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Research Article

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Friction Stir Welded of High Density Polyethylene Sheets

Mustafa Kemal Bilici[1], Batuhan Kurt[1], Hüseyin Kurt[2]

[1]Marmara University, Applied Science High School,Göztepe Campus, İstanbul, Turkey
[2]Gelişim University, Engineering Faculty, İstanbul, Turkey

Abstract 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. The aim of the present work is to investigate the mechanical properties of butt joints produced by friction stir welding (FSW) in high density polyethylene sheets of 4 mm thickness. The effects of critical welding parameters and tool design have affected on mechanical properties, weld surface and macrostructure of friction stir welded polyethylene. Experiments were performed at tool rotational speeds of 600, 900, 1200, and 1500 r/min and traverse speeds of 30, 45, and 60 mm/min, tool diameters (d) of 4, 5, 6 mm and tool shoulder diameters (D) 20, 25, 30 mm. A strength value of 80% of the base material was achieved at the isolated optimum welding condition. According to the tool design, the welding parameters and the mechanical properties changed to a great extent. The highest tensile strength was achieved at low feed rates, high tool rotation speeds and shoulder diameters/pin diameters ratio.

Keywords Friction stir welding, mechanical properties, high density polyethylene, tool design

Introduction

High density polyethylene (HDPE) is widely used as a commodity polymer with high-tonnage production due to its distinctive mechanical and physical properties. Because of its low toughness, weather resistance, and environmental stress cracking resistance as compared to engineering polymers, its application in many areas has been limited. To improve these disadvantages, HDPE has been reinforced with fillers. HDPE filled with mineral particles also improves dimensional stability, opacity, and barrier properties [1]. Fillers, in the form of particulates and fibers, are often added to polymeric materials to improve their stiffness and strength [2]. Because HDPE is crisp, it breaks at low stresses. Most of the water pipes are made of HDPE [2]. It is necessary to use alternative welding methods in complex and large part consolidations [3].

The friction stir welding (FSW) process was developed by The Welding Institute (TWI) in 1991 for joining aluminum alloys [4].The method can guarantee high quality, efficiency, energy saving, and environmental protection. Heat is generated by friction between the rotating tool and the base material, which softened the region near the FSW tool. The traverse movement of tool along the joint line intermixes the work pieces mechanically and forges the softened material by the mechanical pressure The plastic deformation and generated heat caused by rotational welding tool pin and shoulder, accompanied by the tool's traverse motion joins the materials [5,6]. FSW began to be applied on aluminium, copper, stainless steel and magnesium alloys [6-9]. Recently, some researchers have studied application of FSW to thermoplastics [10-14].In the present work, FSW of polyethylene sheets was performed by changing the main process parameters: tool rotational speed, feed rate, pin diameter and shoulder diameter.

Materials and Methods

In this investigation, 4-mm thick HDPE were used. HDPE sheets were purchased from SIMONA AG, Gemany (tensile strength 23 MPa). The plate is cut into rectangular samples of 150 mm length by 100 mm width. In order to develop the FSW tests, a properly designed clamping fixture was utilized to fix the specimens in Fig. 1. The tools used fin welding operations were machined from SAE 1040 steel and heat treated to 40 Rockwell C hardness conversion. The tool dimensions are shown in Table 1. Nine different tool pin profiles were used to fabricate the joints.

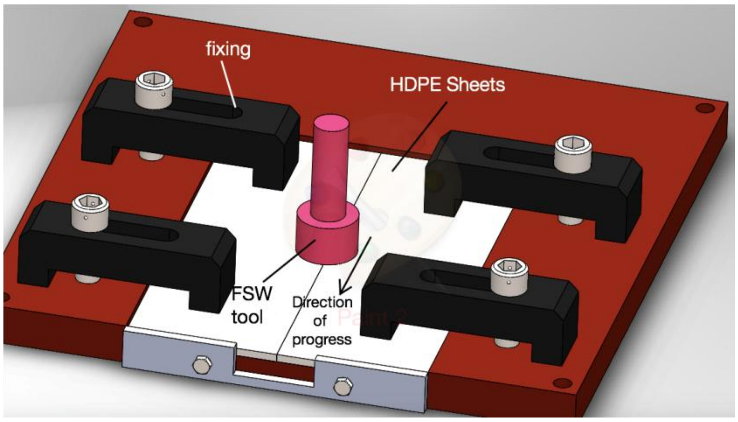
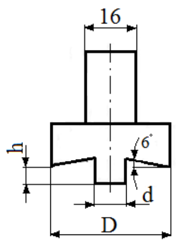


Figure 1: Friction stir welding process for HDPE

Table 1: Friction stir welding tool dimensions

Tool dimensions		
Pinlenght	h (mm)	3,7
Pindiameter	d (mm)	4,5,6
Shoulderdiameter	D (mm)	20,25,30



Experiments are carried out during the investigation of both pin diameters and shoulder diameters. The shoulder angle is 6 degrees on all of teams. The tool tilt angle was used as 1° in all experiments. The tool rotational speeds and feed rates have been selected for all FSSW tools. The tool rotational speeds between 600 and 1500 rpmand feed rates between 30 and 60 mm/min werewere carried out experiments. The tensile specimens were prepared as per ASTM D 412 standard using Zwick/Z010 universal type tensile test machine to determine the tensile properties of the joints. At least five specimens were tested under the same conditions to guarantee the reliability of the results.

Results and Discussion

Since there are many factors that affect the welding, they must be related to each other. Independent evaluation should not be done. The tool rotational speed and the feed rate were changed in a wide range. Average ultimate tensile strength of samples is given in Tables 2-4, and diagrams of data are shown in Figs. 3-5.

Table 2: Data obtained from tensile test (shoulder 20 mm)

Pin diameter, mm	**4**			**5**			**6**			
Feed rate, mm/min	**30**	**45**	**60**	**30**	**45**	**60**	**30**	**45**	**60**	
Average ultimate tensile, MPa	3,6	4,1	5,6	5,1	6,9	9,1	7,4	7,8	9,1	**600 rpm**
	6,1	7,1	8,6	6,1	13,1	11,5	11,2	12,5	12,3	**900 rpm**
	6,3	7,0	7,2	5,9	12,4	10,8	11,4	13,1	12,4	**1200 rpm**
	5,2	6,4	7,1	5,3	8,6	7,0	9,3	9,8	7,8	**1500 rpm**

In Table 2, the tensile strengths obtained at different feed (30, 45, 60 mm/min) rate and tool rotation speeds (600, 900, 1200 and 1500) are given. Fig. 2 reports the tensile strength of the FSW joints at 45 mm/min feed rate and different rotational speeds because the highest tensile strength was obtained at the feed rate 45 mm/min. Values at other feed rates are given in Table 2.

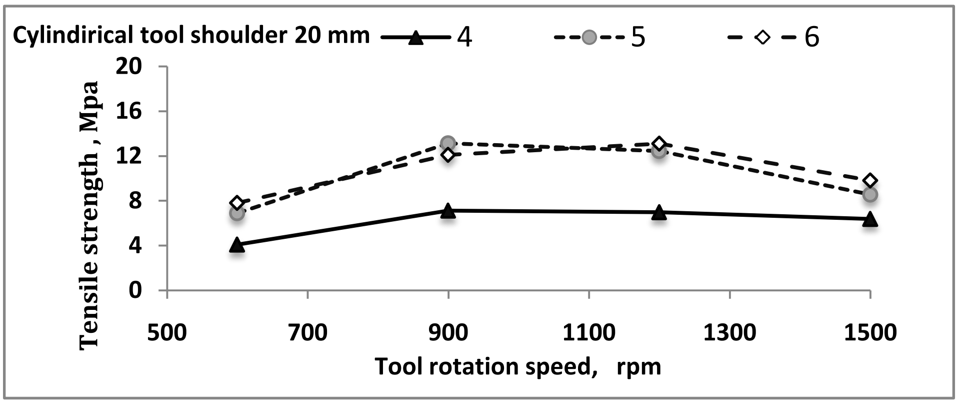


Figure 2: Diagram of tensile strength diagram of welded specimens at a feed rate of 45 mm / min.

The highest tensile strength was obtained at shoulder 20 mm and 5 mm pin diameter in Fig. 2. Shoulder and pin ratio are very important in FSW experiments. While the shoulder generates heat, the pin is mixing. This ratio is 4, when the shoulder is 20 mm. With the increase or decrease of the pin diameter, the tensile strength is reduced in Table 2 and Fig. 2. Heat is generated at 4 and 6 mm of pin, but mixing is insufficient. It is very important in the heat production in the tool rotation speed except the pin and shoulder. In tensile strength, the greatest factor after heat production is the feed rate. It is necessary to ensure that the heat spreads homogeneously in the welding direction during joint. Fig. 4 shows the surface image of the weld with the highest tensile strength (shoulder 20 mm and pin 5 mm). It is evident that the heating material has spread homogeneously at the ideal feed rate in Fig. 3.

Figure 3: (Shoulder 20 mm and pin 5 mm), Surface image of welded specimens at a feed rate of 45 mm / min and 900 rpm.

At the feed rate, when the tool rotation speed increases, it is not ideal to spread the material in the direction of welding as shown in Fig. 4. This status affects both the tensile strength and negatively the weld surface appearance. Excess heat has been generated due to the high tool rotation. That is why the material is out.

Figure 4: (Shoulder 20 mm and pin 5 mm), Surface image of welded specimens at a feed rate of 45 mm / min and 1500 rpm

In Table 3, with 25 mm shoulder diameter and different pin diameters, the tensile strengths obtained at different feed rate and tool rotation speeds are given. From Table 3, the highest breaking strengths were obtained at a feed rate of 45 mm / min. Therefore, a graph of the values for the 45mm / min feed rate is plotted in Fig. 5. In the case of shoulder 25 mm, very close results were obtained at pin diameters of 5 and 6 mm. These results were due to the increase of the shoulder diameter. Significant increases in the tensile strength have occurred at the same pin diameters and different shoulder diameters. Tables 2 and 3 have obviously showed.

Table 3: Data obtained from tensile test (shoulder 25 mm)

Pin diameter, mm		**4**			**5**			**6**		
Feed rate, mm/min	**30**	**45**	**60**	**30**	**45**	**60**	**30**	**45**	**60**	
Average ultimate tensile, MPa	4,2	4,8	4,8	6,0	10,1	8,7	5,7	6,9	9,1	**600 rpm**
	7,2	10,6	6,6	7,2	15,0	12,6	10,0	12,5	13,2	**900 rpm**
	6,5	8,2	9,2	6,9	14,8	11,5	10,3	11,2	13,5	**1200 rpm**
	6,1	7,5	8,3	6,2	8,1	9,2	9,3	8,8	11,3	**1500 rpm**

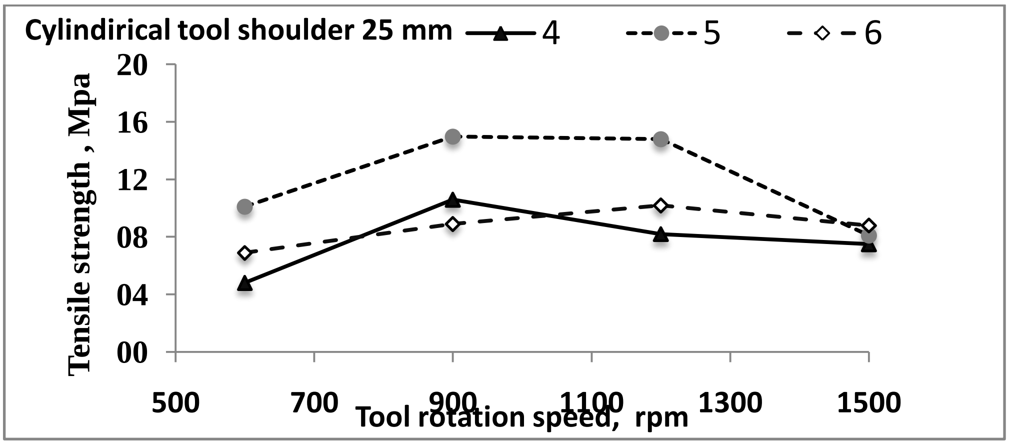


Figure 5: Diagram of tensile strength diagram of welded specimens at a feed rate of 45 mm / min.

Fig. 5 shows the tensile strength of the FSW joints at 45 mm/min feed rate and different rotational speeds. The reason why the breaking strengths are close to each other at 5 and 6 mm diameter is due to the ideal ratio of shoulder to diameter.

They acted together in all resource conditions. There was no significant difference in breaking strength. The FSW showed clearly that the shoulder and pin diameter ratio was 4 or 5 in Figs. 2 and 5. When the ratio of shoulder to pin diameter is 4 to 5, the transport of the heated material and the mixing process are ideal in Figs. 6 and 7. In both tool (5 and 6 mm), the tensile strength increased by 900 rpm, then gradually decreased. However, despite the increased tool rotation speed in the 4-mm tool, there has been no significant change. In the 4-mm tool, the mixing process is not complete.

Figure 6: (Shoulder 25 mm and pin 5 mm), Surface image of welded specimens (at a feed rate of 45 mm / min and 900 rpm.

Figure 7: (Shoulder 25 mm and pin 6 mm), Surface image of welded specimens at a feed rate of 45 mm / min and 900 rpm.

Figs. 6 and 7 show the surface image of the weld with the highest tensile strength (shoulder 25 mm, pin 5, and 6 mm). It is evident that the heating material has spread homogeneously in Figs. 6 and 7.

In Table 4, with 30 mm shoulder diameter and different pin diameters, the tensile strengths obtained at different feed rate and tool rotation speeds are given.

Table 4: Data obtained from tensile test (shoulder 30 mm)

Pin diameter, mm	4			5			6			
Feed rate, mm/min	**30**	**45**	**60**	**30**	**45**	**60**	**30**	**45**	**60**	
Average ultimate tensile, MPa	2.9	3.9	3.5	5.8	5.8	6.0	5.7	6.9	9,1	**600 rpm**
	4.6	4.7	4.8	7.8	8.6	6.5	10.0	11.5	11.2	**900 rpm**
	4.9	4.8	5.2	6.0	6.4	6.4	10.3	12.8	12.5	**1200 rpm**
	4.1	5.0	4.3	4.8	6.4	6.0	9.3	10.5	9.3	**1500 rpm**

From Table 4, the highest breaking strengths were obtained at a feed rate of 45 mm / min. Therefore, a graph of the values for the 45mm / min feed rate is plotted in Fig. 9. In the results of other shoulder measurements said that the FSW showed clearly that the shoulder and pin diameter ideal ratio was 4 or 5. If the shoulder is 30 mm, we can see it directly in Table 4 and Fig. 8. The highest breaking strengths were obtained at 6 mm pin diameters under all test conditions.

The shoulder and pin diameter ratio increases, the tensile strength decreases. It clearly shows the importance of this ratio in FSW process. When shoulder and pin diameter ratio is 5, the highest value is 12.8 MPa. When this ratio is 6, the highest 8.6 MPa is obtained in Fig. 8.

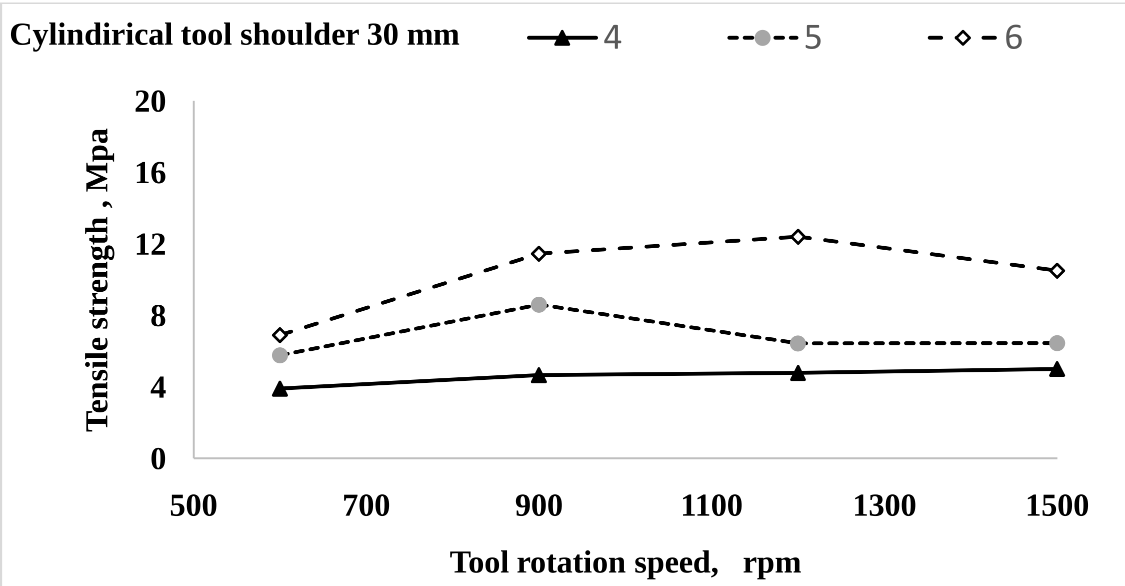


Figure 8: Diagram of tensile strength diagram of welded specimens at a feed rate of 45 mm / min.

Figure 9: (Shoulder 30 mm and pin 6 mm), Surface image of welded specimens at a feed rate of 45 mm / min and 900 rpm

Material overflow has not been carried out since it is suitable for the welding conditions and the tool. It has not come to the extreme heat in figure 9. Although the highest welding strength was obtained this welding tool (Shoulder 30 mm and pin 6 mm), there were disadvantages in welding joint and surface in figure 9 and 10 and table 4.

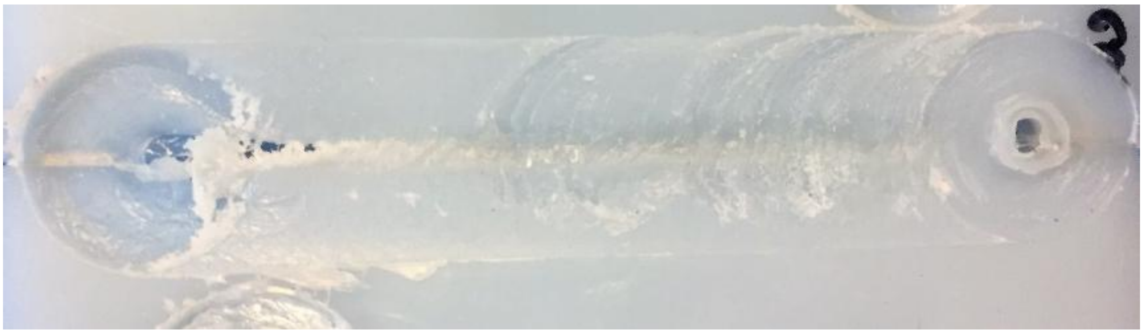


Figure 10: (Shoulder 30 mm and pin 5 mm), Surface image of welded specimens at a feed rate of 45 mm / min and 900 rpm.

Figure 10 shows surface image that shoulder and pin diameter ratio is 6. Due to extreme heat towards the end of the weld, the material overflow is on the weld surface. This condition has affected both the welding joint and the weld surface negatively.

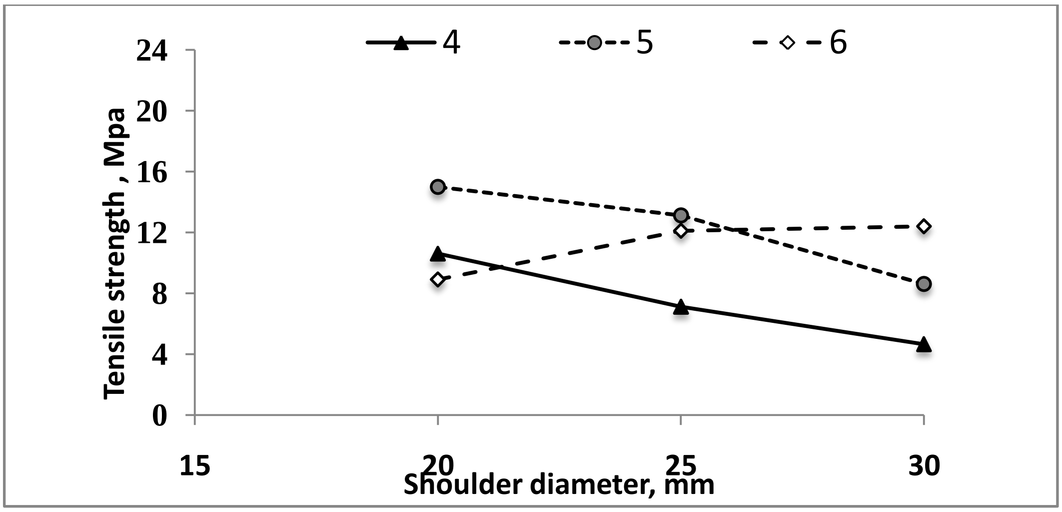


Figure 11: Effect of weld strength of shoulder diameter and pin diameter

Although the ideal ratio of shoulder and pin diameter is 4, 5, when the shoulder diameter is 30 mm, the desired results can not be obtained. This is obviously due to the fact that the shoulder is producing excessive heat, causing the material to move upwards and to reduce the material in the welding area. According to all these results, besides welding conditions, welding tool design is also very important.

The figure 11 shows the effect of the weld strength in relation to the relationship between the shoulder diameter and the pin diameter. At 4 and 5 mm pin diameters, the tensile strength decreases dramatically with the shoulder diameter increases. At 6 mm pin diameters, the tensile strength was increased dramatically with the shoulder diameter increases. The changes in the welding strength occur the tool design. That is why team design is very important in the friction stir welding.

Conclusıon

This study focused on the material properties tool effect on friction stir butt welding of high density polyethylene sheets. The obtained results can be summarized as follows:

- The high density polyethylene (HDPE) sheets were successfully joined by FSW.
- The maximum tensile strength values of welded HDPE plates were obtained by 4 and 5 using ideal ratio of pin and shoulder diameter.
- The experimental results indicated that the maximum tensile strength of the joints, which is about 71% that of the baseplate, was obtained with a tool rotational speed of 900 rpm and feed rate 45 mm/min.
- In general it was found that higher rotational speed and low feed rate resulted in higher tensile strength. This is due to the high local temperature achieved at higher spindle speeds leading to the formation of a large quantity of molten material leading to an efficient joint.
- Increasing the tool shoulder diameter had a decreasing effect on weld tensile strength.

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