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Enhancing The Efficiency of the Friction Stir Welding Joint for Low-Density Polyethylene Sheets by Adding Alumina Powder

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Abstract

The goal of this study is to use friction stir welding to improve the welding zone of Low-Density Polyethylene sheets by adding alumina powder with a particle size of 25 µm. Welding was done with a shoe tool at a zero-tilt angle, with alumina powder percentages of 10, 15, 20, 25, and 30 % added to the welding zone. In all welding experiments, the same 520 rpm tool rotational speed and 20 mm/min tool travel speed were applied. In all instances of the additional percentages of alumina powder, mechanical testing like tensile, flexural, and hardness tests revealed that the welded specimens' mechanical characteristics were better than those of the base substance. The friction stir welding technique increased the mechanical properties, formed defect-free joints, and created excellent low-density polyethylene sheet weldments that were reinforced with alumina powder according to the test results. The best results for mechanical properties were achieved by adding 10% of alumina powder to the welding zone.

Keywords: Friction stir welding, Low-Density polyethylene, mechanical tests, alumina powder.

Introduction

Recently, thermoplastics have been extensively used in many industries, including automotive, aerospace, and construction [1]. Adhesive bonding, mechanical joining, welding, or hybrid joining methods are all options for joining polymers [2].The traditional welding techniques in the field of polymers were accompanied by defects or limitations. These welding methods are hot tool welding, induction welding, laser welding, vibration welding, friction welding, and ultrasonic welding. Hot tool welding was one procedure that required a lengthy cycle time. Laser welding experiment equipment was very expensive. Friction welding needs a flattened face and the machine costs are relatively high. Large joints cannot be welded using ultrasonic welding in one step. Noise pollution (90–95 dB) is caused by vibratory welding [3–5]. Therefore, it became important to create new welding technologies.

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The growth of the plastics sector necessitated the development of high-productivity welding processes, as opposed to fusion welding, which takes a long time to complete [6]. Friction stir welding (FSW) was created as a brand-new welding technique in 1991 at The Welding Institute (UK) [7]. The highly alloyed aluminium alloys, which were thought to be difficult to weld using conventional fusion welding techniques, were the first materials to which it was used [8,9]. After that, applications of the FSW technique extended to include welding titanium alloys [10], magnesium alloys [11], stainless steel [12,13], copper alloys [14,15], zirconium alloys [16], as well as dissimilar alloys [17]. Clark invented different FSW tools to join thermoplastic polymers in 1999, and thermoplastic FSW research began. The extensive research, on the other hand, started in 2005 and increased after 2009 [18]. E. Squeo et al. [19] evaluated how the feed rates and pin rotational speeds affected the durability of the FSW welded Polyethylene (PE) joints. S. Saeedy et al. [20] investigated how different tool rotational speeds (TRS) and tool tilt angles (TA) affected the high-density polyethylene (HDPE) weld quality. The strength increased as the TRS increased from 1000 rpm to 1400 rpm, but declined in the range of TRS above 1400 rpm to 1600 rpm based on the optimum welding condition, where the joint efficiency was 75% of the base material strength. To investigate how FSW factors affect weld strength, Y. Bozkurt [21] selected the optimum welding parameters using the Taguchi method of process parameters as a statistical design of the experiment strategy, and the outcomes were confirmed by additional experiments. The optimum welding conditions for ultimate tensile strength (UTS) were TRS, tool travel speed (TTS), and TA of 3000 rpm,115 mm/min, and 3° respectively. According to the measurement, the UTS and joint efficiency increased from the initial welding parameters by 112% and 105%, respectively. J. Gao et al.[22] joined Polyethylene sheets using underwater FSW by adjusting the TRS and TTS. The findings indicated that the tensile strength increased initially as the TRS and TTS increased, then decreased. The maximum value of tensile strength of the underwater welded joint was 12.3 MPa, which is greater than that of a typical weld joint. I-FSW was proposed by B. Vijendra et al. [23] which is considered a hybrid FSW technique for HDPE joining and included an optical infrared temperature sensor, and an induction power source, also affixed around the heated FSW tool is an induction coil. The temperature controller, which is timed with the induction power source, receives a signal from the temperature sensor, which measures the temperature at the tool's point. Given that the overall width of the transition zone is small and the morphology is less complex, the welded joint's strength was almost equal to that of the base material under the ideal circumstances of a tool-pin temperature of 45 °C and a TRS of 2000 rpm. It is believed that I-FSW's impact on the crystallization mechanism plays a significant role in determining how well joints function mechanically. Eslami et al. [24] constructed a Teflon stationary shoulder to join 3-mm-thick PE plates using various tool diameters and welding conditions. The most important factors in determining the FSW temperature were the tool's diameter, the TRS, and the TTS. When using this tool, heat is predominantly produced by the rotating pin's surface contact with the copper sleeve rather than the base material. In comparison to the UTS of the parent material, the maximum joint efficiency of 97% was attained. High rotational speed and high welding speed produced the strongest welds. R. Azhiri et al. [25] investigated the impact of nano-silica addition in the welding of acrylonitrile butadiene styrene (ABS) united by FSW. The strength of joints is increased by 26% with the inclusion of nano silica reinforcement. Additionally, welding with two passes caused uniform nano silica dispersion in the friction stir processed (FSP) zone, creating a composite-like structure that boosts joint effectiveness by as much as 100%. J. Oleiwi et al.[26] used the friction stir processing technique by adjusting the proportions of polyvinyl chloride (PVC), polypropylene (PP), and

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styrene acrylonitrile (SAN) in the HDPE basic material, the mechanical properties of HDPE plates were studied. A 15% ratio of PVC was added to the welding zone. The optimum mechanical parameters for tensile strength and hardness were preserved. H. Abdulkadhum et al. [6] examined FSW on HDPE sheets reinforced with PP strips added to the weld zone at various percentages, including 15, 20, 25, and 30 %. Welding conditions were TRS 20 rpm and TTS 20 mm/min. Sound welds with improved mechanical properties were obtained for the case when the proportion of PP added to the weld zone was 25 %. It has been discovered that there is little literature available on the FSW of LDPE. The purpose of this research is to investigate the feasibility of creating welds that are highly strengthened, sound, and free of defects by improving the mechanical characteristics of friction stir-welded joints made of LDPE sheets.

Experimental Methods

Materials and Techniques

The test specimen's final measurements (200 mm x 100 mm) were cut from sheets of LDPE with a thickness of 5 mm using a conventional milling machine. Next, a side incision was made in the specimen's first section to serve as a female part for inserting the alumina powder. and the second part was machined in the side profile to act as the male part. The alumina powder (Al_2O_3) was placed between the male and female sections of the specimen, with volumetric additive percentages of 10, 15, 20, 25, and 30 % of the welding zone, respectively. Figure 1 depicts the two portions of the specimen. Figures 2&3 show a shoe tool manufactured of H13 tool steel with 18 mm shoulder diameter, 5 mm pin diameter, and 4.5 mm pin length, the shoe was added to the tool to prevent the plasticized polymer in the welding zone from coming out and keep it within its limits. The finished tool's shoulder was installed on a thrust bearing and placed on an aluminium plate. FSW tests were carried out using a fixture composed of two steel parts and a 20 mm thick high carbon steel backing plate on a vertical milling machine. All examples were welded, the shoulder's lowest point below the surface of the riveted plate was at a depth of 0.4 mm, and the TRS and TTS were 520 rpm and 20 mm/min, respectively. The tool was moved longitudinally along the weld line after a 45-second dwell time during the plunge stage to enable the necessary heat generation and the creation of the pool of semi-molten polymer. The tool will stay in place for 15 minutes after reaching its final position during the welding process in order to avoid distortion.

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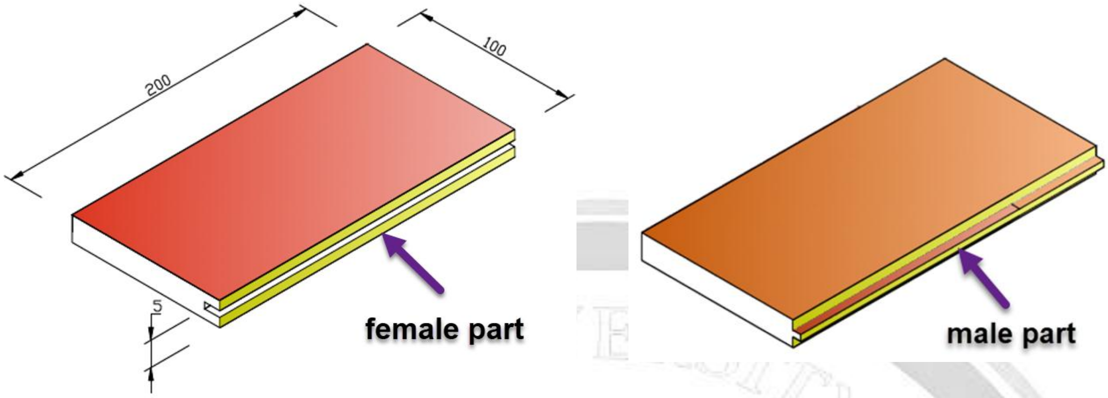

Figure 1: Welding Specimens with Male and Female Sides (dimensions in mm)

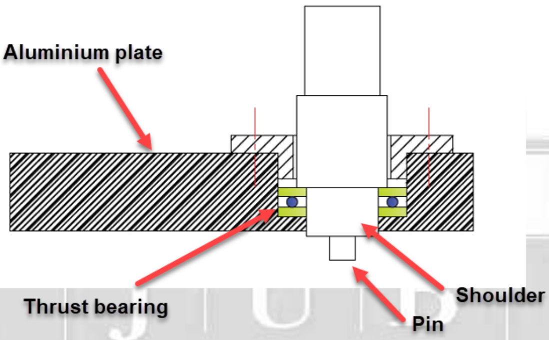

Figure 2: Assembled Parts of FSW Tool

Figure 3: Illustration of the FSW tool during the welding process

Calculations of The Added Alumina Powder

The necessary arrangements have been implemented to prepare the place for placing the alumina powder, by preparing the two parts of the welding specimen as shown in Figure 4, where the two pieces are assembled and the protruding part was mounted with the slot executed in the other part, as shown in Figure 5. Considering the lengths of the welding zone and powder space are the same, the percentage of alumina powder was calculated based on the area of space between the male and the female parts and the area of the welding zone. By assembling the two sections of the welding specimen as shown in Figure 4, and mounting the protruding part with the slot created in the other piece, as shown in Figure 5, the necessary preparations have been made to prepare the area for inserting the alumina powder. The percentage of alumina powder was determined using the area of the gap between the male and female components and the area of the welding zone, keeping in mind that the lengths of the welding zone and the powder space are equal.

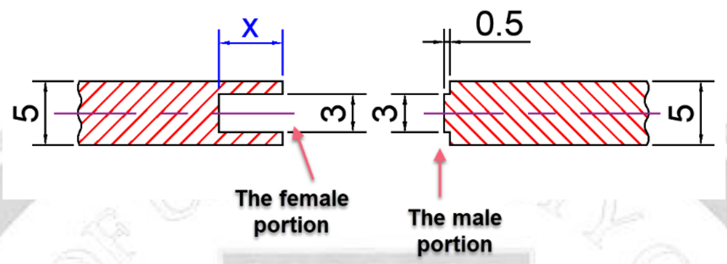

Figure 4: Preparation of the Two Parts of the Welding Specimens (dimensions in mm)

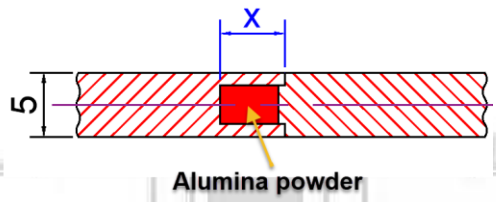

Figure 5: Assembly of the Two Parts of the Welding Specimen

$$A_w = D_{sh}(\mathrm{t}) = 18(5) = 90\ \mathrm{mm}^2$$

Where: $A_w = area\ of\ the\ welded\ zone$

D_{sh} = shoulder diameter = 18 mm,

t = thickness of the welded specimen = 5 mm

$$A_{sp} = w_s(\mathrm{x} - L_p)$$

Where: A_{sp}= The cross-sectional area of the space between male and female parts

x = Depth of slot, (mm)

w_s = Slot width which is constant, (mm)

w_a = Space depth of alumina powder, (mm)

L_p = protrusion length, (mm)

$$Al_p = \frac{A_{sp}}{A_w}(100)$$

Where: Al_p= Percentage of added alumina, (%)

The percentage of added alumina powder is shown in Table 1

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Table 1: Added Alumina Powder

Case	w_s (mm)	x (mm)	L_p (mm)	A_w (mm^2)	A_{sp} (mm^2)	Al_p (%)
1	3	3	0.5	90	7.5	10
2	3	4.5	0.5	90	12	15
3	3	6	0.5	90	16.5	20
4	3	7.5	0.5	90	21	25
5	3	9	0.5	90	25.5	30

Test Procedure

The percentages of alumina powder used, which were 0, 10, 15, 20, 25, and 30%, were used to determine the tensile, flexural, impact, and hardness tests that were performed on the welded examples. According to ASTM D 638-03, a tension test was conducted. with three test specimens chosen for each percentage of alumina powder. The same No. of specimens has been selected for the other tests (flexural, impact, and hardness tests). As illustrated in Figure 6, tensile test specimens were machined to the requisite dimensions, with the specimens being cut in the welding zone along the welding direction.

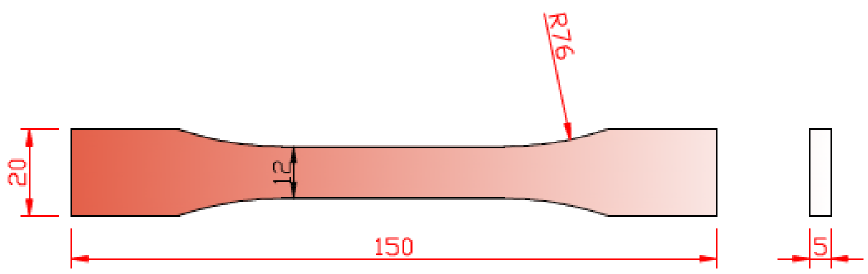

Figure 6: Tensile Test Specimen with ASTM D638-03

Flexural specimens were created in accordance with ASTM D790, milled to final standard measurements of 100 mm x 10 mm x 5 mm, and cut in the welding direction. The weld face was tested on three samples from each experiment, and the weld root was tried on the remaining samples. These tests were conducted at room temperature and took into account the average value of the flexural strengths, which was obtained using a universal test machine. For plastics, a 3-point flexural test has been carried out and is advised. Three specimens with final standard measurements of 80 mm x 10 mm x 5 mm were cut for the proportion of alumina powder for the impact test. The impact test was carried out using Izod's impact machine in line with ISO 180.

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Results and Discussion

Preliminary Test

The parameter that was the subject of this research was expressed as a percentage of reinforcement. Given that the best mechanical properties were obtained by using these welding parameters, it was adequate to provide the best welding parameters that had been chosen from a number of welding experiments on LDPE sheets in comparison to base materials. As a result, all tests used the TRS and TTS welding parameters (520 rpm, 20 mm/min). With a 45-second dwell time, the pin was inserted into the joint surface to a depth of 0.4 millimeters.

Effect of Reinforced Material

Figure 7 displays the findings of the tensile test. This demonstrates how adding alumina powder to the LDPE base material affects the tensile strength of the welded connection. Maximum tensile strength was observed when the second material, alumina powder, was added to the LDPE sheet at 30 %, and it was also observed that the strength of all specimens reinforced with alumina powder was improved. Strength and stiffness are produced during the reinforcing step. Most of the time, the reinforcement is more rigid, strong, and durable than the matrix.

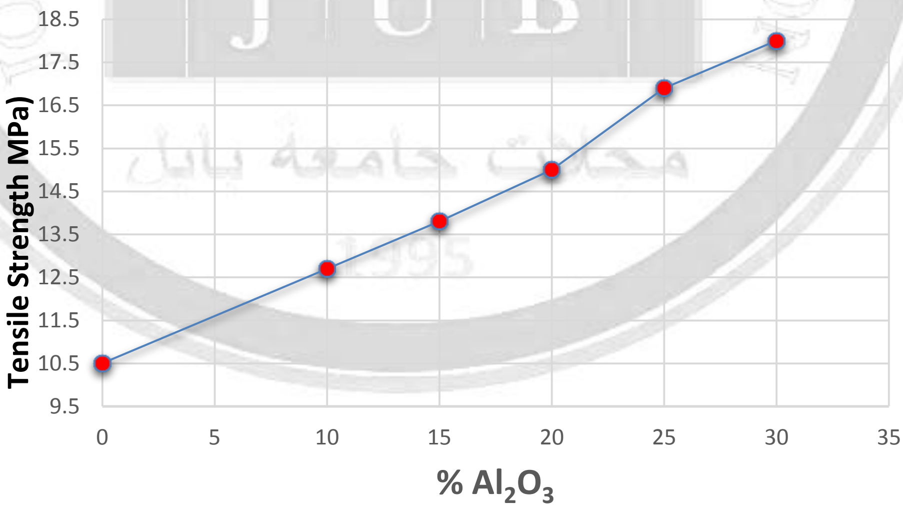

Figure 7: Tensile Strength with ASTM D638-03

Maximum flexural strength was observed when the second material, alumina powder, was added to the LDPE sheets at 30 %, and it was also observed that the strength of all specimens reinforced with alumina powder was improved. The relationship between the percentage of added powder and strength is a direct relationship. Figure 8 displays the findings of the flexural test. The result is the same as a tension test.

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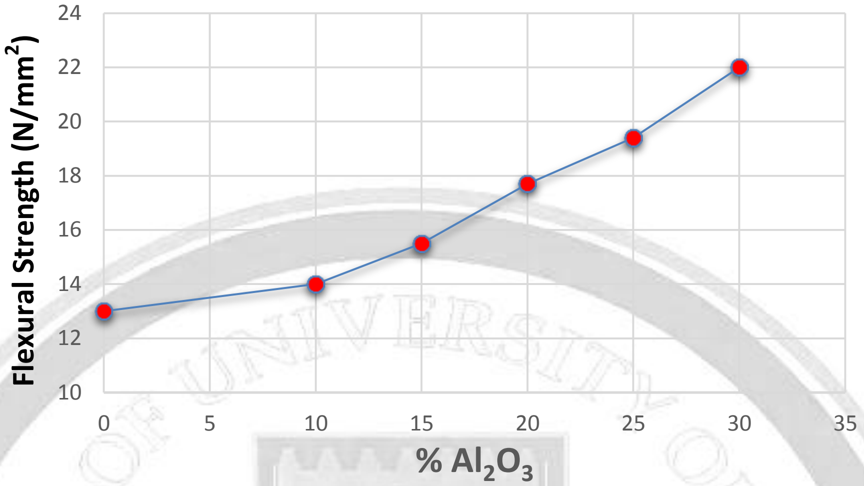

Figure 8: Flexural Strength LDPE Welded Sheets

The results of the impact test indicated that there was no break in all the specimens that were used in the test.

The Hardness test (Shore-D), which has a scale graduation (0-100) hardness number was carried out on the specimens for each added percentage of alumina powder. The results are shown in Figure 9. The test was performed according to ASTM D224003. It can be observed that as the alumina powder percentage of the welded specimens increases, the hardness value increases.

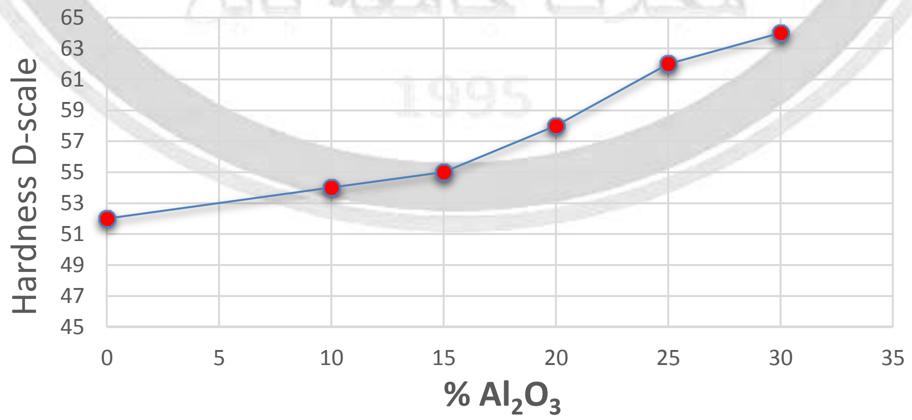

Figure 9: Hardness Test (Shore-D) of LDPE Welded Sheets.

If no alumina powder was added, Table 2 shows that the LDPE sheet's FSW efficiency was 80.5 % when compared to the basic material's tensile strength. Additionally, even though all samples added with alumina powder had tensile strengths greater than the base material, increasing the value of this property for higher values of the welded area's tensile strength is not advantageous. As a result, the lowest added percentage of alumina powder may be used

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to achieve a weld efficiency close to 100% or a welded zone's tensile strength close to the tensile strength of the base material.

Table 2: Welding Efficiency Based on the Tensile Strength.

Experiment no.	Alumina Powder (%)	Tensile Strength (MPa)	Welding Efficiency (%)
1	0	9.5	80.5
2	10	12.5	105.9
3	15	13	110.2
4	20	14	118.6
5	25	16	135.6
6	30	17.5	148.3
Base material	--	11.8	

Conclusions

In this research, LDPE sheets were welded using FSW, and the impact of adding alumina powder to the weld zone on the weld's mechanical properties was examined. All weld experiments employed the same TRS and TTS. Based on the amount of alumina powder added, a number of mechanical tests including tensile, flexural, hardness, and impact tests were carried out to assess welding effectiveness. Examining and contrasting the outcomes with welded specimens devoid of the alumina oxide powder was done. The following summarizes the major conclusions:

1. The welding parameters applied in each welding trial were TRS of 520 rpm and TTS of 20 mm/min.
2. In terms of tensile strength, flexural strength, and hardness, the mechanical characteristics of the welded specimens with alumina powder were superior to those of the welded specimens excluded from alumina powder.
3. In terms of tensile strength, flexural strength, and hardness, the mechanical properties of the samples welded with alumina powder were superior to those of the samples welded without alumina powder.
4. The mechanical properties of tensile strength, hardness, and bending flexural strength were improved, and this was achieved when 10% alumina powder was added to the weld zone.

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5. Because the tensile strength, hardness, and flexural strength values are all greater than the values of the mechanical properties of the parent material, the case in which 10% alumina powder was added can be deemed adequate. Any further development is therefore useless.

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تعزيز كفاءة اللحام بالاحتكاك والخلط لألواح البولي إيثلين منخفضة الكثافة عن طريق إضافة مسحوق الألومينا

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الخلاصة

الهدف من هذه الدراسة هو استخدام اللحام بالاحتكاك والخلط لتحسين منطقة اللحام لألواح البولي إيثلين منخفضة الكثافة عن طريق إضافة مسحوق الألومينا بحجم حبيبي ٢٥ مايكرومتر. تم إجراء اللحام باستخدام أداة خاصة لهذا الغرض بزاوية ميل صفري، مع إضافة نسب مسحوق الألومينا ١٠,١٥ , ٢٠ , ٢٥ و٣٠ بالمائة إلى منطقة اللحام. في جميع تجارب اللحام، تم تطبيق نفس السرعة الدورانية للأداة ٥٢٠ دورة في الدقيقة وسرعة خطية ٢٠ مم / دقيقة في جميع النسب المئوية المضافة من مسحوق الألومينا، كشفت الاختبارات الميكانيكية مثل اختبارات الشد والانحناء والصلادة أن الخصائص الميكانيكية للعينات الملحومة كانت أفضل من تلك الخاصة بالمادة الأساسية. زادت تقنية اللحام بالاحتكاك والخلط من الخواص الميكانيكية، وشكلت وصلات خالية من العيوب، وأنتجت لحاماً عالي الجودة لألواح البولي إيثلين منخفضة الكثافة المقواة بمسحوق الألومينا، وفقًا لنتائج الاختبار . تم تحقيق أفضل النتائج للخواص الميكانيكية بإضافة ١٠٪ من مسحوق الألومينا إلى منطقة اللحام.

الكلمات الدالة: اللحام بالاحتكاك والخلط، البولي إيثلين منخفض الكثافة، الاختبارات الميكانيكية، مسحوق الألومينا.