International Journal of the Physical Sciences Vol. 6(19), pp. 4595-4601, 16 September, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.866
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Effects of friction stir welding process parameters on appearance and strength of polypropylene composite welds

G. H. Payganeh, N. B. Mostafa Arab*, Y. Dadgar Asl, F. A. Ghasemi and M. Saeidi Boroujeni

Faculty of Mechanical Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran.

Accepted 29 July, 2011

Friction stir welding is a solid-state joining process that has gained acceptable progress in recent years. This method which was first used for welding of aluminum and its alloys is now employed for welding of other materials such as polymers and composites. In this article, friction stir welding has been used for butt joining polypropylene composite plates having 30% glass fiber by weight. The effects of important process parameters such as tool pin geometry, tool rotational speed, work linear speed and tool tilt angle on weld appearance and tensile strength were investigated experimentally. Different tool pin geometries were used to find their effects on weld quality. Using the tool pin which produced the best weld quality, the effects of other process parameters on weld quality were also investigated. The results indicated that tool pin geometry had a significant influence on weld quality and the effects of rotational speed and tilt angle on weld appearance and strength were more than that of work linear speed.

Key words: Friction stir welding, polypropylene composite, glass fiber, weld appearance, tensile strength.

INTRODUCTION

Friction stir welding (FSW) is a solid-state joining process which welds the materials whose characteristics must remain unchanged as far as possible. Unweldable and weldable alloys can be joined by this process without melting and recasting (Shinoda, 2001). Welding defects such as porosity and hot cracking are not an issue in FSW and joints with low residual stresses, improved dimensional stability, good mechanical properties and high surface finish are produced which require no post weld cleaning (Barcellona et al., 2006; Kallee and Mistry, 1999; Dickerson and Pryzdate, 2003). Absence of toxic fumes and spatter of molten material increases FSW safety. Because of the absence of weld pool and consumable requirements, such as, shielding gas and filler material, welding operation in all positions is possible. Important FSW process parameters are tool rotational speed, work linear speed, axial force, and tilt angle. A number of research works have been reported to study the effects of the above parameters on material flow, microstructure formation and mechanical properties of FSW joints for metals and composites (Saeid et al., 2008; Ren et al., 2007; Cavaliere et al., 2006, 2008; Abbasi et al., 2006; Amirizad et al., 2006). The effects of process parameters, TiC percentage, and tool profile on ultimate tensile strength (UTS) of aluminium matrix composite were investigated and it was found out that the welding speed and tool pin profile had the most significant influence on UTS (Gopalakrishnan and Murugan, 2011). Kumbhar et al. (2011) investigated the microstructure of the FSW of aluminum alloy AA5052 in four regions of base material, nugget, advancing side and retreating side and reported that most of the specimens fractured away from the nugget and showed ductile mode of failure. Sundaram and Murugan (2010) investigated the tool pin profile, tool rotational speed, welding speed, and tool axial force influence on UTS and tensile elongation of dissimilar FSW of aluminum alloys 2024- T6 and 5083-H321. Vijay and Murugan (2010) studied the effect of tool pin profile on metallurgical and mechanical

*Corresponding author. E-mail: n.arab@srttu.edu.

Abbreviations: UTS, ultimate tensile strength; **FSW,** friction stir welding; **GF,** glass fibre; **pp,** polypropylene.

Table1. Characteristics of the raw material.

Polypropylene	GF (Wt.%)	Ultimate strength (MPa)	Elongation (%)
Base	30	35	2

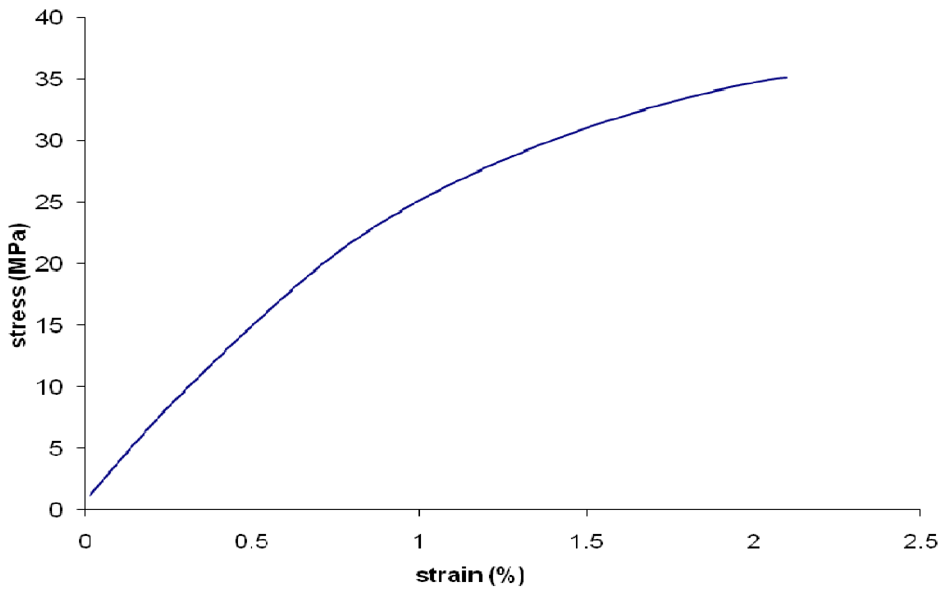

Figure 1. Stress-strain curve for the raw material.

properties of friction stir welded Al–10 wt.%TiB_2 metal matrix composites and concluded that joints welded with straight square pin profile had better mechanical properties compared to other pin profiles.

Polypropylene (pp) and pp composites are commonly joined by some of the welding or bonding techniques (Rudolf et al., 1999; Maguire, 1989; Yousefpour et al., 2004). Kiss and Czigany (2007) studied the FSW of PP and found out that the strength of weld area is less than 50% of the original material and weld area toughness is higher than the farther areas. They explained this behavior by considering the distribution of generated heat at the weld line and regions around it which causes non-uniform crystallization rate of material in these regions. Scialpi et al. (2007) used titanium tool for FSW of PP extruded sheets and compared it with that of common welding methods such as hot gas welding and extrusion. They concluded that mechanical properties of the welds and the welding speed of FSW are higher than the other two methods. Considering the research works done on pp composites, it is observed that a serious lack of published report regarding their weldability by FSW exists. Due to this, in the present research work, a study is carried out to assess FSW of PP composites with 30% glass fibre (GF). The effects of several FSW parameters such as tool pin geometry, tool rotational speed, work linear speed and tool tilt angle on weld appearance and tensile strength of this composite are also investigated.

MATERIALS AND METHODS

Parent material

PP composite plates with 30% random chopped or particle GF and 100 mm × 50 mm × 5 mm size with characteristics given in Table1 and Figure 1 were used as the raw material.

FSW tools

The rotating tools were made of heat treated steel. In order to study the tool geometry effect on weld appearance and strength, four different friction stir tools with different pins and shoulders were used and experiments conducted. Details of these tools are shown in Figure 2 and Table 2. The shoulder diameter and pin length of the tools were 15 and 4.8 mm, respectively as dictated by thickness of plates.

Welding procedure

Square-butt joint configurations were prepared to weld the plates. The plates were welded on a vertical milling machine along their length after fixing them in a proper position using mechanical clamps.

This research work was carried out in two stages. In the first stage, tools with different pin geometries and their effects on weld appearance and strength were studied to select the tool which produces better welds. For this phase of the work, a number of trial runs were conducted and the tool rotational and work linear speed and tilt angle were selected to be 500, 12 mm/min. and 1° respectively. In the second stage, the selected tool was used to

Figure 2. FSW tools with different pins and shoulders.

Table 2. Different pin geometries of friction stir tools.

Tool #	Description of pin geometry	Large diameter of pin (mm)	Small diameter of pin (mm)
1	Taper pin with groove	5	3
2	Triangle pin with screw thread	5	5
3	Triangle pin	5	5
4	cylindrical pin with groove	5	5

Table 3. Range of FSW parameters.

Rotational speed (rev./min.)	Work linear speed (mm/min.)	Tilt angle (degree)
400	8	0
630	16	1
1000	20	2

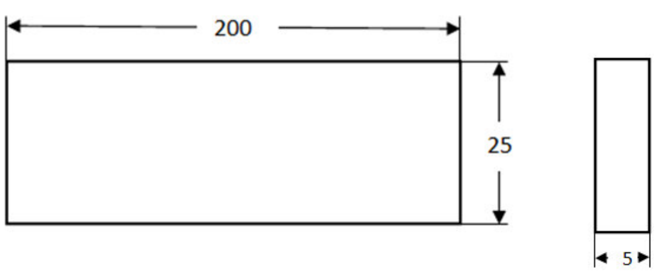

Figure 3. Tensile test specimens geometry and dimensions (mm).

carry out extra trial runs to establish range of FSW parameters given in Table 3 to investigate the effects of other process parameters (tool rotational speed, work linear speed and tool tilt angle) on weld tensile strength.

Tensile test specimen preparation

The tensile test specimens whose dimensions are given in Figure 3 were prepared according to ASTM (2002) from the middle of the welded plates to eliminate the start and end effects of the welding process.

RESULTS AND DISCUSSION

Effect of tool geometry on weld appearance

Weld appearance is one of the important characteristics of a high quality weld whose properties must be similar to the base material as much as possible. Figure 4 shows the surface appearance of welds made with different friction stir tools. The visual examination of these welds shows that the best weld appearance was obtained using friction stir tool # 1 (taper pin with groove). The welds produced by this tool had a clean appearance with uniform width, and no obvious surface defects could be found. This feature of the weld may be because of larger contact surface between this tool and the plates which causes more frictional heat. The higher generated heat

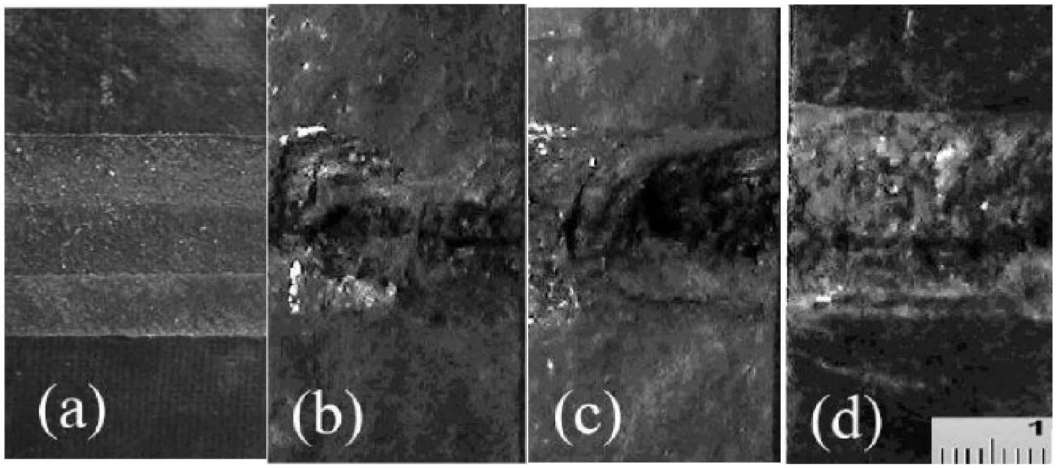

Figure 4. Weld surface appearance with different tools: (a) tool # 1, (b) tool # 2, (c) tool # 3, (d) tool # 4.

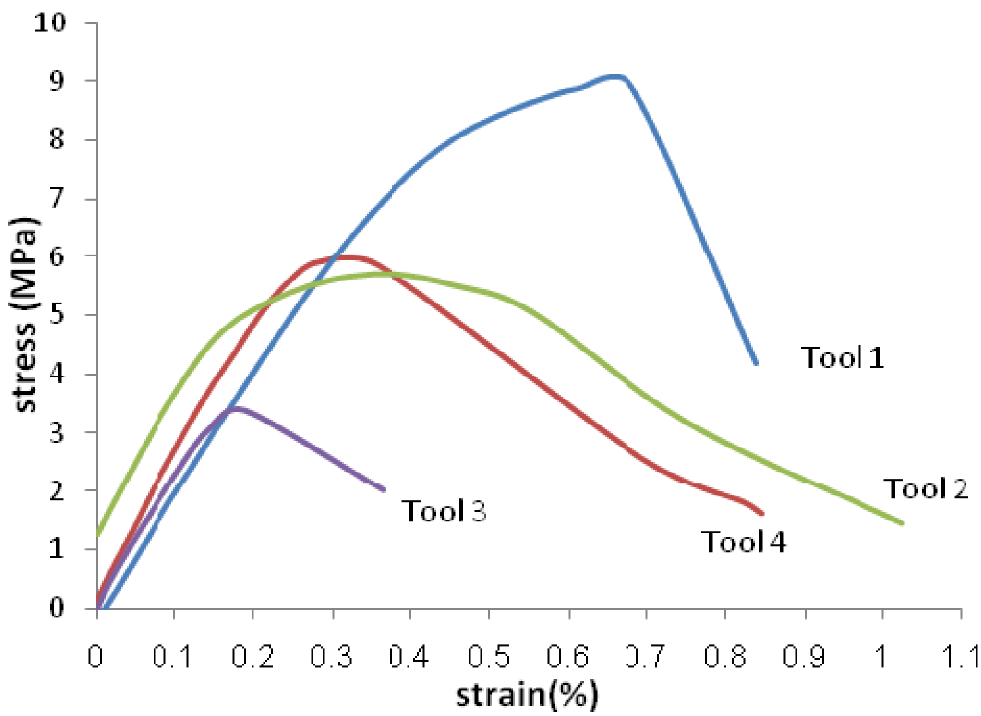

Figure 5. The tensile test results.

and better mixing of the material through the weld may be the reasons for better surface appearance. Tool # 3 which has a pin of triangular cross section contacts the workpiece at only three edges or points and therefore generates lowest frictional heat and consequently lowest stirring and mixing of the weld. Tool # 2 which has a pin of triangular cross section with screw thread stirs the weld better than tool # 3 and causes a better weld surface appearance. Similarly, the contact surface of tool # 4 with the workpiece is more than that of tools # 2 and # 3, therefore the higher frictional heat generated results in better blending of the weld material and hence better weld surface appearance is obtained by this tool.

Effect of tool geometry on tensile strength

The effects of different tool pin geometries on tensile strength of friction stir welds are compared with the help of stress-strain curves shown in Figure 5. All the tensile test specimens fractured from the weld zone as shown in Figure 6 indicating this zone is the weakest part of the

Figure 6. The tensile test fractured specimen.

Figure 7. Tunnel defect in stir zone.

joint.

Figure 5 shows that the UTS of the weld made by tool # 1 is about 9 MPa which is almost 25% of the UTS of the parent PP composite. Welds produced by other tools were much weaker in strength than the weld produced by tool #1. The same argument mentioned earlier for better weld surface appearance when welding with tool #1 could also be one of the reasons for higher tensile strength of welds with this tool. The presence of surface and probably subsurface defects, such as tunnel defects shown in Figure 7 may be the other reasons for lower tensile strength of welds made by other tools.

Effect of process parameters on tensile strength

In order to study the welding process parameters effects on tensile strength of the joints, tool # 1 which produced better welds was used.

Figure 8 shows the effect of tool rotational speed on tensile strength of the joints. The maximum UTS of about 7 MPa was obtained at the tool rotational speed of 630 rev./min.

With the rotational speed of 400 rev./min, the wormhole phenomenon at the retreating side of the weld due to insufficient frictional heat generation and insufficient matrix transportation which is reported by Lakshminarayanan and Balasubramanian (2008), may be the reason for lower strength of the joint. The lower strength of the joint with the rotational speed of 1000 rev./min., can be a result of the tunnel defect (Figure 7) formed. The formation of this defect may be attributed to excessive turbulence of the weld caused by high tool rotational speed. Therefore, with the rotational speed of 630 rev./min., a just sufficient amount of frictional heat is generated which with proper turbulence of the weld results in the highest tensile strength.

The effect of work linear speed on tensile strength of the joints is not significant as shown in Figure 9. This is more obvious especially at speeds higher than 16 mm/min. When the linear speed is increased from 8 to 16 mm/min., the tensile strength decreases with a sharp slope compared to the speed between 16 and 20 mm/min. The excessive heat input per unit length of the weld at higher linear speeds and inadequate flow of the matrix which may cause tunnel defect could be the factors contributing to lower strength of the joints at higher linear speeds

The influence of tool tilt angle on tensile strength of the welds is illustrated in Figure 10. Tilt angle affects the vertical and horizontal flow of the weld material. Improper tilt angle may cause tunnel and crack-like defects in the welds. At 0° tilt angle, the insufficient vertical and horizontal flow of the weld material may cause these defects that reduce the strength of a weld. Increasing the tilt angle, improves the flow characteristics of the weld

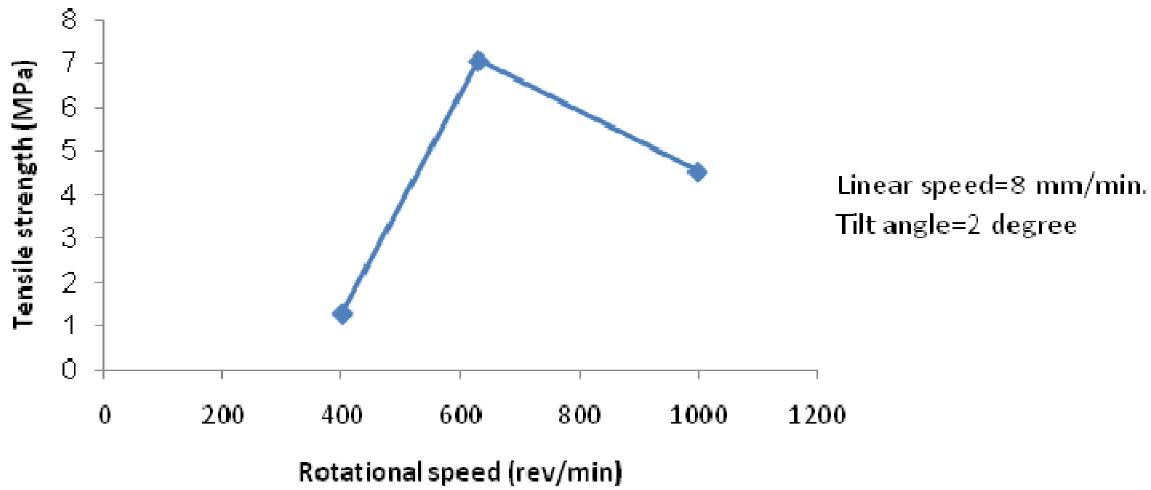

Figure 8. Effect of rotational speed on tensile strength.

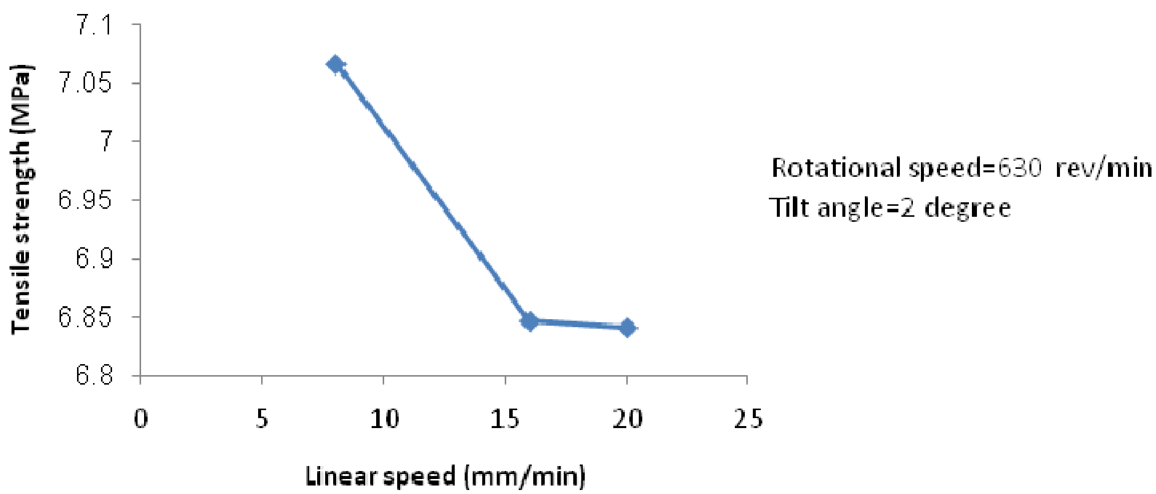

Figure 9. Effect of linear speed on tensile strength.

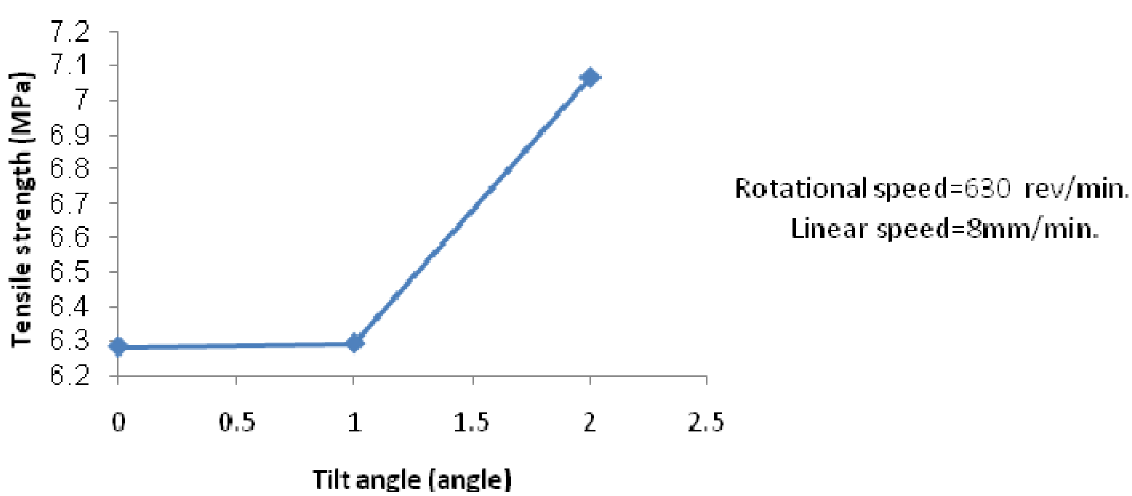

Figure 10. Effect of tilt angle on tensile strength.

material and hence, tool movement forges the weld material better to fill the defects and consequently increases the weld strength.

Conclusions

In this paper, pp composite plates with 30% GF were welded using FSW process. The effect of tool pin geometry on weld appearance and tensile strength was first investigated experimentally to select a proper tool design to produce quality welds. The effects of tool rotational speed, work linear speed and tool tilt angle on tensile strength of the welds were also studied. The results indicated that:

1. Although the tensile strength of the welded specimens was about 9 MPa which is almost 25% that of the base plate, the FSW process can be employed to weld pp composites with 30% GF. Further research is recommended in this respect.
2. The tool pin geometry had a significant effect on weld appearance and tensile strength.
3. Increasing the tool rotational speed had an increasing and then a decreasing effect on weld tensile strength. The tool rotational speed of 630 rev./min. produced the strongest weld.
4. Increasing the work linear speed from 8 to 20 mm/min. had a decreasing effect on tensile strength.
5. Tensile strength of the welds increased when tilt angle was changed from 0 to 2˚.

ACKNOWLEDGMENTS

This work was supported by a grant from Shahid Rajaee Teacher Training University.

REFERENCES

Abbasi GM, Kokabi AH, Daneshi GH, Shalchi B, Sarrafi R (2006). The influence of the ratio of ''rotational speed/traverse speed'' (o/v) on mechanical properties of AZ31 friction stir welds. Int. J. Mach. Tools Manufact., 46: 1983–1987.

Amirizad M, Kokabi AH, Abbasi Gharacheh M, Sarrafi R, Shalchi B, Azizieh M (2006). Evaluation of microstructure and mechanical properties in friction stir welded A356+15%SiC cast composite. Mater. Lett., 60: 565–568.

ASTM Standard D 3039 (2002). Standard test method for Tensile Properties of Polymer Material. Annual book of ASTM standard, p. 15.03.

Barcellona A, Buffa G, Fratini L, Palmeri D (2006). On microstructural phenomena occurring in friction stir welding of aluminum alloys. Mater. Proc. Technol., 177: 340-343.

Cavaliere P, Squillace A, Panella F (2008). Effect of Welding Parameters on Mechanical and Microstructural Properties of AA6082 Joints Produced by Friction Stir Welding. J. Mater. Proc. Technol., 200: 364–372.

Cavaliere P, Campanile G, Panella F, Squillace A (2006). Effect of Welding Parameters on Mechanical and Microstructural Properties of AA6056 Joints Produced by Friction Stir Welding. J. Mater. Proc. Technol., 180: 263–270.

Dickerson TL, Pryzdatek J (2003). Fatigue of friction stir welds in aluminium alloys that contain root flaws. Int. J. Fat. 25 (12): 1399-1409.

Gopalakrishnan S, Murugan N (2011). Prediction of tensile strength of friction stir welded aluminium matrix TiC particulate reinforced composite, Materials and Design, 32: 462–467.

kallee SW, Mistry A (1999). Friction stir welding in the automotive body in white production. 1st International Symposium on Friction Stir Welding Thousand Oaks, pp. 14-16.

Kiss Z, Czigany T (2007). Applicability of friction stir welding in polymeric materials. Per. Pol. Mech. Eng., 51/1, 15-18.

Kumbhar NT, Sahoo SK, Samajdar I, Dey GK, Bhanumurthy K (2011). Microstructure and microtextural studies of friction stir welded aluminum alloy 5052. Materials and Design, 32: 1657–1666.

Lakshminarayanan AK, Balasubramanian V (2008). Process parameters optimization for friction stir welding of RDE-40 aluminum alloy using Taguchi technique. Trans., Nonferrous Met. Soc. China, 18: 548-554.

Maguire DM (1989). Joining Thermoplastic Composites. SAMPE J., 25: 11–14.

Ren SR, Ma ZY, Chen LQ (2007). Effect of welding parameters on tensile properties and fracture behavior of friction stir welded Al–Mg–Si alloy. Scripta Materialia, 56: 69–72.

Rudolf R, Mitschang P, Neitzel M, Rueckert C (1999). Welding of High-PerformanceThermoplastic Composites. Polymer and Polymer Composites, 7: 309–315.

Saeid T, Abdollah zadeh A, Assadi H, Malek Ghaini F (2008). Effect of friction stir welding speed on the microstructure and mechanical properties of a duplex Stainless steel. Mater. Sci. Eng., 496: 262–268.

Scialpi A, Troughton M, Andrews SL (2007). In-Line Reciprocating Friction Stir welding of Plastics. Joining Plastics Magazine, p.1.

Shanmuga Sundaram N, Murugan N (2010).Tensile behavior of dissimilar friction stir welded joints of aluminium alloys. Materials and Design, 31: 4184–4193.

Shinoda T (2001). Recent development of friction stir welding - new solid-state joining technology. Int. J. Mater. Prod. Technol., 2: 453–460.

Vijay SJ, Murugan N (2010). Influence of tool pin profile on the metallurgical and mechanical properties of friction stir welded Al–10 wt.% TiB2 metal matrix composite. Materials and Design, 31: 3585–3589.

Yousefpour A, Hojjati M, Immarigeon JP (2004). Fusion bonding/welding of thermoplastic composites. J. Thermoplast. Compos. Mater., 17: 303–341.