryogenic	-
Rotation speed	1,580			rpm

(a) (b)

Fig. 2 Experimental set-up and cooling methods
(a) cryogenic cooling. (b) cutting fluid cooling.

The welded specimens were segmented for tensile testing and polished for hardness testing in accordance with ASTM E384-17, ASTM E-8 respectively. FUTURE-TECH Model FM-800 Digital Micro Vickers Hardness Tester using a pyramid-shaped diamond indenter, square base. It was used to measure the micro hardness of different zones of the weld. A 100 g load was applied for 15 second for the hardness

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measurement. The distance between the two notches was measured at 0.2 mm as shown in Fig.3. The tensile test was performed on a universal testing machine, brand LLOYD, model LD100K, with a load cell size of 100 KN, using a test speed of 1.002 mm./min[22].

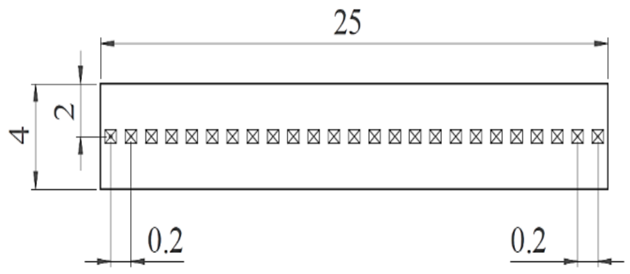

Fig. 3 hardness testing

III. RESULT AND DISCUSSION

A tensile test was performed to determine the effect of cooling on the % elongation and tensile strength of the weld with 3 samples per condition. Fig. 4 shows that the average ultimate tensile strength of the weldment. It was found that cutting fluid cooling condition yielded the highest strength in all conditions, around 78.9% of the based material which obtained from the experiment of shoulder size 15 mm and welding speed 60 mm/min. Cryogenic cooling joints were slightly higher than that of non-cooling joints.

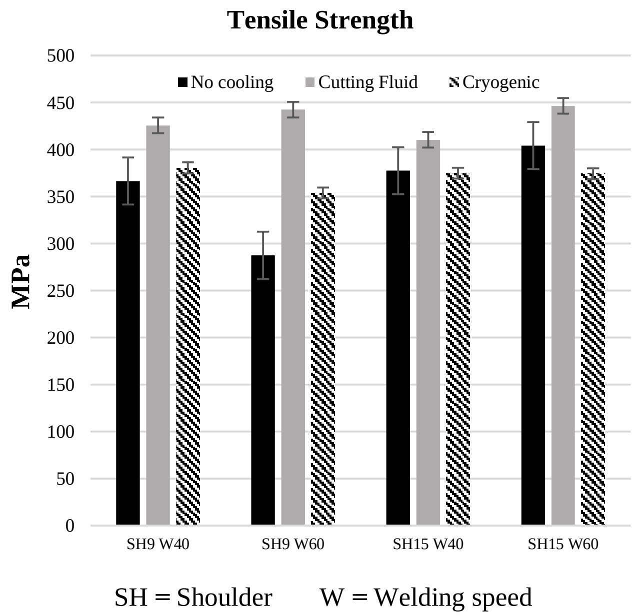

Fig. 4 Comparison of ultimate tensile strength of FSW joints.

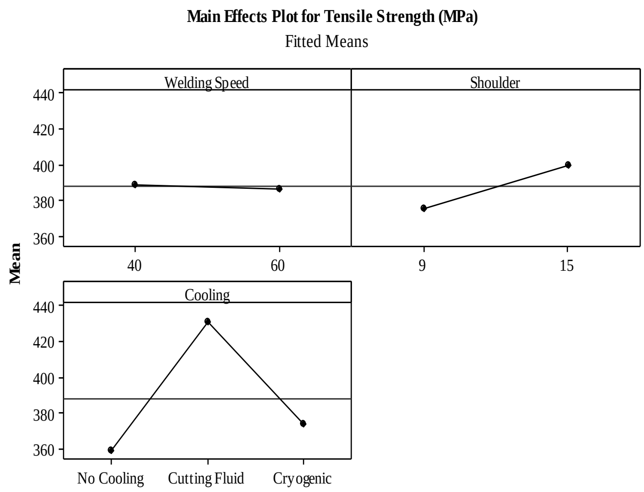

Fig. 5 Main Effects Plot for Tensile.

The Main Effects Plot for tensile strength shown in Fig. 5, there was found that welding speed has little or no effect on tensile strength. Different shoulder sizes result in different strengths. Different cooling methods have a noticeable effect on the strength of joints. Cutting fluid could be considered as very outstanding compared to other cooling methods.

Elongation of the weldment was showed in Fig.6. It was obviously observed that the weldment of cutting fluid and cryogenic cooling were the same level and higher than no cooling condition. It might be caused by the cooling effect which makes the TMAZ and HAZ zones to form smaller grain size [15]. Increasing of welding speed and tool shoulder size also found to increase the % elongation. The weldment with a welding speed of 60 mm./min, shoulder 15 mm. and cooled by cutting fluid showed the highest percentage of elongation.

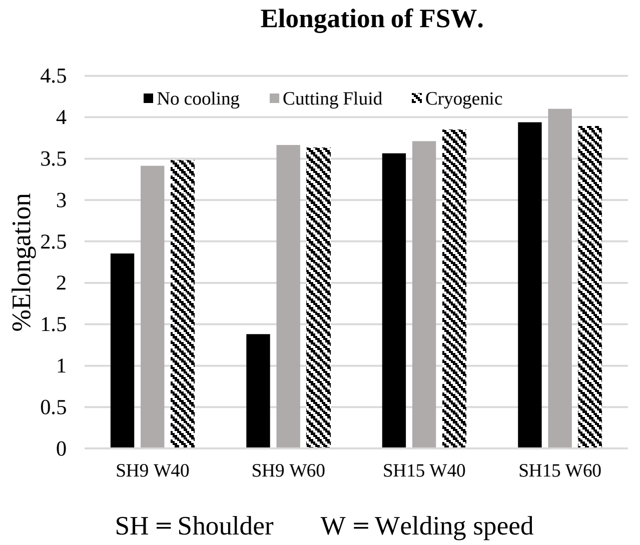

Fig. 6 Comparison of % elongation of FSW joints.

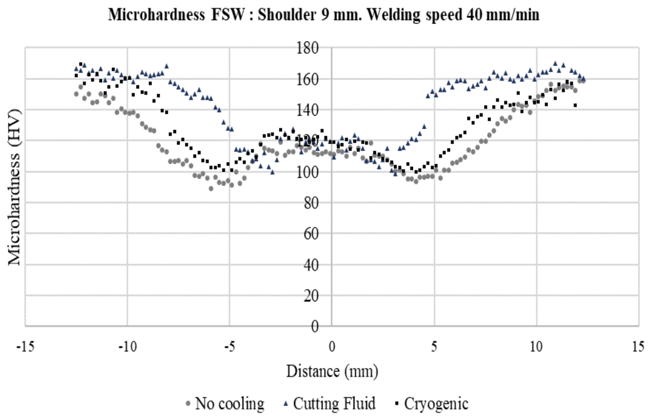

Fig. 7 Microhardness FSW : Shoulder 9 mm. Welding speed 40 mm/min

Fig. 7 shows the distribution of microhardness across the weldment at a welding speed of 60 and a shoulder of 9 mm. The specimen with Cutting fluid cooling showed the highest hardness values in HAZ and TMAZ compared to uncooled and cryogenic cooling. This might indicate that the grains in such zones may be finer in size than the uncooled one. Fig. 7 might imply that the rapid cooling after FSW can significantly increase the hardness in HAZ and TMAZ, Fig. 7 and Fig.8. These results were also reported in the same trend by Bocchi et al., there were concluded that joints with cooling process can significantly increase the hardness values in TMAZ and HAZ[23].

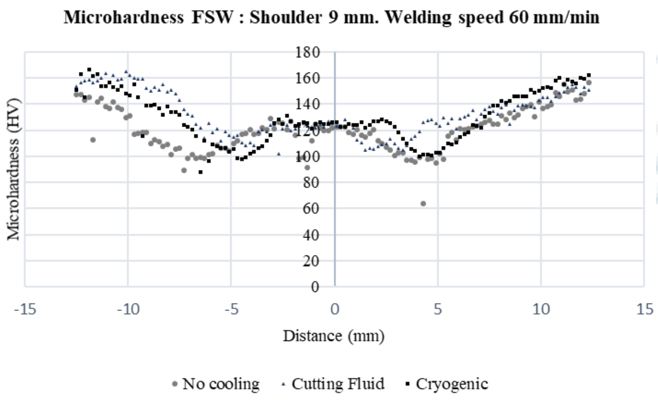

Fig. 8 Microhardness FSW : Shoulder 9 mm. Welding speed 60 mm/min

IV. CONCLUSIONS

In this work, the focus was on investigating effects of rapid cooling after FSW with cutting fluid and cryogenic on mechanical properties such as tensile strength and the elongation of the friction stir welding of alloy AL7075. The results of the experiments were concluded as follows;

1) Cutting Fluid and Cryogenic cooling processes greatly affect the mechanical properties of weldment. which has the highest tensile strength of 446.52 MPa, representing 78.9% of the based material which obtained by cutting fluid cooling, welding speed 60 mm./min., and shoulder 15 mm.
2) Rapid cooling after FSW increased the % elongation in both cutting fluid and cryogenics coolings.
3) Both cooling methods affected the increase of hardness in HAZ and TMAZ, but it seem to had no effect in NZ.

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