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Experimental Investigation of Friction stir Welding on Ultra High Molecular Weight Polyethylene

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Abstract — *Friction stir welding (FSW) is a solid state joining technique that is widely used for joining materials which are difficult to join with traditional fusion welding in many application of commercial importance. This process is considered as "Green Technology" due to its energy efficiency, environment friendliness and versatility. In recent years, FSW is employed for welding of polymers and its composites. Friction stir welding parameters affect the weld strength of thermoplastics, such as Ultra High Molecular Weight Polyethylene (UHMW-PE) sheets. The effect of welding parameters on tensile strength of friction stir weld of UHMW-PE were investigated. For joint formation and maximum tensile strength tool rotational speed, welding speed and tool pin length were determined to be important.*

Keywords*- FSW, UHMW-PE, Welding Speed, Tool pin length*

I INTRODUCTION

The Friction Stir Welding (FSW) is a process in which weld between two materials can be produced by plastic deformation of materials by heating them below their melting temperature with the help of tool having different types of profiled pins. FSW was invented and patented by The Welding Institute (TWI) in December 1991. It is a widely used as solid state joining process for soft materials like aluminum alloys, copper alloys, titanium, zinc, magnesium and thermoplastics that are hard to weld by conventional fusion welding. FSW creates a high quality weld because it avoids many common problem of fusion welding like high heat input, distortion and solidification defects. FSW produce high quality joints without use of flame and filler material which make this process environment friendly. Since, it is in its developing stage, the process has received world-wide attention.

A constantly rotated tool with profiled nib is inserted at a constant rate between two clamped work pieces arranged as like butt joint. This nib is slightly shorter than the weld depth required, with the tool shoulder riding a top the work surface. Frictional heat is generated between the wear resistant welding components and the work pieces. As the pin is moved forward a special profile on its leading face forces plasticized material to the rear where clamping force assists in a forged consolidation the weld. The half-plate where the direction of tool rotation is the same as that of welding is called the advancing side, with the other side designated as being retreating side.

II EXPERIMENTAL WORK

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 specifications is given in Table 1. The samples used in this work consisted of two 150 X 125 X10 mm (length, width, depth) UHMWPE 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. Double sided welding procedure was used to fabricate the joints.

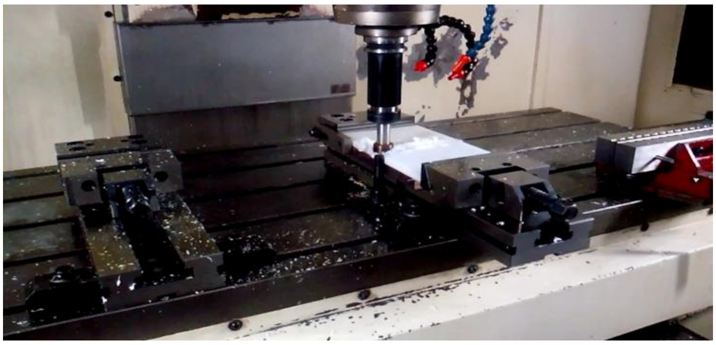

Fig.1 Friction stir welding of UHMW-PE

The non-consumable rotating tools (shown in fig-2) used in this study had Threaded pin profile and a cylindrical shank. The tool made of En-8 material with a nominal pin diameter 7 mm and shoulder diameter 32 mm was used in the present investigation. Fixed and variable welding parameters selected in the present study for the friction stir welding of ultra high molecular weight polyethylene material are shown in table-1 and table-2.

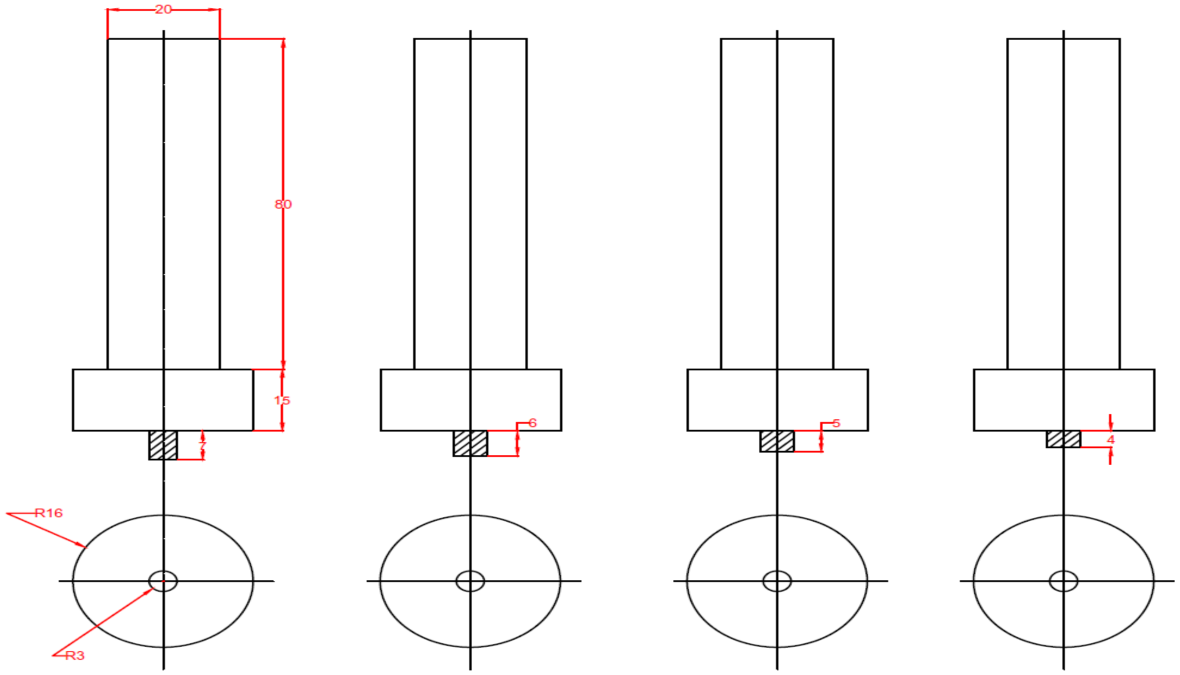

Fig. 2 Designed threaded pin tool used in experimentation work

Thickness of plate	10mm
Material	UHMW-PE
Tool tilt angle	0^0
Spindle rotation direction	Anti-clockwise

Table-1 Fixed process parameters for FSW of UHMW-PE

Due to lack of standard working limit of process parameters, a number of trial runs were carried out using 10mm thick plates of UHMW-PE to find out the feasible working limits of FSW process parameters. Different combination of process parameters were used to carry out the trial runs.

Level	Pin length (A), mm	Welding speed (B), mm/min	Tool rotational speed (C), rpm
Range	4-7	45-90	400-1000
Level-1	4	45	400
Level-2	5	60	600
Level-3	6	75	800
Level-4	7	90	1000

Table-2 Range of Variable process parameters

Test procedure

The basic test for determination of tensile strength of welded joint is the tensile test. Generally, it is carried out by standardized round and flat specimens. Fig. 3 shows standard specimen used for testing according to ASTM D 638 standard. A specimen was fixed between upper and lower head of Universal testing machine UTM-400 (manufactured by Samarth engineering) and ruptured by applying tensile load. During testing actual tensile force and elongation of specimen were measured. With these measured values, tensile strength of welded joint in MPa and behavior of rupture were investigated.

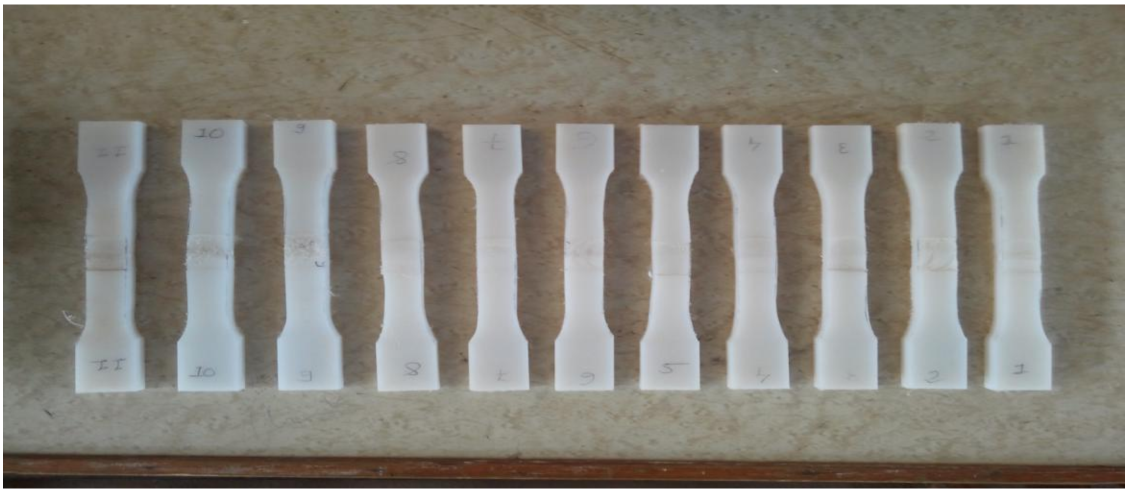

Fig. 3 Standard tensile test specimens

Run	Pin length (A), mm	Welding speed (B), mm/min	Rotational speed (C), rpm	Tensile strength (TS) N/mm^2	Run	Pin length (A), mm	Welding speed (B), mm/min	Rotational speed (C), rpm	Tensile strength (TS) N/mm^2
1	4	45	400	23.78	33	6	45	400	29.68
2	4	45	600	19.15	34	6	45	600	17.68
3	4	45	800	12.94	35	6	45	800	20.83
4	4	45	1000	21.05	36	6	45	1000	24.91
5	4	60	400	16.52	37	6	60	400	26.73
6	4	60	600	14.94	38	6	60	600	27.47
7	4	60	800	12.94	39	6	60	800	27.15
8	4	60	1000	18.88	40	6	60	1000	27.78
9	4	75	400	21.27	41	6	75	400	25.57
10	4	75	600	14.94	42	6	75	600	13.36
11	4	75	800	15.33	43	6	75	800	13.89
12	4	75	1000	18.10	44	6	75	1000	22.96
13	4	90	400	15.10	45	6	90	400	26.63
14	4	90	600	13.94	46	6	90	600	24.73
15	4	90	800	13.15	47	6	90	800	23.01
16	4	90	1000	17.25	48	6	90	1000	26.20
17	5	45	400	21.61	49	7	45	400	20.84
18	5	45	600	15.26	50	7	45	600	16.63
19	5	45	800	14.90	51	7	45	800	14.37
20	5	45	1000	26.36	52	7	45	1000	19.52
21	5	60	400	24.10	53	7	60	400	24.21
22	5	60	600	25.10	54	7	60	600	25.05
23	5	60	800	25.47	55	7	60	800	25.21
24	5	60	1000	30.77	56	7	60	1000	25.78
25	5	75	400	23.95	57	7	75	400	21.57
26	5	75	600	12.21	58	7	75	600	17.90
27	5	75	800	12.63	59	7	75	800	19.05
28	5	75	1000	26.42	60	7	75	1000	15.26
29	5	90	400	15.26	61	7	90	400	17.68
30	5	90	600	13.78	62	7	90	600	18.31
31	5	90	800	12.00	63	7	90	800	18.63
32	5	90	1000	26.73	64	7	90	1000	19.52

Table 3 Results of Tensile strength tests

III RESULTS AND DISCUSSION

Influence of pin length on tensile strength

Fig.4 and Fig.5 show that influence of variation in pin length on tensile strength during welding of UHMW-PE at various combination levels of rotational speed and welding speed using En-8 welding tool. It has been observed that increase in tensile strength is very minor with increasing pin length from 4mm to 5mm and major increase in tensile strength from 5mm to 6mm pin length and then decrease in tensile strength up to pin length 7mm. Small pin length create very small weld stir zone which results into low tensile strength. Higher pin length expelled the material out of weld zone which also results in lower tensile strength.

Influence of welding speed on tensile strength

Fig.4 and Fig.5 show that the effect of variation in welding speed on tensile strength of weld observed during welding of UHMW-PE. It has been observed that increase in tensile strength is major with increasing welding speed from 45mm/min to 60mm/min and then decrease in tensile strength with increasing welding speed from 60mm/min to 75mm/min. Tensile strength remains steady between welding speed from 75mm/min to 90mm/min. At lower welding speed, stirring action takes place into weld zone is longer which leads to improve tensile strength. Higher welding speed induces higher amount of thermo-mechanical stress at weld zone which result into poor tensile strength.

Influence of rotational speed on tensile strength

Fig.4 and Fig.5 show that the effect of variation in tool rotational speed on tensile strength of weld observed during welding of UHMW-PE. It has been observed that major decrease in tensile strength with increasing rotational speed from 400 rpm to 600rpm and then minor decrease in tensile strength with increasing rotational speed from 600rpm to 800rpm. Above rotational speed of 800rpm tensile strength start increasing up to 1000rpm. Lower rotational speed causes insufficient flow of material and on other hand higher rotational speed increase turbulence which destroy regular flow of material.

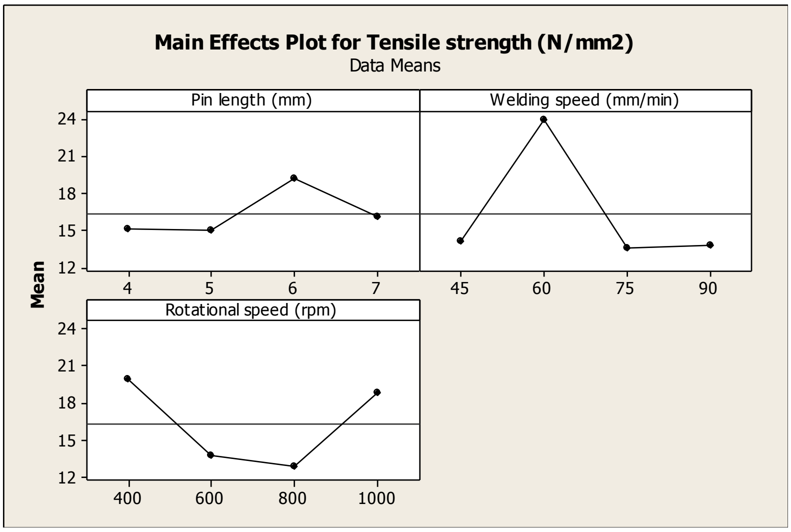

Fig.4 Main effects plot for Tensile strength

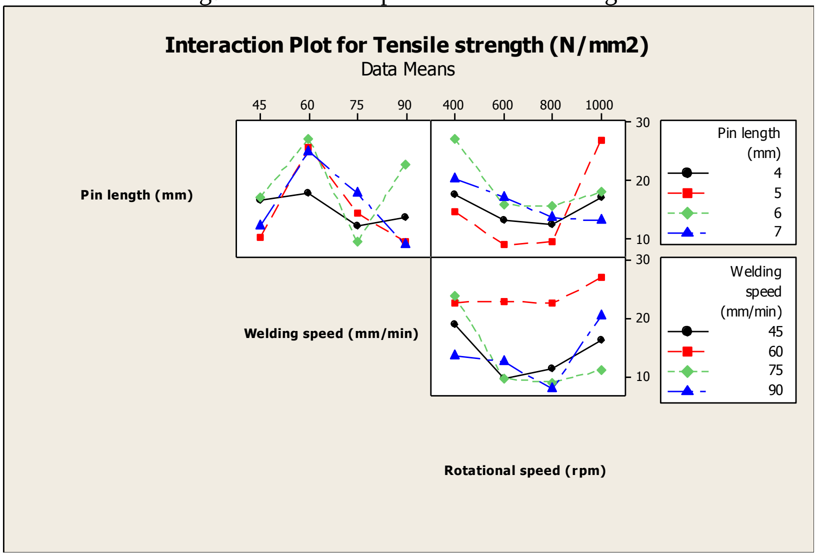

Fig. 5 Interaction plot for tensile strength

Table 4 ANOVA test results

Source	DF	Seq.SS	Adj.SS	Adj.MS	F	P	%contribution
Pin length (A)	3	374.917	374.917	124.972	35.80	0.000	21.41
Welding speed (B)	3	269.917	269.917	89.771	25.71	0.000	15.20
Rotational speed (C)	3	359.526	359.526	119.842	34.33	0.000	20.50
A*B	9	268.018	268.018	29.780	8.53	0.000	13.90
A*C	9	186.002	186.002	20.667	5.92	0.000	9.08
B*C	9	150.093	150.093	16.677	4.78	0.001	6.97
Error	27	94.264	94.264	3.491			12.94
Total	63	1702.133					100
S= 1.86849		R-Sq = 94.46%		R-Sq(adj.) = 87.08%			

From results it was found that pin length and rotational speed were the dominant factors in weld tensile strength

V CONCLUSIONS

In this investigation the effects of friction stir welding parameters on tensile strength of Ultra high molecular weight polyethylene sheets was studied by using the ANOVA. Pin length and rotational speed were dominant factors in weld tensile strength. The optimum welding parameters to achieve maximum tensile strength was tool rotational speed 1000rpm, welding speed of 60mm/min and pin length of 6mm.

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