VOL. 11, NO. 22, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ROLE OF PIN PROFILE ON MATERIAL FLOW DURING FRICTION STIR WELDING OF NYLON-6

Adeel Zafar, Mokhtar Awang, Sajjad Raza Khan and S. Emamian
Department of Mechanical Engineering, Universiti Teknologi Petronas, Bandar Seri Iskandar, Tronoh, Perak, Malaysia
E-Mail: adeel_ze@ymail.com

ABSTRACT

In friction stir welding, pin profile of the tool has a strong influence on weld quality due to its key-role in material flow. Its influence has been investigated on nylon-6 plates using three different pin profiles; threaded, square and tapered. Marker material insert technique was utilized for visual analysis of material flow of post-weld specimens. Results have shown uniform vertical stirring with symmetrical pattern for all pins either marker material is on advancing side or retreating side. Unlike metals, major role of pin profile was found in horizontal displacement in which square pin showed largest backward displacement of marker material. Moreover, no forward flow on any side (advancing or retreating side) of all pin profile was found.

Keywords: friction stir welding, pin profile, nylon-6, marker insert technique.

INTRODUCTION

The cost effective and efficient friction stir welding (FSW) process is a proven technique for welding low melting to high melting metals and polymers [1]. This solid-state thermo-mechanical joining process uses no consumables. Generally, in this process a rotating tool is plunged into the faying surfaces and then it traverses along the joining line. The frictional heat from tool plasticizes the material, whereas tool rotation along with its traversing, stir the plasticized material. Subsequently, stirred material solidifies and produces the weld [2, 3].

In the FSW process, the material flow has significant role in determining the weld quality and properties of the weld joint [4, 5]. In order to investigate the mechanism of the joints and defects formation, the material flow in FSW process must be deeply examined [6]. The material flow can be influenced by pin profile of the tool, welding speed, rotation rate and tilting of the tool [7]. The pin geometry plays key role in material flow and eventually the quality of weld [8].

Currently, the focus of reported studies in FSW is mostly on the workpiece material, mechanical and microstructural behaviors of the weldment. The reported work on the role of pin profile in material flow during FSW of materials, particularly polymeric materials, is not fully understood. So far the approaches to explore the material flow include; 'the visualization of material flow using dissimilar materials weld', 'marker insert technique' and 'stop action' [7]. Colegrove *et al*. [9] modelled the flow mechanism during FSW using CFD. They used triflute and trivex tool for flow model. Zhao *et al*. [7] used straight cylindrical, tapered and tapered with threads pin profiles to study the role of pin profile in flow. They reported asymmetrical flow during the process with significant difference of flow on advancing side (AS) and retreating side (RS). Kumar *et al*. [10] have reported the influence of pin and shoulder in flow and weld formation.

In the present work, marker insert technique is used to investigate the material flow by different pin profiles in nylon-6 FSW. In order to understand and compare the flow process of different pin profiles, specimens have been sectioned in different ways and their visual analysis is performed.

MATERIALS AND METHOD

The materials used in this experiment were 10 mm thick nylon-6 plates. The marker material used was carbon nanotube (CNT) in powder form. It was chosen due to its wide application as a filler material [11]. After the welding, CNT will provide large contrast with the matrix material. Three different pin profiles namely square, threaded and tapered were utilised with the aim to observe the role of pin profile in stirring phenomenon. Three different tool profiles used in this study are shown in Figure-1. The detail of the tools is listed in table 1. The experiments were conducted at the optimum set of parameters as reported by Zafar *et al*. [12]. It was 300 RPM rotation rate, 25 mm welding speed and 0-degree tilt angle.

Figure-1. Tools with different pin profiles.

Table-1. Pin geometry of tools.

No.	Description	Size	Pitch
1	Square Pin	7.5 mm diagonal	No pitch
2	Threaded Pin	7.5 mm diameter	1 mm pitch
3	Taper Pin	7.5 mm big,4 mm small diameter	No pitch

VOL. 11, NO. 22, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

In order to visualize the flow phenomenon in all directions (x, y and z-axis), marker insert technique was designed. For this purpose, 1 mm holes were drilled at faying and top surfaces of workpieces, and filled with CNT powder as shown in Figure-2. The hole at faying surfaces is the horizontal placement of marker material, whereas hole at top surfaces is the vertical placement of marker material. The horizontal placement of marker material was at 4 mm down (at center of pin length) from upper surface as shown schematically in Figure-2 (a-d).

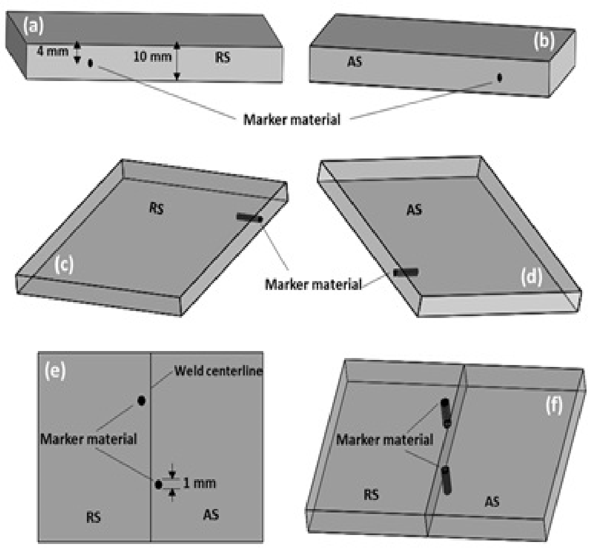


Figure-2. (a-d) Different views of horizontal placement of marker material, (e, f) Different views of vertical placement of marker material.

Vertical holes with depth equivalent to pin length (8 mm), were placed 2 mm away from weld center line. It is schematically illustrated in Figure-2 (e) and (f). Vertical placement was designed to observe horizontal flow and horizontal placement was chosen to see the vertical flow. In order to examine the flow variation on AS and RS, a total of two markers one on AS and the other one on RS were placed on each welding sample.

RESULTS AND DISCUSSION

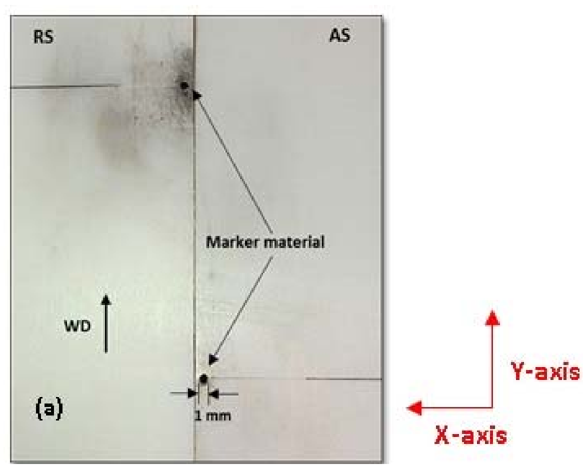
Pin profile has significant effect on the weld quality of friction stir welded specimens [13, 14]. Its investigation can be useful to understand the defects formation and hence to improve pin design [15]. The plasticized material can flow in horizontal or/and vertical direction. Various sections of specimens are cut to examine the flow.

Horizontal flow analyses

Figure-3 (a) shows the specimen before welding which contains marker material (CNT powder) on AS and RS. After welding, specimens were horizontally sectioned. The horizontal sections of welded specimens are shown in Figure-3(b-g). These horizontal sections were visualized to understand the flow in x and y-directions. The arrow signs on workpieces indicate the original position of marker material. The sectioned specimens clearly indicate some general material flow pattern. Marker material is displaced behind the pin and no forward displacement is seen, either it is on AS or RS. Pin-driven material flows layer by layer to make the weld. All the pin profiles showed an oval shape of marker material which indicates its independency on pin profile and can be attributed to rotation of pin.

The horizontal movement of material can be studied in x-direction and y-direction. X-direction is perpendicular to welding direction (WD), whereas, y direction is parallel to welding direction. For x-direction flow, Figure-3 indicates that the 1 mm diameter marker material spread to 7.5 mm width for each pin profile. This 7.5 mm width is equal to pin diameter. It was symmetrical, either marker materials is on AS or RS. This observation indicates the uniform mixing of stirred material during the welding process.

The horizontal flow in y-direction can be described in terms of marker material displacement from its original position (indicated by arrow) to final position. A large backward displacement by all three pin profiles is observed. However, the size of this displacement varies with pin profile. Square pin profile showed the highest displacement with length equal to 12 mm, threaded pin has 9 mm displacement, whereas tapered pin showed 8 mm displacement which is slightly higher than pin diameter. The displacement by square and taper pin profiles is much larger than the pin diameter. This observation leads to force phenomenon produced by pin of the tool. It is believed that higher backward force can reduce the blow holes and voids by closely packing the displaced material layer. Apparently, square pin profile did not show blow holes or voids, however lack of bonding and flash formation at RS is found. The same reason that tapered pin specimens, shown in Figure-3 (f, g) show voids with poor surface morphology. The farthest displacement by square pin can be attributed to flat surfaces on pin profile, which can apply large force compared to circular pin profile.



VOL. 11, NO. 22, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

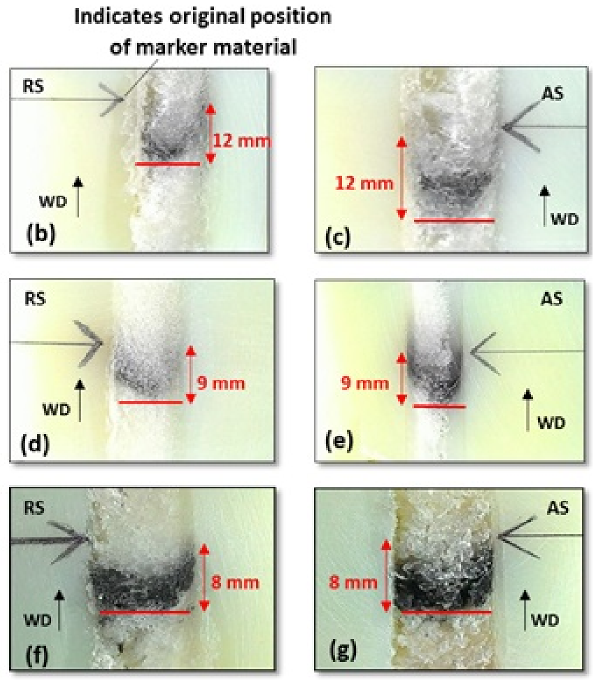


Figure-3. (a) Marker material placement-before welding, (b, c) Marker material displacement after welding by Square (d, e) Threaded and (f, g) Tapered pin profile.

Threaded pin, due to increased surface area generates higher heat input which plasticizes the material [16]. This plasticized material is easily displaced far-off by pin. Zhao *et al*. [7] also have mentioned the influence of threads on higher heat generation and displacement. The horizontal flow of material can be summarized as:

- In all pin profiles no forward movement of marker material, either it is on AS or RS is observed.
- All the specimens showed backward movement of marker material. Therefore, material is displaced behind the pin.
- Oval shape of displaced marker material is found for all tools.
- Considering the x-direction flow, it was found that marker material, either it is on AS or RS, spreaded in complete welding zone which was equivalent to pin diameter in size. It was symmetrical for all three pin profiles.
- The major difference in flow of three pin profiles is found in the length of backward displacement of marker material. Square pin profile showed highest backward displacement of marker material which is almost 12 mm. Threaded pin tool gave 9 mm backward displacement, whereas taper pin tool showed 8 mm backward displacement.

Vertical flow analyses

In order to analyze the vertical flow of the workpiece, the marker material was placed in horizontal drilled holes at faying surface of the workpieces. Holes were drilled 4 mm down (at center of pin length) from surface. This placement was made on both sides, AS and RS. Specimen before welding is shown in Figure. 4 (a, b). Post-weld specimens were sectioned vertically at the joining line. Sectioned specimens are shown in Figure. 4(c-h). From visual analysis of specimens, it is clear that marker material spreaded all over the pin-plunged zone in each pin profiles. And this vertical flow pattern was almost the same for AS and RS specimen. Unlike metals, it is found that stirring remained limited until the pin plunged zone and no flow from pin plunged zone to base material was found. It is due to thermal insulator nature of polymer which limits the spreading of heat to pin-plunged zone. On the other hand, vertical spreading of marker material indicates the vertical stirring of material which is essential for uniform mixing.

The vertical flow of material can be summarized as:

- The spreading of 1 mm wide marker material in 8 mm long pin-plunged zone indicates the vertical uniform mixing of material. This observation was symmetrical for all pin profiles on AS and RS.
- No cross flow of material from pin plunged zone to base material was found in any pin profile.

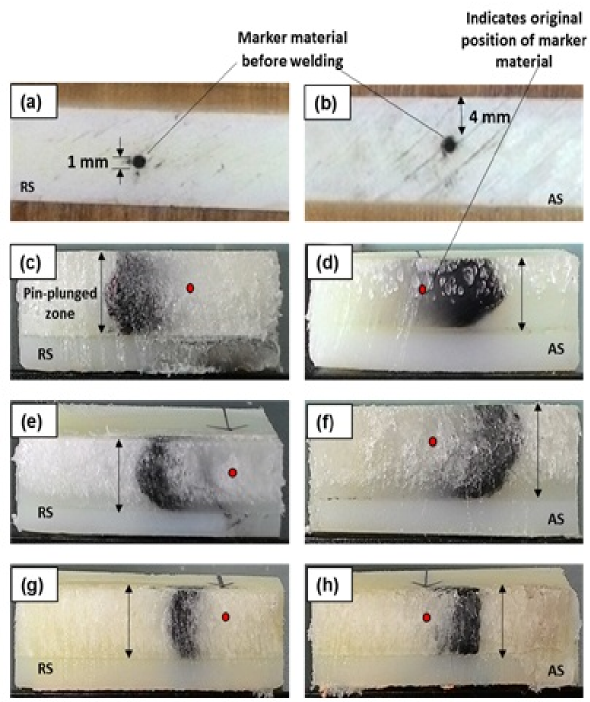


Figure-4. (a, b) Marker material placement-before welding, vertical displacement of marker material after welding by (c, d) Threaded pin (e, f) Square pin (g, h) Tapered pin.

CONCLUSIONS

The role of pin profile on material flow has been investigated using marker insert technique. Three widely used pin profiles, square, threaded and tapered have been employed on nylon-6 plates at optimum set of parameters.

From visual analysis of displaced marker material, it was found that material flow in polymers is significantly different from metals. Obtained results can be concluded as;

- 4 mm up and 4 mm down vertical spreading of 1 mm diameter marker material from its original position (center of pin length) indicates the uniform vertical stirring. It was found symmetrical in all pin profiles.
- The absence of cross flow from pin plunged zone to base material at the tip of pin differentiate it from flow in metals.
- All three pin profiles showed backward displacement of marker material and no forward flow on any side (advancing or retreating side) was found.
- Square pin profile showed highest backward displacement of marker material, which indicates that square pin applies higher force at same parameters when compared to threaded and tapered pin.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of Universiti Teknologi Petronas through Graduate Assistantships.

REFERENCES

[1] P. Vilaça and W. Thomas, "Friction stir welding technology," in Structural Connections for Lightweight Metallic Structures, ed: Springer, 2011, pp. 85-124.

[2] R. S. Mishra and M. W. Mahoney, Friction Stir Welding and Processing: ASM International, 2007.

[3] R. Fonda, A. Reynolds, C. Feng, K. Knipling, and D. Rowenhorst, "Material flow in friction stir welds," Metallurgical and Materials Transactions A, vol. 44, pp. 337-344, 2013.

[4] O. Lorrain, V. Favier, H. Zahrouni, and D. Lawrjaniec, "Understanding the material flow path of friction stir welding process using unthreaded tools," Journal of Materials Processing Technology, vol. 210, pp. 603-609, 3/1/ 2010.

[5] Y. Morisada, H. Fujii, Y. Kawahito, K. Nakata, and M. Tanaka, "Three-dimensional visualization of material flow during friction stir welding by two pairs of X-ray transmission systems," Scripta Materialia, vol. 65, pp. 1085-1088, 2011.

[6] Z. Chen, T. Pasang, and Y. Qi, "Shear flow and formation of Nugget zone during friction stir welding of aluminium alloy 5083-O," Materials Science and Engineering: A, vol. 474, pp. 312-316, 2008.

[7] Y.-H. Zhao, S.-B. Lin, F.-X. Qu, and L. Wu, "Influence of pin geometry on material flow in friction stir welding process," Materials science and technology, vol. 22, pp. 45-50, 2006.

[8] F. Gratecap, M. Girard, S. Marya, and G. Racineux, "Exploring material flow in friction stir welding: Tool eccentricity and formation of banded structures," International journal of material forming, vol. 5, pp. 99-107, 2012.

[9] P. A. Colegrove and H. R. Shercliff, "3-Dimensional CFD modelling of flow round a threaded friction stir welding tool profile," Journal of Materials Processing Technology, vol. 169, pp. 320-327, 11/10/ 2005.

[10] K. Kumar and S. V. Kailas, "The role of friction stir welding tool on material flow and weld formation," Materials Science and Engineering: A, vol. 485, pp. 367-374, 6/25/ 2008.

[11] R. F. Zinati and M. R. Razfar, "Finite element simulation and experimental investigation of friction stir processing of Polyamide 6," Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 229, pp. 2205-2215, 2015.

[12] A. Zafar, M. Awang, S. R. Khan, and S. Emamian, "Effect of Double Shoulder Tool Rotational Speed on Thermo-Physical Characteristics of Friction Stir Welded 16mm Thick Nylon6," Applied Mechanics and Materials Journal, vol. 799-800, pp. 251-255, 2015.

[13] Y. Chen and K. Nakata, "Effect of tool geometry on microstructure and mechanical properties of friction stir lap welded magnesium alloy and steel," Materials & Design, vol. 30, pp. 3913-3919, 2009.

[14] S. Vijay and N. Murugan, "Influence of tool pin profile on the metallurgical and mechanical properties of friction stir welded Al–10wt.% TiB 2 metal matrix composite," Materials & Design, vol. 31, pp. 3585-3589, 2010.

[15] C. Leitão, R. Leal, D. Rodrigues, P. Vilaça, and A. Loureiro, "Material flow in friction stir welding," Microscopy and Microanalysis, vol. 14, pp. 87-90, 2008.

[16] M. Ilangovan, S. R. Boopathy, and V. Balasubramanian, "Effect of tool pin profile on microstructure and tensile properties of friction stir welded dissimilar AA 6061–AA 5086 aluminium alloy joints," Defence Technology, vol. 11, pp. 174-184, 2015.