Mechanical Properties of Friction Stir Welding Joining of PolyTetraFluoroEthylene

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Mechanical Properties of Friction Stir Welding Joining of PolyTetraFluoroEthylene

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Abstract – *This study has aimed to investigate the mechanical properties of PolyTetraFluoroEthylene joined by Friction Stir Welding (FSW). The joining process has been conducted on CNC milling machine at speeds of 20, 25 and 30 mm/min and rotation of 750, 1000 and 1250 rpm. Tensile and impact tests have been done based on ASTM D638 and D6110 standard, respectively. Photomacrograph and SEM photomicrograph have been used to analyses the fracture mode and the fracture surface, respectively. The results have showed an increase in tensile and impact strength, along with rising in each rotational speed. However, there have been decreases in these strengths on each speed increase. In addition, the results have showed 20 mm/minute welding, and an increased rotation raises the tensile and impact resistance. At the same rotation speed, the rise in welding speed reduces the strengths. Furthermore, at 20 mm/minute, the strengths have been higher than at 25 and 30 mm/minute.*

***Keywords**: Friction Stir Welding, PolyTetraFluoroEthylene (PTFE), Welding Speed, Mechanical Properties*

Nomenclature

FSW	Friction Stir Welding
HAZ	Heat Affected Zone
PC	Poly Carbonate
PP	Poly Propylene
PTFE	PolyTetraFluoroEthylene

I. Introduction

Over the past few decades, thermoplastic polymers have progressively replaced metals in many industries applications. The use of polymer materials is cost efficient, weight-saving, and flexible. Therefore, polymer application development needs to be followed by developing reliable joining technologies [1], which are required for plastic materials with complex shapes and large-scale production. The methods used for joining thermoplastic materials are categorized as follows: mechanical, adhesive, and direct or fusion bonding [2]-[6]. Mechanical joining is usually used to fasten the adherents by bolts and riveting. This method causes stress concentration near the holes, thus leading to material failure, and weight increase, which distorts the lightweight design [4]. In addition, adhesive bonding uses a layer to distribute load to larger adherent areas evenly. This method is complicated and needs careful attention in order to obtain the target specification, and it is involved in surface preparation. Furthermore, it is important to consider surface adherent treatment to achieve a reliable bonding [2], [4]. Adhesive and mechanical joining has several benefits. However, they have productivity and recyclability difficulty because of time requirements and other machining processes for joining. Adhesive bonding is also affected by environmental temperature and humidity [3]. Some researchers have put interest in direct bonding such as welding. However, they cause thermal degradation by excessive heating during the process [7]. Furthermore, direct thermoplastic bonding is referred to as welding (fusion) and “glueless” or auto adhesion [4]-[6]. The fusion takes advantage of the thermoplastic flowing property when heated, and then it returns to its baseline mechanical properties upon cooling. In addition, the direct bonding method can be applied to join many thermoplastic materials. This method has long been used in automotive, aircraft, packaging, and medical industries [8]. Currently, several direct bonding methods have been developed, and Friction Stir Welding is one of them.

FSW is a technique that joins materials in solid-state, and it has advantages over conventional welding techniques such as fewer defects, little power requirements, no use of consumables, and high weld qualities [9], [10], [26], [27]. In this process, the tool-rotating pin penetrates the material, and the shoulder tool pin travels over the weld joint surface [11]. Furthermore, it is expected to increase sufficiently the joining temperature near the melting point but still in solid-state.

Therefore, the rotational shoulder, the welding speed, and the pin tool geometry are parameters that affect welding quality [12]-[14]. Mechanical and microstructure properties of welded polypropylene sheets using the hot shoe method have been of particular interest. Welding at low feed rate, high shoe temperature, long pressure time,

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and large pin produced a minimal polymer microstructure disruption [15]. FSW parameters are 800 and 1200 rpm rotation, 40 and 200 mm/min transverse speed and axial force ranging from 1-5 kN welded at 5 mm polypropylene plate thickness. These processes have been done with different tool profiles (square, cylindrical, and triangular threaded pin). Therefore, 950 rpm rotation tool, 9 mm/ min feed rate, and 1° tilt angle results in yield strength of about 10 MPa or almost 45% of the parent materials [16]. Furthermore, this technique has also successfully realized thermoplastic polymers joining such as Poly Propylene. The PP has been welded with friction stir welding parameters which were 620 rpm rotation, 7.3 mm/minute transverse or traveling speed, and 0.02 mm plunge depth tool, which produces 8.1 MPa bending strength [17]. In addition, FSW has to join Poly Carbonate (PC) with the highest specific shear strength of about 25 MPa. This strength has been achieved by friction stir welding with 5 mm pin diameter, 10 mm shoulder and 0° tilt angle. The parameters are 8 mm/min plunging speed, pre-heating time (T_p=7 s), dwell time 21s, and the rotational tool speed (n=1260 rpm) [18].

Therefore, the effects of rotation on Poly Caprolactam weld quality (Nylon 6) have been investigated. The results have showed that the highest FSW joining strength has been obtained at 300 rev/min rotation, 0° tilt angle, and 27.21 MPa, which corresponds only to about 32% of base material [19]. Furthermore, in order to obtain the best PTFE joining quality, the rotation and the travel speed variables need to be chosen. These parameters have resulted in optimum heat generation and material flow to produce high joining quality [20]. The present study addresses the effect of tool rotation and welding speed on the tensile strength and impact strength of PTFE joint by the FSW technique. PTFE plates with 10 mm thick have been welded by FSW method with the variation of speed and tool rotation. FSW joined of PTFE have been tested by tensile based on ASTM D638 and impact test based on ASTM D6110. SEM photomicrograph has been done to analyze the fracture surface of specimens.

II. Materials and Methods

The experiment has started with FSW tool preparation, which has the following dimensions: 5 mm of screwed pin diameter, 9 mm length, 16 mm shoulder diameter and 75 mm of its length. The tool has been made from ST 37 steel and the dimension for FSW processes are shown in Fig. 1. Furthermore, 25%-carbon-filled PTFE sheets have been cut into 320×50×10 mm dimensions. During the process, welding speed varies among 20, 25, and 30 mm/minute, while the rotational speed variations are 750, 1000, and 1250 rpm at 1 mm plunge depth. Tensile and impact specimens have been prepared based on ASTM D638 and D6110. There are five for each variation and they have been tested at room temperature and at 100 mm/s tensile test speed. The dimensions and the photos are shown in Fig. 2 and Fig. 3 respectively.

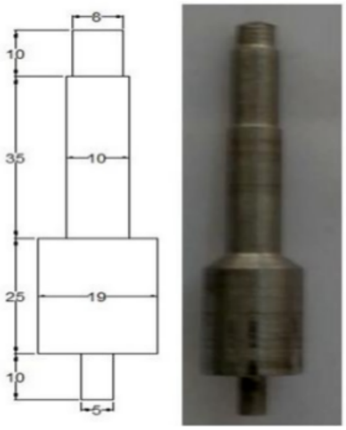


Fig. 1. Tool dimension (in mm) and photo of tool shoulder

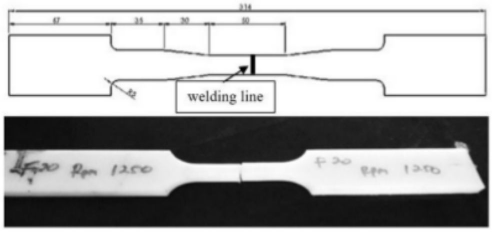


Fig. 2. Dimension and photo of tensile test specimen (in mm)

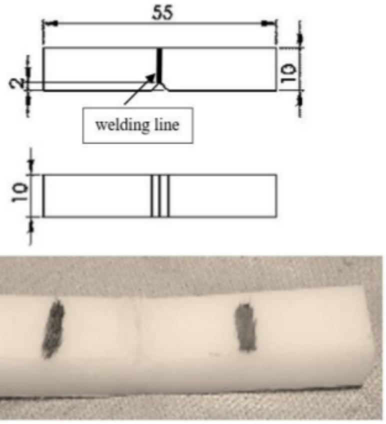


Fig. 3. Dimension and photo of impact test specimen (dimension in mm)

Those specimens have been tested by the tensile and Charpy impact test machines. In the last test, a scanning electron microscope has been used to evaluate the fractographic image of tensile tested specimens.

III. Results and Discussions

The tensile and the impact strength of FSW welded PTFE have speed and tools rotation variations shown in

Fig. 4 and Fig. 5 respectively. The results show that there are increases in tensile strength along with increases in rotational speed, but they show a decrease in tensile strength with a rise in welding speed. FSW impact test shows an increase in strength with a rise in rotation speed, although there is a decrease in impact strength when welding speed is higher as shown in Fig. 5. Higher tool rotation and lower welding speed affect the time of contact between tool and surface of materials and results in higher heat generated. The quality of welded joining are dependent on the heat generated when FSW process.

Consequently, heat generation and welding time affect the joining quality [12], [15]. Low heat causes porous joints, resulting in less strength. In addition, 1250 rpm rotation and 20 mm/min welding yield the highest strengths (Fig. 4 and Fig. 5). These results are in accordance with Kumar et al., which have stated that maintaining the maximum range of rpm and minimum traverse speed resulted in maximum tensile properties [21]. Fig. 6(a) shows fracture surface or FSW joining at 30 mm/minute welding speed and rotation of 750 rpm.

Fig. 6(b) denotes the fracture surface of FSW at 20 mm/minute and rotation of 1250 rpm. Furthermore, lower tool rotation and higher speed generate lower heat of joining. This leads to a lower welding temperature that produces unaccomplished coalescence of surface joining.

Fig. 6(a) shows the flat fracture surface indicates delamination. Welding at low tool rotation and high welding speed have resulted in a lack of welding temperature yielded incomplete fusion, and cracks have been formed around the joining zone due to uncontrolled strain rate [22]. Fig. 6(b) shows the better quality of FSW; there is no delamination in the fracture surface of specimens. FSW at 1250 rpm and 20 mm/minute has resulted in a higher temperature for coalescent the PTFE.

The fracture surface of PTFE shows that plastic deformation occurs before fracture. It is very similar to the SEM photomicrograph of the fracture surface of raw material of PTFE (Fig. 7). Fig. 7 shows the fracture surface with dimples surface that shows plastic deformation before fracture. Fig. 6(b) shows fracture of PTFE with less dimple of PTFE that shows the less plastic deformation observed. FSW at 1250 rpm and 20 mm/minute, fracture of welded PTFE at fusion area (Fig. 8). Thermal from FSW process transforms solid phase of PTFE into viscous.

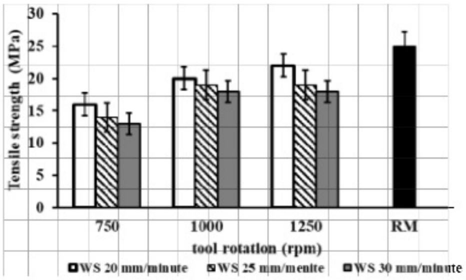


Fig. 4. Tensile strength of FSW joined with variation of welding speed and tool rotation

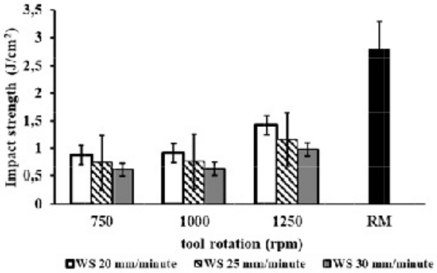
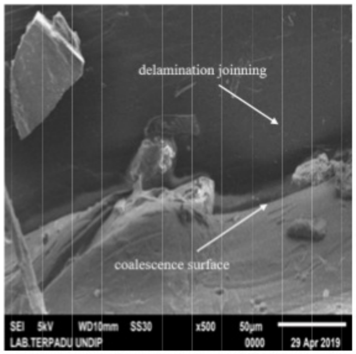
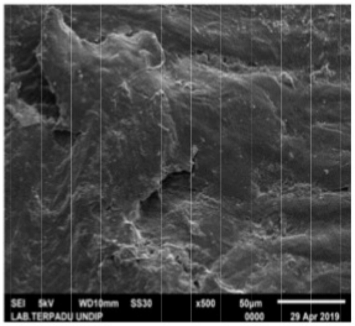


Fig. 5. Impact strength of FSW joined with variation of welding speed and tool rotation



(a) SEM photomicrograph fracture surface of FSW at welding speed 30 mm/minute and 750 rpm rotation tool



(b) SEM photomicrograph fracture surface of FSW at welding speed 20 mm/minute and 1250 rpm rotation tool

Figs. 6. Fracture surface FSW joining

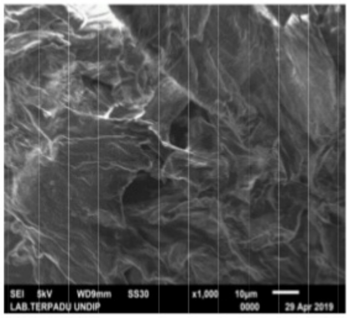


Fig. 7. The fracture surface of PTFE

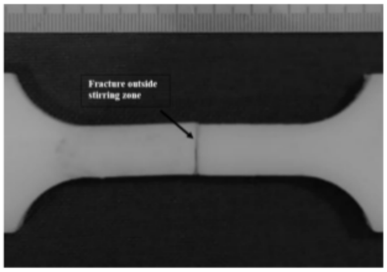


Fig. 8. Photomacrograph of fracture surface of PTFE at welding speed 20 mm/minute and tool rotation 1250 rpm

There are transformation crystalline and amorphous phases of PTFE during welding, causing the brittle of PTFE [23]-[25]. Fig. 8 shows the photomacrograph of PTFE fracture surface at a welding speed of 20 mm/minute and tool rotation of 1250 rpm, which shows fracture across the outer stirring zone. In addition, the joining has been fractured at the HAZ area. FSW at rotation of 30 mm/minute and 750 rpm has produced different macro photomicrograph (Fig. 9) than at rotation of 20 mm/minute and 1250 rpm (Fig. 8). In addition, Fig. 9 shows a flat, fracture surface across the stirring zone because of incomplete coalescence or crack, which leads to stress concentration, and causes a break [20], [22]. In this study, FSW joining of PolyTetraFluoroEthylene (PTFE) at rotation of 1250 rpm and welding speed of 20 mm/minute has yielded tensile and impact strength of 22 MPa and 1.42 J/cm^2 respectively, which is about 90% tensile and 60% impact strength of PTFE.

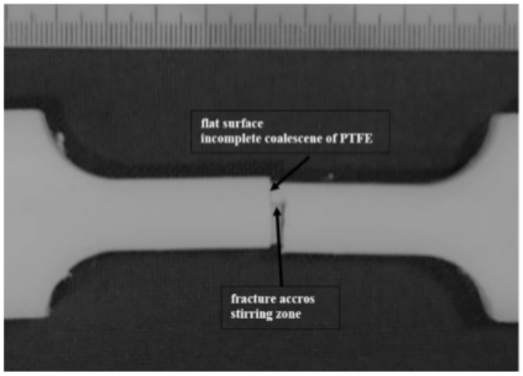


Fig. 9. Photomacrograph of fracture surface of PTFE at welding speed 30 mm/minute and tool rotation 750 rpm

IV. Conclusion

The welding process using the FSW method on PTFE sheets shows an increase in the tensile strength along with an increase in rotation in each welding speed.

However, a decrease in strength occurs in addition to the speed. FSW at rotation of 1250 rpm and welding of 20 mm/min produces the highest tensile strength of 25 MPa (about 90% of PTFE tensile strength). The lowest is 13 MP at 750 rpm and 30 mm/min rotational and welding speed, respectively. The impact test has also showed an increase in strength along with rise in rotational speed. However, it has showed a decrease in impact strength along with increase in welding speed.

The highest impact strength has been 1.42 J/mm^2 at 1250 rotation and welding of 20 mm/min, while the lowest impact strength has been 0.61 J/mm^2 at 750 rpm rotation 30 mm/min welding. Therefore, the formation of crack or cavities happens because of low heat generation, which causes stress concentration at joining area, and yields low tensile and impact strength.

Acknowledgements

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References

[1] M. K. Bilici, Application of Taguchi approach to optimize friction stir spot welding parameters of polypropylene, *Materials and Design*, vol. 35, pp. 113–119, 2012.

[2] D. Lee, Y. Oh, S. Nam, J. Choe, and D. G. Lee, Adhesion characteristics of fiber-exposed glass composite, *Composite Structures*, vol. 165, pp. 9-14, 2017.

[3] Sugiman and Sulardjaka, Water absorption and desorption behaviour and their effect on the tensile properties of fm 73m adhesive film, *International Journal of Technology*. Vol: 3, pp. 438-446, 2016.

[4] A. Pramanik, A.K. Basak, Y. Dong, P.K. Sarker, M.S. Uddin, G. Littlefair, A.R. Dixit, S. Chattopadhyaya, Joining of carbon fiber reinforced polymer (CFRP) composites and aluminum alloys: A review, *Composite Part A*. vol. 101, pp. 1-29, 2017.

[5] R. E. Murray, J. Roadman, and R. Beach, Fusion joining of thermoplastic composite wind turbine blades: Lap-shear bond characterization, *Renewable Energy*. Vol. 140, pp. 501-512, 2019.

[6] K. Panneerselvam, S. Aravindan, and A. N. Haq, Study on resistance welding of glass fiber reinforced thermoplastic composite, *Materials and Design*, vol. 41, pp. 453-459, 2012.

[7] W. E. Reitz and R. M. Oman, How to join plastics. *Advanced Materials & Processes*, vol. 158, pp. 49-52, 2000.

[8] R. Jain, S. K. Pal, and S. B. Singh. A study on the variation of forces and temperature in a friction stir welding process: an element approach, *J Manuf Process*, vol. 23, pp. 278-286. 2016.

[9] S. Inaniwa, Y. Kurabe, Y. Miyashita, and H. Hori, Application of friction stir welding for several plastic materials, *Proceedings of the 1st International Joint Symposium on Joining and Welding*, Japan, pp. 137-143, 2013.

[10] B. Vijendra, and A. Sharma, Induction heated tool assisted friction-stir welding (i-FSW): a novel hybrid process for joining of thermoplastics, *J Manuf Process*, vol. 20, pp. 234-244, 2015.

[11] M. Pirizadeh, T. Azdast, S. R. Ahmadi, S. M. Shishavan, and A. Bagheri, Friction stir welding of thermoplastics using a newly designed tool. *Materials and Design*, vol. 54, pp. 342-347, 2014.

[12] A. Paoletti, F. Lambiase, and A. D. Ilio, Optimization of friction stir welding of thermoplastics. *Procedia CIRP*. Vol. 33, pp. 562-567, 2015.

[13] S. Eslami, T. Ramos, P. J. Tavares, and P.M.G.P. Moreira, Effect of friction stir welding parameters with newly developed tool for lap joint dissimilar polymers. *Procedia Engineering*, vol. 114, pp. 199-207, 2015.

[14] S. Eslami, T. Ramos, P. J. Tavares, and P. M. G. P. Moreira, Shoulder design developments for FSW lap joint of dissimilar polymers. *Journal of Manufacturing Processes*, vol. 20, pp. 15-

23, 2015.

[15] R.S. Seth, D. S. Carl and W. N. Tracy. In Effects of friction stir welding on polymer microstructure. *ANTEC*, pp. 1078-1082, 2003.

[16] V. Jaiganesh, B. Maruthu, and E. Gopinath, Optimization of process parameters on friction stir welding of high density polypropylene plate, *Procedia Engineering*, vol. 97, pp. 1957-1965, 2014.

[17] Kusharjanta B, Raharjo WP, Triyono, Temperature comparison of initial, middle and final point of polypropylene friction stir welded, *AIP Conference Proceedings*, vol. 1717(1), 040011, 2016.

[18] F. Lambiase, A. Paoletti, A. Di Ilio, Effect of tool geometry on mechanical behavior of friction stir spot welds of polycarbonate sheets, *The International Journal of Advanced Manufacturing Technology*, vol. 88(9-12), pp. 3005-3016, 2016.

[19] A. Zafar, M. Awang, S.R. Khan, S. Emamian, Investigating friction stir welding on thick Nylon 6 plates', *Welding Journal*, Vol. 95, pp. 210.s-2018.s, 2016.

[20] R. Kumar, R. Singh, I.P.S. Ahuja, R. Penna, L. Feo, Weldability of thermoplastic materials for friction stir welding- A state of art review and future applications, *Composites Part B*. (2017). doi: 10.1016/j.compositesb.2017.10.039

[21] R. Kumara, R. Singh, I.P.S. Ahuja, Mechanical, thermal and micrographic investigations of friction stir welded: 3D printed melt flow compatible dissimilar thermoplastics, *Journal of Manufacturing Processes*, Vol. 38, pp. 387–395., 2019.

[22] H. A. Derazkola, A. Eyvazian, A. Simchi, Modeling and experimental validation of material flow during FSW of polycarbonate, *Materials Today Communications*, vol: 22, 100796, 2020,

[23] R.P. Reed, R.E. Schramm and A.F. Clark, Mechanical, thermal and electrical properties of selected polymers, *Cryogenics*, 67–82, 1973.

[24] P. J. Rae, G. T. Gray, D. M. Dattelbaum and N. K. Bourne, "The taylor impact response of PTFE (teflon)", *AIP Conf. Proc*. 706, 671, 2004. doi: 10.1063/1.1780328

[25] P.J. Rae and D.M. Dattelbaum, The properties of poly(tetrafluoroethylene) (PTFE) in compression *Polymer* 45 7615–7625, 2004.

[26] Sabry, I., Mourad, A., Thekkuden, D., Comparison of Mechanical Characteristics of Conventional and Underwater Friction Stir Welding of AA 6063 Pipe Joints, (2020) *International Review of Mechanical Engineering (IREME)*, 14 (1), pp. 64-70. doi: https://doi.org/10.15866/ireme.v14i1.17483

[27] El-Kassas, A., Sabry, I., Mourad, A., Thekkuden, D., Characteristics of Potential Sources - Vertical Force, Torque and Current on Penetration Depth for Quality Assessment in Friction Stir Welding of AA 6061 Pipes, (2019) *International Review of Aerospace Engineering (IREASE)*, 12 (4), pp. 195-204. doi: https://doi.org/10.15866/irease.v12i4.16362

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