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JOURNAL OF UNIVERSITY OF BABYLON

For ENGINEERING SCIENCES (JUBES)

Vol.31, No.2.| 2023

Effect of Friction Stir Welding Parameters on the Mechanical Properties of Dissimilar Polymer Joints

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Received:	**29/11/2022**	**Accepted:**	**14/3/2023**	**Published:**	**19/3/2023**

Abstract:

Welding joints of materials that are difficult to weld with traditional methods, particularly polymeric materials, require friction stir welding (FSW). In this research, two types of polymers have been used to study the effect of friction stir welding (FSW) parameters on the properties of dissimilar polymer joints. High density polyethylene (HDPE) and polyvinyl chloride (PVC) plates with dimension of (5x100x200 mm) were welded by using milling machine as friction stir welding machine. The welding tool was used with shoulder diameter of (18 mm) and pin diameter of (6 mm) with height of (4.8 mm). The rotation speed was applied in the range of (340 to 1660 rpm) with welding linear speed of (24 and 40 mm/sec). The result shows that the hardness was increased with increasing rotational speed until (850 rpm) then decreased when the welding speed equal to (24 mm/sec). However, its decreased with increasing welding linear speed when it became (40 mm/sec). In addition, the maximum hardness and tensile strength was found at rotational speed equal to (495 rpm) and welding linear speed equal to (24 mm/sec) which equal to hardness of (72 Shore D) and tensile strength of (39 MPa). Finally, the result displays that there is an opportunity to weld dissimilar polymers.

Keywords: Friction, Stir, Welding, HDPE, PVC, Polymer, Hardness

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1. Introduction

In 1991, the FSW process was discovered by Thomas, which is a solid-state welding process that is suitable for welding most metals and for similar or dissimilar joints. It can be defined as one of the main non-conventional welding processes that used friction heat instead of traditional energy source like electricity [1]. One of the advantages of (FSW) is that the material to be welded does not reach the melting point, which avoids the defects associated with the process of solidification of the molten material as a result of friction, and also it is possible to weld materials that are difficult to weld by traditional methods. So as, it is considered an environmentally friendly, economical, and non-dangerous process for the welding worker [2]. The (FSW) process is affected by many variables that directly affect the quality of the welding joint, including (rotational and linear speed, the shape of the tools used, etc.). The welding process takes place in several stages, which are the start of the rotational movement of the tool, penetration of the surface of the material to be welded, the dwell time, and the linear movement along the welding area. As a result of these stages, sufficient heat for welding is generated as a result of friction between the welding tool and the welded material, where kinetic energy is converted into thermal energy [3,4,5]. Plastics have distinctive properties that differ from metals, so they have recently been used as a successful alternative in various products, such as parts of various means of transportation, mechanical and food industries, and many different industries due to their unique physical, chemical, and mechanical properties. [6]. Due to the development of thermoplastic materials, which began to take a wide field in advanced industries for the purpose of increasing the efficiency of materials, they began to be strengthened by adding fibers for the manufacture of composite materials. Furthermore, it is possible to connect dissimilar materials by (FSW) method [2]. The other types of polymers like thermosets, and elastomers, it is difficult to weld by friction stir spot welding method because of their rheological properties and their flow behavior [7]. FSW of polymers have different physical and rheological properties which make it is critical polymer. The optimum parameters that have to be used becomes more challenging in the welding process of polymers because it has low melt viscosity such as nylon-6. Therefore, pin profile in FSW process should be designed carefully. On the other hand, the major parameters in friction stir welding for polymers is rotational speed which should be used according to the properties of materials that need to be weld. The result application shows that the poor mixing of polymer was happened on the lower rotational speed, however, the degradation of polymer occurred on the higher rotational speed [8, 9].

FSW of the polymer has been developed rapidly in recent years with external heat introduction. Furthermore, material movement through the welding process has been studied by the marker insert technique. Table 1 shows the review of the main research and development that are done in this process [8].

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Table 1: Review of friction stir welding for different polymers [8]

Author (s)	material	Plate thickness (mm)	Tool pin profile	Tensile Strength (Mpa)	Joint efficiency (%)
Inaniwa et. al.	Nylon-6	5	Threaded	67.1	35
	HDPE	=	=	31.9	70
	PVC	=	=	66.5	45
Panneerselvam et. al.	Nylon-6	10	=	34.8	40
Zafar et. al.	=	16	=	27.22	32
Sadeghian et. al.	(ABS) (Acrylonitrile butadiene styrene)	8	Cylindrical	41.42	99.1
			Conical	39.30	94
Bagheri et. al.	=	5	Threaded	32.62	88.76
Pirizadeh et al.	=	=	(Double shoulder) tool with convex pin	20.7	60.6
			Double shoulder tool with simple pin	15.48	45.6
Mendes et. al.	=	6	(Stationary shoulder) with conical threaded pin	29.48	67
Oliveira et. al.	(PMMA) (Poly(methyl methacrylate)	3	Refill friction stir spot welding tool	9.5	11.87
Ahmadi et. al.	PP (Polypropylene)	4	Simple cylindrical conical	5.7	-
			Threaded conical	3.84	-
Kiss et. al.	=	15	Traditional milling tool	11.5	50
Bozkurt	(HDPE)	4	-	19.4	86.2
Gao et. al.	=	4	Threaded Cylindrical	12.3	-
Azarsa et. al.	=	10	Threaded	33.76	95.69
Arici et. al.	MDPE	5	Cylindrical	20	100
Aydin	UHMW-PE (Ultra-high-molecular-weight polyethylene)	4	Threaded	28.5	89

Recently, friction stir spot welding technique of polymers has been developed. The results survey demonstrated that the friction stir joining technology was produced high joining quality compared with traditional welding processes. promising technique has low cost of machine and tools compared with other joining technologies. A very high strengths of welded polymer may be obtained which are closed to base material [10]. The friction stir welding process for polymers still under progress which has not been completely applied in the industrial applications [8]. Therefore, in this research friction stir welding method will be applied to join dissimilar polymer materials which are of high density polyethylene and polyvinyl chloride.

2. Experimental Work

2.1 Milling Machine

Some special attachments are fit to the vertical milling machine to prevent the piece to be welded from moving and slipping due to the force generated during FSW as shown in Figure 1.

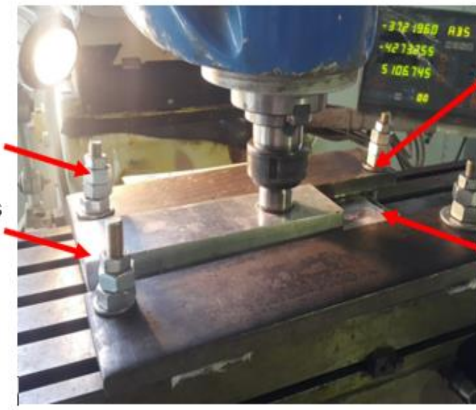

Figure 1: Special attachments fixed on the machine milling

2.2Materials

Two types of materials have been used in this research which are high density polyethylene HDPE and polyvinyl chloride PVC with dimension of 5 X 100 X 200 mm as shown in Figures 2 and 3.

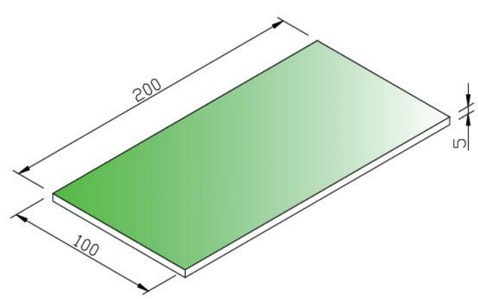

Figure 2: PVC Polymer plate

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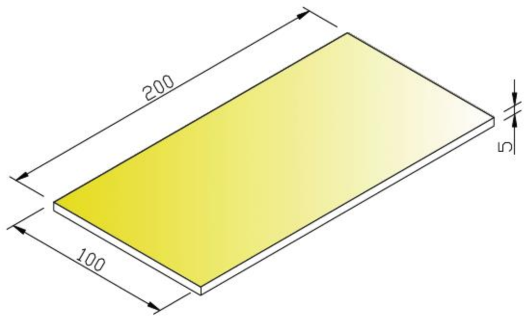

Figure 3: HDPE Polymer plate

2.3 FSW Tool

Table (2) shows the characteristics of the tool, and Figure (4) shows the parts of it.

Table (2): Shoe tool parts

Tool feature	Tool details
Shoulder diameter	18 mm
Pin diameter	6 mm
Pin length	4.8 mm
Material	Low alloy steel
Hardness	35 HRC
Thrust bearing	No. 51104
Aluminum base	Al-alloy 7012

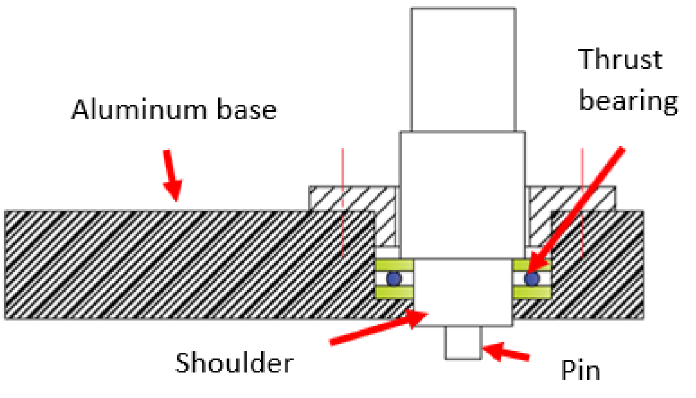

Figure (4): Parts of the shoe tool

2.4 Procedures

Different rotational speed and welding speed are used to welding HDPE and PVC plates. Rotational speed lies in the range of 340 to 1660 rpm and welding speed of 24 and 40 mm/sec as shown in Table (3).

Table 3: Friction stir welding condition

Test No.	Rotational speed (rpm)	Welding speed (mm/sec)
1	340	24
2	495	24
3	675	24
4	850	24
5	1660	24
6	340	40
7	495	40
8	675	40
9	850	40
10	1660	40

3 Results and Discussion

3.1 Hardness

The hardness of welded polymer has been tested using (Shoe D) hardness which has a scale graduation of (0-100) hardness number according to ASTM –D 2240-03 and samples were prepared with dimensions of 20 x 20 x 5 mm as shown in Figure (5). The hardness value of welded samples is shown in Table (4) and Figure (7). As shown in figure (6), there is a significant improvement in the hardness of the weld area, especially at the rotational speed of 495 rpm. This increase can be attributed to the molecular structure which provides a large

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separating barrier and thus makes the polymeric material relatively rigid and robust. The amount of the hardness number begins to decrease when increasing the rotational speed, and the peak of the decrease was when the rotational speed reached 1660 rpm, where the heat was generated as a result of friction increases at high speeds, and then molecular dissolution occurs as a result of overheating at high temperatures. The components of the polymeric chain appear where they begin to separate. They interact with each other to change the properties of the polymer.

Table 4: Hardness of FSW

No.	Rotational speed rpm	Welding speed mm/sec	Hardness Shore D
1	340	24	67
2	495	24	72
3	675	24	66
4	850	24	68
5	1660	24	60
6	340	40	62
7	495	40	68
8	675	40	59
9	850	40	63
10	1660	40	58

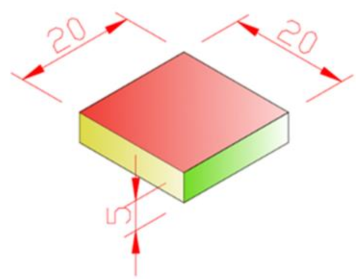

Figure 5: Dimension of welded

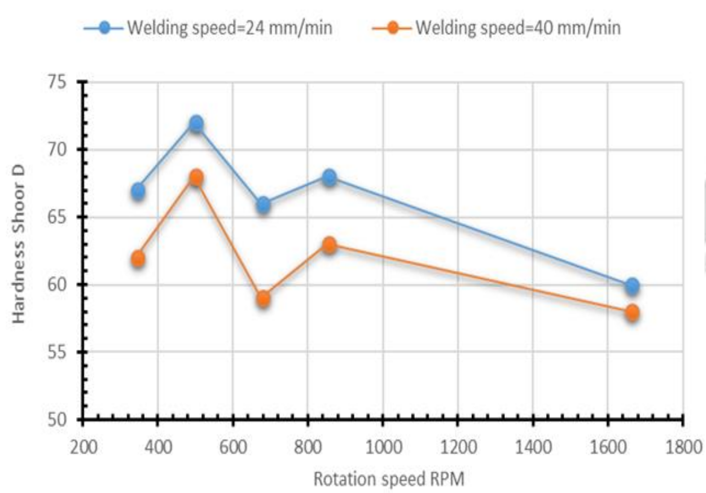

Figure 6: Hardness of friction stir welding

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3.2 Tensile Strength

Tensile strength of welded polymer has been tested according to ASTM –D 638-03 and samples were prepared with dimension of 150 x 20 x 5 mm as shown in Figure (7). The values of tensile strength for welded samples are shown in Figure (8) and Table (5). An increase in the value of tensile strength is observed, especially at the rotational speed of 495 rpm, which indicates that the temperature generated as a result of friction at that temperature is optimal. This result is also related to the nature of the molecular structure and the compatibility between the components of the polymer blend formed in the welding area.

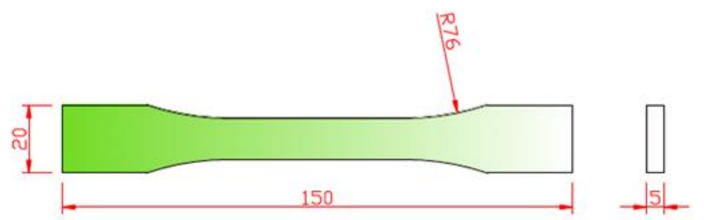

Figure 7: Dimension of welded sample for tensile strength test.

Table 5: Tensile strength of FSW

Test No.	Rotational speed (rpm)	Welding speed (mm/sec)	Tensile strength (MPa)
1	340	24	33
2	495	24	39
3	675	24	35
4	850	24	32
5	1660	24	28
6	340	40	31
7	495	40	36
8	675	40	32
9	850	40	33
10	1660	40	30

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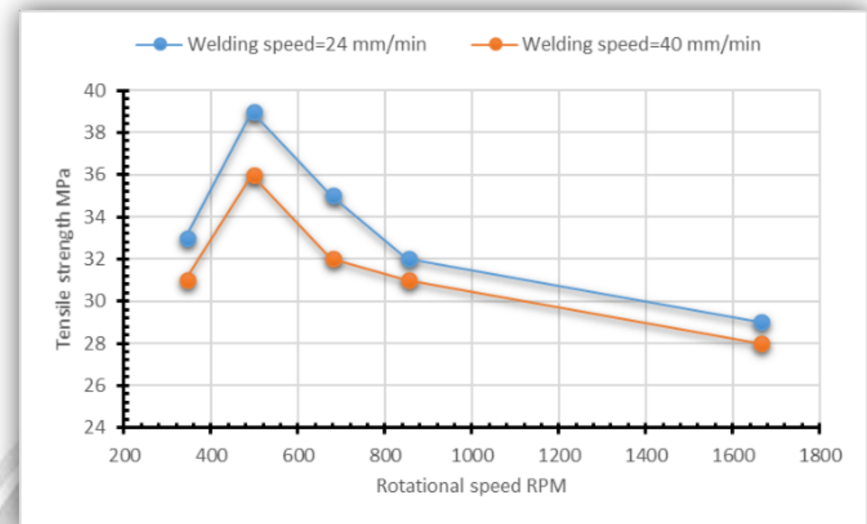

Figure 8: Tensile strength of friction stir welding

4 Conclusions

- Hardness is increased when rotational speed increases until (850 rpm) when the welding speed was equal to (24 mm/sec).
- Hardness was decreased with increasing welding linear speed when it became (40 mm/sec).
- The maximum hardness and tensile strength found at a rotational speed of (495 rpm) and welding linear speed equal to (24 mm/sec) which is equal to the hardness of (72 Shore D) and tensile strength of 39 MPa.
- There is an opportunity to weld dissimilar polymers.

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Vol.31, No.2.| 2023

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تأثير متغيرات لحام الخلط والاحتكاك على الخواص الميكانيكية لوصلة لحام البوليمرات الغير متشابهة

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الخلاصة:

تتطلب وصلات اللحام من المواد التي يصعب لحامها بالطرق التقليدية، وخاصة المواد البوليميرية، لحام الخلط الاحتكاكي (FSW). في هذا البحث تم استخدام نوعين من البوليمرات لدراسة تأثير بعض عوامل اللحام الاحتكاك (على الخواص الميكانيكية لوصلات لحام البوليمرات الغير متشابهة. تم لحام ألواح البولي إيثيلين عالي الكثافة (HDPE) والبولي فينيل كلورايد (PVC) بأبعاد (5 × 100 × 200 مم) باستخدام تقنية الخلط الاحتكاكي (FSW). تم استخدام اداة اللحام بقطر الكتف (18 مم) وقطر المسمار (6 مم) بارتفاع (4.8 مم). تم استخدام السرع الدورانية (340, 495, 675, 850, 1660 دورة في الدقيقة) مع سرعتين خطية (24 , 40 مم / ثانية). أظهرت نتائج الاختبارات الميكانيكية زيادة الصلابة مع زيادة سرعة الدوران حتى (850 دورة في الدقيقة) ثم انخفضت عند سرعة اللحام الخطية (24 مم / ثانية). وكذلك انخفضت قيمة الصلابة عند السرعة الخطية (40 مم / ثانية). بالإضافة إلى ذلك تم الحصول على أقصى صلادة ومقاومة شد عند السرعة الدورانية والخطية (495 دورة في الدقيقة)، (24 مم / ثانية) على التوالي، حيث كانت اقصى صلابة (72 شور د) ومقاومة شد (39 ميجا باسكال). أخيرًا، أظهرت النتائج بنجاح هذه التقنية من اللحام في لحام المواد البوليميرية الغير متشابهة.

الكلمات الدالة: الاحتكاك، الخلط، اللحام، البولي إيثيلين عالي الكثافة، البولي فينيل كلورايد، البوليمير، الصلابة.