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Procedia Engineering 38 (2012) 3927 – 3940

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Modeling, Optimization and Computing (ICMOC 2012)

Investigation on Effect of Tool Forces and Joint Defects During FSW of Polypropylene Plate

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Abstract

Friction Stir Welding (FSW) is a solid-state method of joining thermoplastic materials. In this investigation, an attempt was made to join the polypropylene plate of 10 mm thickness with different tool pin profiles (square, triangular, threaded and grooved with square pin profile). During FSW, Forces acting on the tool along the travel distance and defects occurred in the joints are observed with respect constant rotational speed and different welding feeds. From this investigation, it is found that the joint fabricated using threaded pin profile tool produce less amount of force and square, triangular & grooved with square pin profile produced defect free welds.

*Keywords:*FSW; polypropylene; tool pin profiles

1. Introduction

Friction stir welding (FSW) is a novel solid-state welding process for the joining of metallic alloys and composites; it is the numerous applications in manufacturing situations [1, 2].

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doi:10.1016/j.proeng.2012.06.450

FSW considered to be one of the most significant welding processes, FSW has the advantage of non-consuming fabrication of continuous linear welds, the most common form of weld joint configuration. This joining technique is energy efficient, environmentally friendly and versatile [3]. In general, the process is carried out by plunging a rotating FSW tool into the interface of two rigidly clamped sheets, until the shoulder touches the surface of the material being welded, and transverse along the weld line. The frictional heat and deformation heat are utilized for the bonding under the applied normal force [4]. The primary heat source is frictional heat from tool shoulder and secondary heat source is deformation heat from the tool pin [5]. This process is illustrated in fig.1. The spindle speed and feed rate are the most significant factors that determine the tool temperature [6, 7]. The yield and tensile strengths as well as elongation are decreased after FSW [8] due to recrystallization effects in the weld zone [9]. Most of the literature on FSW focuses on aluminium alloys; however, recently interest has grown in applying this technique to the joining of thermoplastic materials. Currently, there is no report in the literature on the study of the tool pin profile on polymers after FSW [10]. This paper addresses this gap of a study on the effects of process parameters such as welding speed and tool pin profile. In this research, the effect of tool pin profiles and feeds are analyzed over the tool force and joint defects.

2. Experimental procedure

FSW was performed on samples that were held using a specially designed clamping fixture that allowed the samples to be fixed on to a CNC vertical machining center for welding and specification is given in table 1. The samples used in this work consisted of two 220x95x10mm (length, width, depth) polypropylene sheets. Square butt joint configuration, was prepared to fabricate FSW joints. The initial joint configuration was obtained by securing the plates in position using clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the joints.

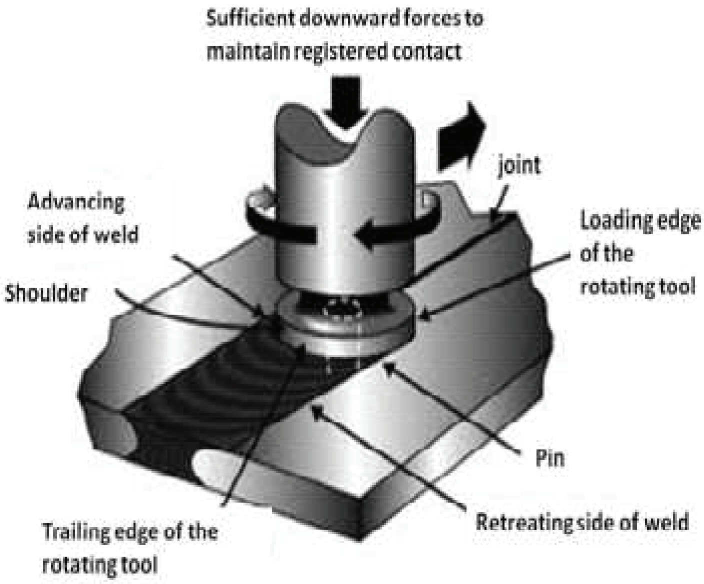

Fig.1.The FSW process

Table 1 Specifications of CNC vertical machining center

S.No.	Specifications	Values
1	Table size	810x400mm
2	Travel X-axis	510mm
	Y-axis	400mm
	Z-axis	400mm
3	Spindle speed	60-8000rpm
4	Maximum force in X-axis(Linear force)	4000 N
	Y-axis(crosswise force)	4000 N
	Z-axis(vertical force)	4000 N
5	Feed	1-7000mm/min
6	Spindle motor power	7.5Kw

The non-consumable rotating tools (shown in fig.2) used in this study had six different tool pin profiles (Straight pin, Square pin, Grooved with square pin, Taper pin, Triangular pin, and Threaded pin) and a cylindrical shank. The fixed pin type tool made in mild steel with a nominal pin diameter 6mm and shoulder diameter of 24mm was used in the present investigation. Various nomenclature of tool is shown in fig.3. Details of friction stir welding conditions are shown in table 2.

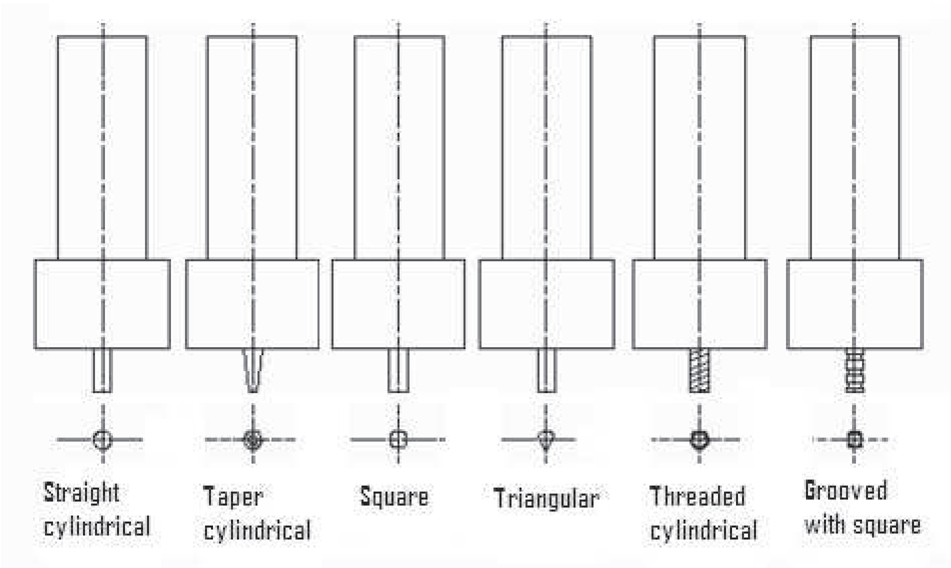

Fig.2. Different types of tool pin profiles used in this investigation

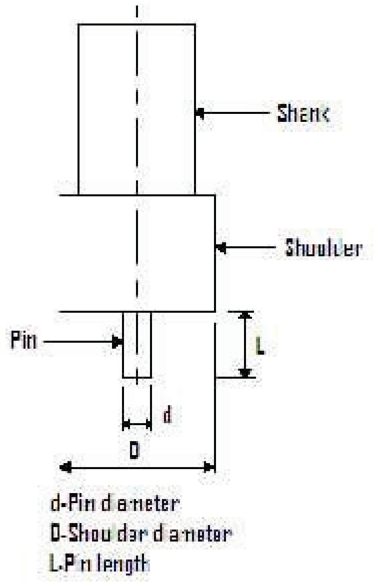

Fig. 3 Various nomenclature of FSW tool

Table 2
Welding parameters selected in the present study for the friction stir welding of polypropylene materials

	Level -1	Level -2	Level-3	Level-4	Level-5	Level-6
Tool pin profile	Threaded	Grooved with square	Square	Triangular	Straight	Taper
Welding Feeds (mm/min)	15	30	45	60		
Travel Distance (mm)	50	100	150	200		

After clamping the samples, the rotating tool pin was inserted into the butt line of the parts and the tool was driven downward until the shoulder face contacted the surface of the parts. After the shoulder dwell time for preheating and softening of the material, the tool was traversed along the joint line. The tool was removed when it reached the end of the line and a hole was thus created at the end of the butt line. The different tool pin profiles were used in the reported experiments. There was no need to apply cooling or cleaning procedures since the tool rapidly cooled in the air and no chips or flashes were produced in the process. Trial experiments were carried out as per designed parameter given in Table 2. For the designed parameters the observed results were present in the Table 3.

3. Result and discussion

Table 3 shows the different linear force values at corresponding feed rate. In this study, took the 210mm length of plate and the force value was observed at step of 10mm distance along the weld line. Normally, the vertical force (Z-axis) and transverse forces (X & Y-axis) were not much changed at the period of tool traveling times and those were changed between 10% and 20% of the force of the machine in the corresponding directions. But, the linear force variation depends upon the tool pin profiles. At lower speeds by means of less than 1000rpm insufficient heat is created and thus the polymer does not soften enough to make a strong weld and fusion does not occur at the root and walls of the weld. At very high rotational speeds by means of more than 2500rpm the flow of the softened material cannot be controlled and thus instead of being squeezed into the sides of the seam weld the melt is ejected from the butt line. A rotational speed in between 1500rpm and 2500rpm appears to be a good compromise between generating enough heat and excessive flow of softened polymers. So, 1500rpm was taken as spindle rotation speed for this investigation.

Fig 4 and fig 5 shows the effects of the force for straight and taper pin profile at different feed rate for entire tool travel distances. Normally, straight pin profile produce more force for all feed rate compared with other tool pin profiles. Linear force produced by straight pin tool does have much variation compared between initial and final condition. Taper pin profile was somewhat similar to the traight pin profile. Same findings were occurred in taper pin profile but linear force requirement was just less compared with straight pin profile and any other changes not occurred in this profile.

Here, straight pin and taper pin profiles were mostly broken in starting of second trail operation after completion of previous one because of the over force at welding time in the linear direction as shown the fig 6. some amount of materials threw out through the shoulder of the tool. So, pin created the concave shape of the weld butt line as shown the fig 7.

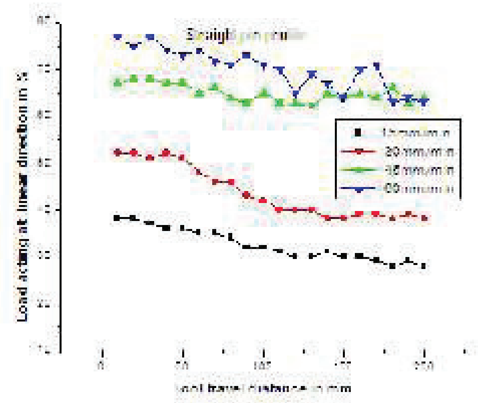

Fig.4 linear forces for straight pin profile

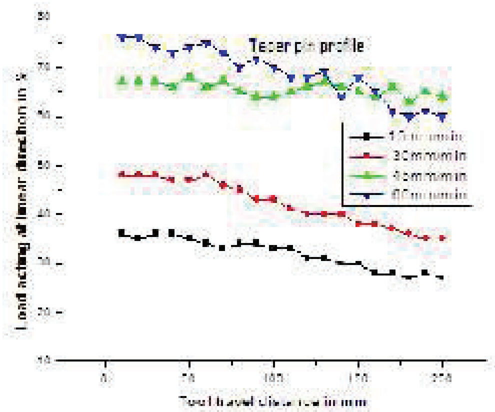

Fig. 5 linear forces for taper pin profile

Table 3 Linear force acting(X-axis) on the work piece for different feed rate at constant speed (1500rpm)

S. No.	Travel Distance in mm	Straight pin				Square pin				Grooved pin				Taper pin				Triangular pin				Threaded pin			
		Feed rate in mm/min				Feed rate in mm/min				Feed rate in mm/min				Feed rate in mm/min				Feed rate in mm/min				Feed rate in mm/min			
		15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60
1	10	38	52	67	77	35	45	54	59	34	45	50	50	36	48	67	76	34	44	47	50	35	44	46	50
2	20	38	52	68	75	35	45	50	48	34	45	51	45	35	48	67	76	34	43	45	48	30	44	42	41
3	30	37	51	68	77	35	43	47	43	34	42	51	48	36	48	67	74	32	43	45	43	30	40	41	38
4	40	36	52	67	74	34	41	45	40	33	42	47	46	36	47	66	73	33	42	40	40	28	40	38	35
5	50	36	51	67	73	33	40	45	40	32	41	47	40	35	47	68	74	32	42	40	38	28	38	35	30
6	60	35	48	65	74	33	40	40	37	31	40	43	42	34	48	66	75	32	40	39	34	27	37	33	28
7	70	35	46	66	72	32	38	37	35	30	39	42	40	33	46	67	73	31	39	38	33	27	35	31	24
8	80	34	46	64	71	30	37	35	31	30	37	36	36	34	45	65	70	30	39	35	33	26	33	28	25
9	90	32	43	63	73	31	37	35	30	30	36	36	35	34	43	64	72	29	35	34	31	27	33	25	21
10	100	32	42	65	71	31	34	33	27	28	34	32	30	33	43	64	70	28	35	34	27	24	32	21	20
11	110	31	40	63	70	30	33	30	24	27	34	30	25	33	41	65	68	27	34	31	25	24	30	20	18
12	120	30	40	63	65	28	33	28	23	27	34	27	22	31	40	66	68	27	32	31	26	22	32	18	16
13	130	30	40	62	69	29	31	28	21	28	33	24	22	31	40	67	69	27	30	30	23	21	30	17	14
14	140	31	38	65	67	30	30	27	20	26	30	22	21	30	40	66	64	26	28	29	20	20	28	19	16
15	150	30	38	64	64	28	29	27	21	24	30	22	20	30	38	65	68	24	27	26	21	19	26	18	15
16	160	30	39	65	70	27	29	28	19	24	28	21	21	28	38	64	65	22	26	24	19	19	25	19	15
17	170	29	39	64	71	27	28	26	20	23	27	21	19	28	37	66	61	21	28	21	17	18	21	15	14
18	180	28	38	66	63	26	27	26	18	23	27	20	17	27	36	63	60	20	24	21	17	17	20	17	16
19	190	29	39	63	64	25	27	25	21	23	24	20	18	28	35	65	61	20	22	20	16	17	19	16	15
20	200	28	38	64	63	24	27	26	20	21	25	20	17	27	35	64	60	21	20	20	17	17	18	17	14

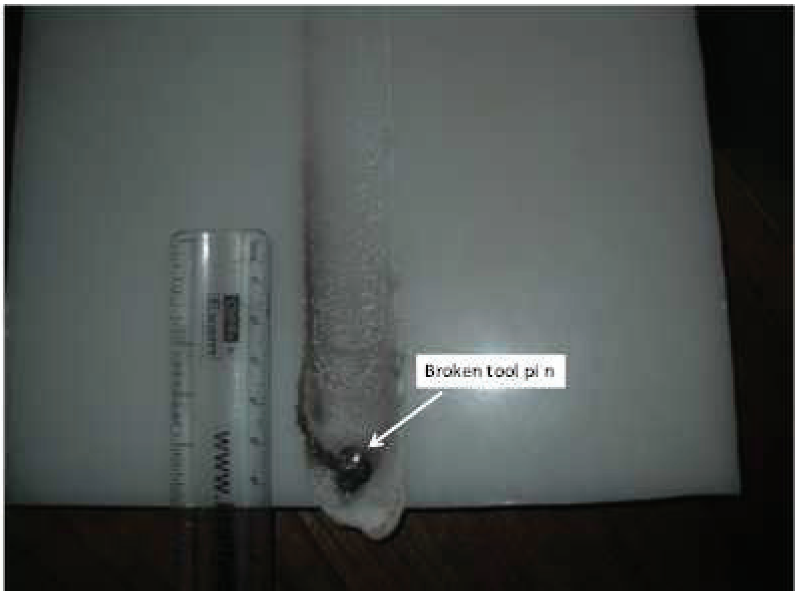

Fig.6 broken taper tool pin at initial time

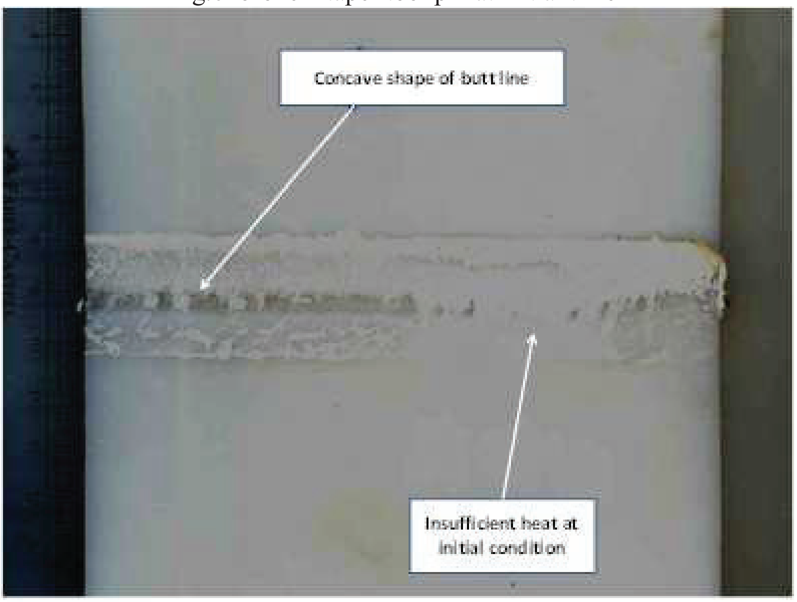

Fig.7 concave shape of the butt line and insufficient heat effect

Square pin profile produce nominal amount of linear force for different feed rate as shown the fig 8. The linear force variation at initial level was high depends upon the feed rate. But, for all feed rate, the linear force was gradually reduced and came to particular limited level at end condition or completion of the welding. Square pin profile created good weld region on the butt line as convex shape. But, the voids and blow holes are presented on the butt line as shown the fig 9 and fig10. Particularly when increased feed rate for 1500rpm speed rate, the presentation of the voids and blow holes were also increased. At the feed rate 15mm/min and 30mm/min, the voids and blow holes presentation were less compared with the other feed rates. The linear force reduction was fewer amounts at lower feed rate particularly for 15mm/min. the force verse tool travel distance was gradually reduced as shown in fig 8.

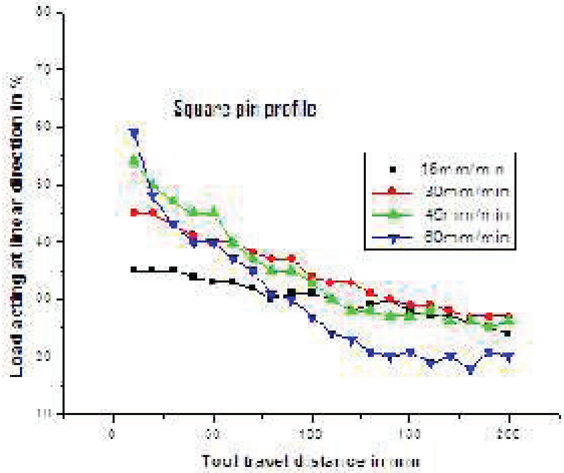

fig.8 linear force for square pin profile

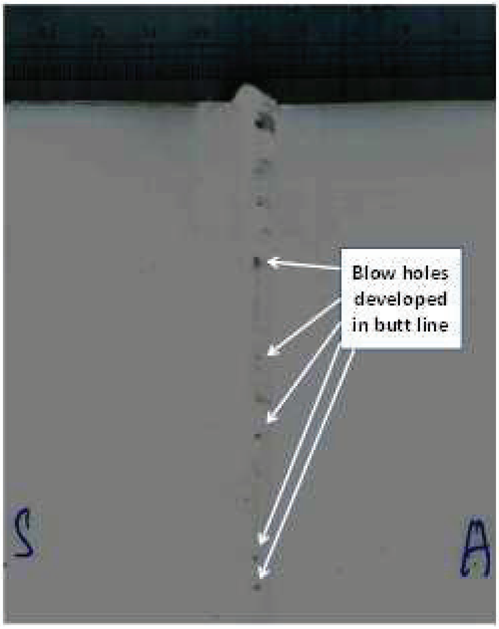

Fig.9 blow holes developed in butt line

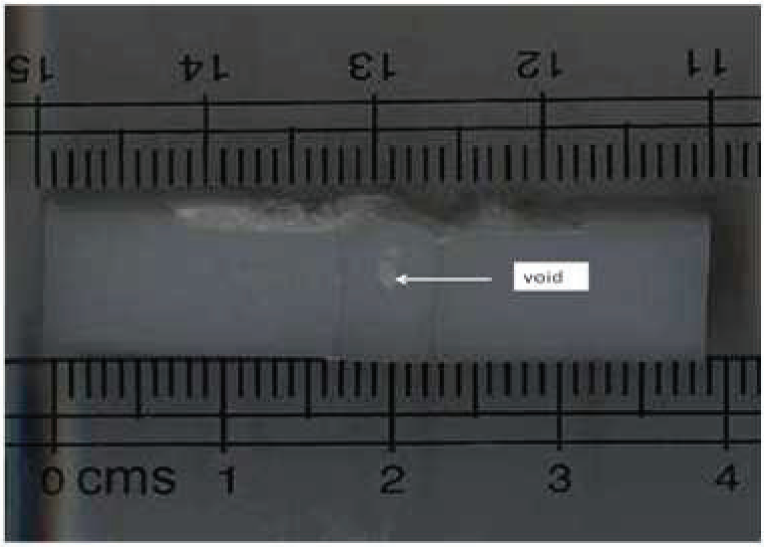

Fig.10 voids developed in inside of the butt line

Fig 11 and fig 12 show the effects of the force for grooved with square pin profile and triangular pin profile at different feed rate for entire tool travel distances. Grooved with square pin profile and triangular pin profile availed moderate amount of linear force compare with other tool pin profiles. These were similar to square pin profile except the more voids and blow holes creations. The linear force variation at initial level was high depends upon the feed rates. But, forces reduced at particular limited level in the completion of welding for the entire feed rate. These both profile created good weld region on the butt line as convex shape. Mostly the voids creation was avoided in the triangular pin profile for different feed rates. But, grooved with square pin profile was created less numbers of voids as well as blow holes at the feed rate more than 30mm/min. surprisingly these pin profiles were also maintained gradual amount of linear force at 15mm/min feed rate. It was similar to square pin profile.

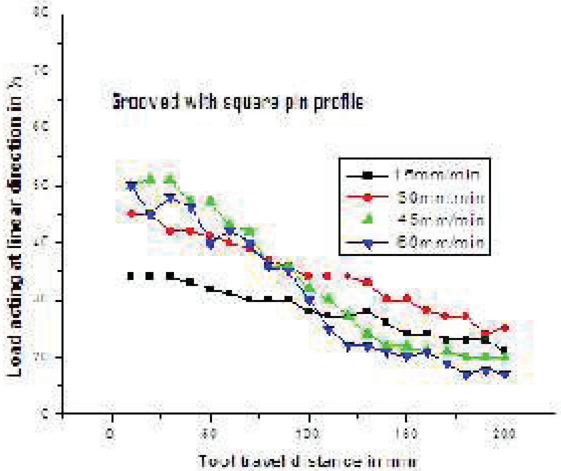

Fig.11 linear force for grooved with square pin profile

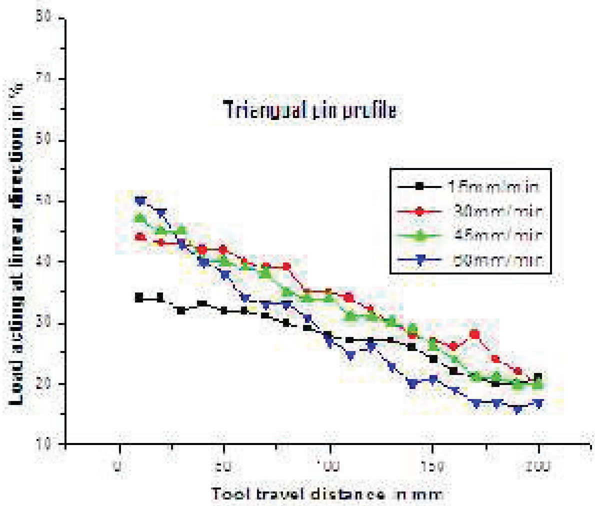

Fig 12. Linear force for triangular pin profile

Compare with other tool pin profiles, threaded pin profile utilized very less amount of linear force as shown in fig 13 and force decrement was also very randomly reduced for gradual tool travel distance. At initial level, profile took more amount of linear force for different feed rate. But, after tool traveled 30 to 40mm distance, the availed force was randomly decreased to lowest level. The weld region is not well in this tool pin profile because threaded pin profile created more heat compare with other pin profiles. Due to this reason, the butt line material come colloid level within very short period of time as well as small amount of tool travel distance. In the friction stir welding process, the tool shoulder creates more heat because of friction. But, in this welding process particularly for threaded pin profile, shoulder threw away the colloid form material to advancing side as shown the fig 14. So, the butt line come concave shape and the advancing side of this weld came as convex shape at entire length of tool travel. At 15mm/min and 30mm/min feed rate, the above problem was created after half of the tool travel distance. But, in the remaining processes, these problems occurred after 20 to 30mm distance from the starting level.

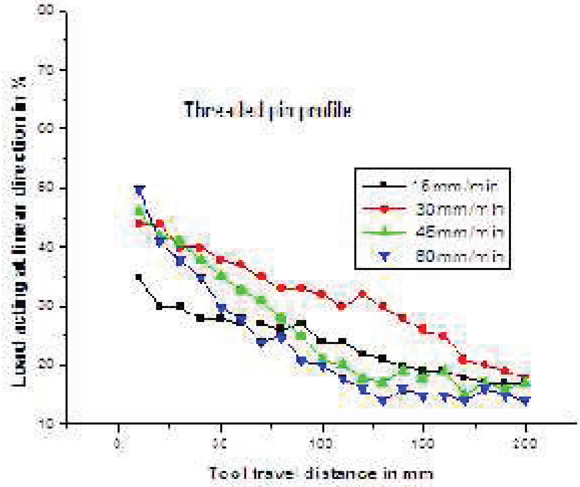

Fig 13. Linear force for threaded pin profile

Fig 14. Material deposited on advancing side

Fig 15, fig 16, fig 17, and fig 18 show the effects of force for different tool pin profile for particular feed rate. For all feed rate condition, threaded pin took less amount of linear force and straight pin profile took high amount of linear force. At the 15mm/min feed rate, all the tool pin profile availed less amount of force and gradually decreased at the end d of the level as shown the fig 15. Somewhat problem was occurred in straight pin and taper pin profiles at 30mm/min feed rate because both the pin took more force in this feed rate compare with other pin profiles. At initial condition, other pin profile took more or less equal amount of force even end condition may be different.

The result of the graph at 45mm/min and 60mm/min feed rate were more or less equal. Here availing force was somewhat varied. But, initial and end condition of the tool travel distance and force verse tool travel distance were similar one. At both the feed rate, straight pin and taper pin came out by means of avail the more amount of force and decrement of force was less. Threaded pin profile was also come out to avail the less amount of linear force and decrement of force was very randomly. Square pin and grooved with square pin and triangular pin were very close to avail the linear force utilization and gradually decreased up to the end condition. So, in this investigation, square pin, grooved with square pin and triangular pin profiles better result based on linear force as well as visible failures. But, compare in between these pin profile, triangular pin profile is best one among the other pin profile because square pin profile created voids and blow holes at all the feed rate. Grooved pin profile created more voids and blow holes at high feed rate and less amount of these problems at low feed rates.

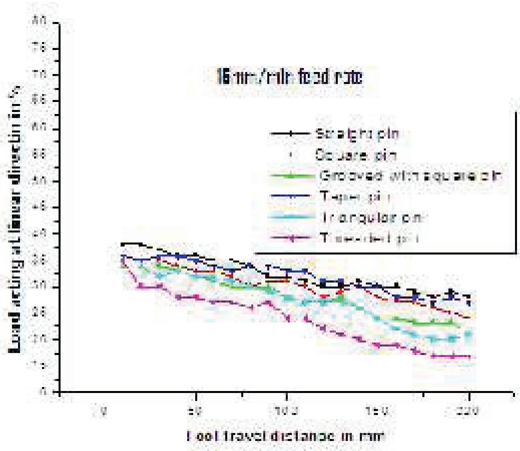

Fig 15. Linear force for all pin profile at 15mm/min feed rate

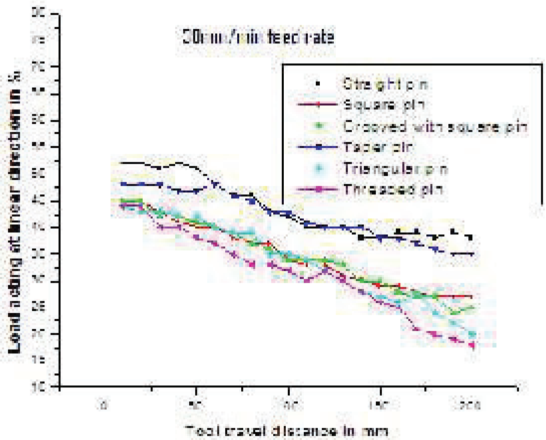

Fig 16. Linear force for all pin profile at 30mm/min feed rate

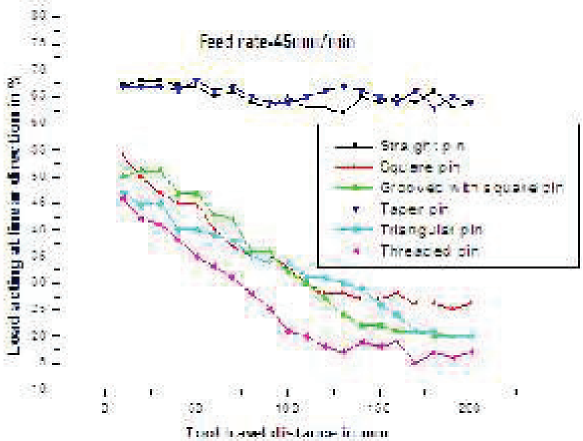

Fig 17. Linear force for all pin profile at 45mm/min feed rate

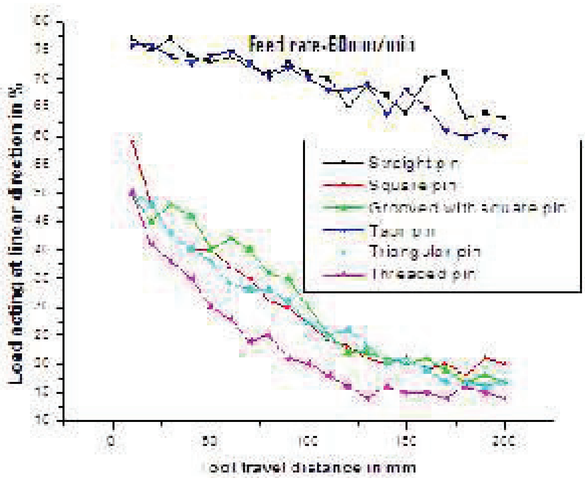

Fig 18. Linear force for all pin profile at 60mm/min feed rate

4. Conclusions

In this investigation, an attempt was made to select proper tool pin profile to friction stir weld polypropylene material. From this investigation, the following important conclusions are derived:

- Based on the average tool force produce on the tool, the tool pin profiles were arranged as follow threaded pin, triangular pin, grooved with square pin, square pin, taper pin, and straight pin.
- The threaded pin tool profile produce less amount of linear tool force at different feed rate, it also soften the material sufficiently for good joint formation. It also observed the maximum material along the weld line was deposited in the advanced side.
- Similarly the triangular pin tool profile and grooved with square pin tool profile were produced defect free weld joint and minimum amount of tool forces were produced in linear direction.
- The joint fabricated with square pin profile was taken minimum linear force compare with threaded pin profile. Even though the square pin tool profile produce good joint at initially , blowholes were observed on the middle of the joined region.
- The taper and straight pin tool profiles produce more linear force, the tools were insufficiently to soften the workpiece material, the average tool force is almost constant through out the weld line, the tool pin broke.
- For the feed rate of 15mm/min and 30mm/min , the force acting on the all pin profiles was less and also force verses tool travel distance was gradually decreased. For the feed rate of 45mm/min and 60mm/min, the force acting in linear direction for straight and taper pin profiles was more and also force verses tool travel distance was gradually decreased. But, for other pin profiles initially took normal amount of force and suddenly decreased very lower amount.

References

[1] Bahemmat P, Haghpanahi MK, Rahbari A, Salekrostam R. Mechanical micro and macrostructural analysis of AA7075-T6 fabricated by friction stir butt welding with different rotational speeds and tool pin profiles. ImechE-part B-2009;**224**:419-433.

[2] Abbasi Gharacheh M, Kokabi AH, Daneshi GH, Shalchi B Sarrafi R. The influence of the ratio of rotational speed transverse speed on mechanical properties of AZ31 friction stir welds. Int J Mech Tools-2006; **46**:1983-1987.

[3] Mishra RS, Mab ZY. Friction stir welding and processing. Mater.sci.engg part R-2005;**50**:1-78.

[4] Rowe CED, Wayne Thomas. Advances in tooling materials for friction stir welding.Technical report. International publication by TWI 13th January-2005.

[5] Padmanaban G, balasubramanian V. Selection of FSW tool pin profile, shoulder diameter and material for joining AZ31B magnesium alloy- An experimental approach. Materials and design-2009;**30**:2647-2656.

[6] Scialpi A, De Filippis LAC, Cavaliere P. Influence of shoulder geometry on microstructure and mechanical properties of friction stir welded 6082 aluminium alloy. Mater Des-2007; **28**:1124-1129.

[7] Elangovan K, Balasubramanian V. Influence of tool pin profile and rotational speed of the tool on the formation of friction stir processing zone in AA2219 aluminium alloy. Mater Sci eng-2007; **459:**7-18.

[8] Zadpoor, Sinke J, Benedictus R, Pieters R. Mechanical properties and microstructure of friction stir welded tailor-made blanks. Material science Engg-2008; **494**:281-290.

[9] Peel M, Stenwer A, Preuss M and Withers PJ. Micro structure, mechanical properties and residual stresses as a fuction of welding speed in aluminium AA5083 friction stir welds. Acta mater-2003;**51**:4791-4801.

[10] Arici A, Sinmaz T. Effects of double passes of the tool on friction stir welding pf polyethylene. J Mater sci-2005; **40**:3313-3316.