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RESEARCH ARTICLE Open Access

JOINT EFFICIENCY AND AVERAGE BURN-OFF LENGTH OF FRICTION WELDED ABS TER-POLYMERS

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Abstract:
Welding is one of the most efficient techniques used throughout the decades. Among different techniques, friction welding being one of the most sufficient methods. In addition, polymer is one of the materials that has wide applications such as automobiles, aerospace, medical etc. The present study has been carried out to investigate the efficiency of similar friction-welded ABS terpolymer joints. The study was conducted using the rotary friction welding method. Three different cases of rotational friction speeds (605, 820, 1220 rpm) and times (15, 30, 60 seconds) were examined for each case by taking nine specimens. The tensile strength of welded joints is compared to that of ABS tensile specimen as received welding. The joint efficiency and burn-off length were calculated. The joint efficiency and burn-off results are compared and discussed. Then the study concluded that the optimum joint efficiency was 17.24% at 605 rpm and 60 seconds. The lower burn-off length was 2 mm at 605 rpm and 15 seconds.

Key Words: *Rotary Friction Welding; ABS Terpolymer; Joint Efficiency; Burn-off Length.*

1. Introduction

In the new global economy, thermoplastics have become a central issue for manufacturing due to their nature of exhibiting thermal, physical, mechanical, chemical, and morphological properties. A primary concern of thermoplastics is melting and glass transition temperature, fracture resistive capacity, amorphous vs. crystalline. In addition, molecular arrangement, surface behavior, carbon chain length, and molecular weight vs. molecular density are the other concerns [1]. Polymers have long been a question of great interest in a wide range of fields because of their identical low surface free energy, viscoelastic properties, higher level of physical properties, higher melting points and very good resistance to degradation. Of particular concern with the adhesive and mechanical components of friction force, polymers are affects drastic tribological differences [2; 3]. One of the greatest challenges is polymers can reduce heat generation at the contact surface and reduces the wear and tear. Manufacturing are a dominant feature of polymers due to less weight and low density [4; 5]. Polymer pyramid, listing thermoplastics with an amorphous or semi-crystalline morphology about cost, performance and formability is shown below in Figure 1. In accordance with industrial manufacturing, welding is one of the most frequently stated problems with thermoplastics. Innovations in technology allowed joining of most materials by fusion and solid-state welding techniques. It is difficult to obtain good-quality weld joints using molten welding methods for thermoplastics. Consistent with this method, friction welding is a solid-state welding process in which the joint is produced under the influence of frictional heat generated at the rubbing surfaces. The two surfaces are forged together under high pressure when the temperature at the interface rises high enough [6; 7].

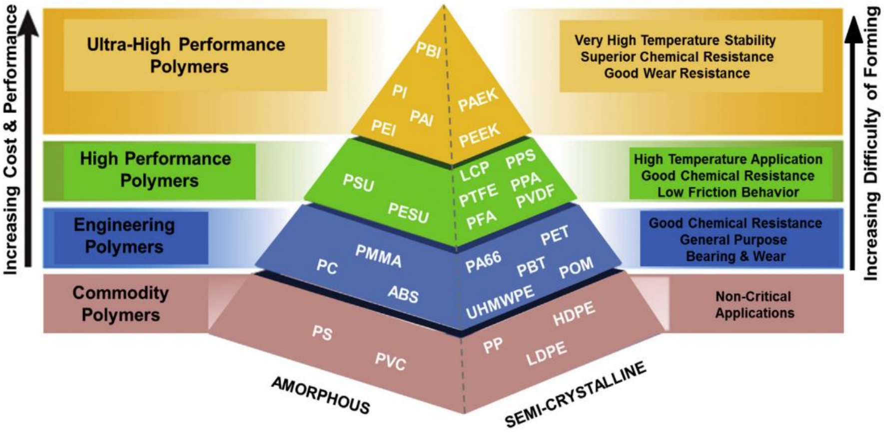

Figure 1: Polymer pyramid [5]

In this method one part of specimens is rotated at nominal constant speed while the other opposite part rotates under an applied pressure. This rotation and pressure are maintained for the identified period until sufficient thermal and mechanical conditioning of the interface region is obtained. Subsequently, the axial force and the rotation is stopped when the machine is braking, then the pressure is increased to upset parts together immediately. An axial force maintains intimate contact between these two parts and plastic deformation of the material occur near the weld interface [8; 9; 10; 11]. The plasticized layer is formed on the interfaces and the local stress system with the assistance of the rotary movement, which extrudes material from the interface into the flash [12]. Previous research has established that nearly 90% of the energy that occurred during plastic deformation is converted into heat, but 10% of this energy remains in specimens as strain energy. The highest temperature tip is at the beginning of friction state [13; 14; 15].

Several attempts have been made to study friction welding properties of different thermoplastics and metals. An experimental study by [16], who studied the effect of solvent or co-solvent on the weld joint between parts of PMMA with PVC. In a study investigating weld joints, [16], reported that welding zone can be eliminated residual stress and the bonding strength is increased while consuming less material [16]. Friction welding parameters are formed the central focus of a study by Geo et al., [17] in which the author worked on welding lap joints of high-density polyethylene (HDPE) and acrylonitrile butadiene styrene (ABS) using by submerged friction stir welding. Using multi-walled carbon Nanotubes (MWCNTs) were introduced into the HDPE/ABS joint to improve the tensile properties of the joints. The effects of different rotational rates, plunge depths, and traverse speeds on the microstructure and tensile strength of joints were investigated [17]. [1] performed the compatibility analysis of two dissimilar polymers (ABS and PA6) by establishing their melt flow properties after aluminum (Al) metal powder reinforcement. The authors utilized two methods such as twin screw extrusion (TSE) and fused deposition modeling (FDM) [1]. Although all these studies had been conducted about rotary friction welding of different materials with rare using polymer materials, almost all of them were about aluminum alloy, copper, stainless steel, low alloy steel, unfortunately, the research about welding ABS terpolymers using rotary friction welding methods are still limiting. ABS is easily machined like turning, drilling, milling, sawing, die-cutting and shearing, ability to cut with standard shop tools and line bent with standard heat strips. Therefore, the aim of this research is to study the joint efficiency and average burn-off length of ABS terpolymers butt joint to achieve this aim the rotary friction welding process was carried out.

3. Materials and Methods

3.1 Material

In this study, Acrylonitrile Butadiene Styrene (ABS) was used as a thermoplastic polymer. ABS has no true melting point, for most applications, ABS can be used between −20 and 80 °C as its mechanical properties vary with temperature. ABS can be chemically affixed to itself and other like-plastics [11]. Mechanical, physical, and thermal properties of ABS are shown in table 1.

Table 1: Properties of ABS ter-polymers [20]

Types	Properties	Values
Physical Properties	Density (g/cm^3)	1.07
Mechanical Properties	Tensile Strength, Yield (GPa)	76
	Elongation at Break	2.5-40 %
	Flexural Modulus (GPa)	3.65
	Flexural Yield Strength (MPa)	128
Thermal Properties	Melting point	No specific point
	Melt Flow	18 - 23 g/10 min
	Deflection Temperature at 1.8 MPa (264 psi) (°C)	87
	Coefficient of Thermal Expansion	2.0 – 10.3 cm/cm.

3.2 Specimen Preparation

A 27 mm diameter cylindrical base metal bars were machined by lathe machine according to ASTM-D638 for ten specimens with the dimensions shown in

Figure 2. Then the specimens were prepared for friction joint testing while one of the specimens were prepared for tensile test without welding (as received).

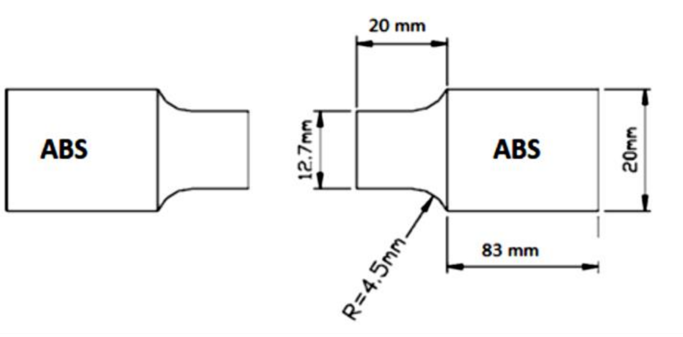

Figure 2: Schematic of Specimens

3.3 Welding Procedure

Welding was performed by taking three different range of friction speeds 1220, 820, and 605 rpm. The friction welding was performed at a three different friction time for each friction speed. The similar material was used which is rotating member and stationary member are ABS. The machine is stopped when the preset displacement has occurred, then the pressure is increased for producing a high-quality solid-state joint. The length of bars was measured before and after welding for evaluating the burn-off length.

3.4 Tensile Test

The tensile specimen was performed at room temperature on a universal tensile machine (LY-1066A) at a crosshead speed of 50 mm/min. The joint strength of friction welding is evaluated in tensile test. The tensile test is controlled by computer software for inputting and recording all parameters (elongation, force, peak elongation, area etc.) the load is applied until the fracture occurs. The joint efficiency is calculated by equation (1) in terms of tensile strength for welded specimen and as received specimen [18], and the results are shown in Table 3.

$$\text{Joint Efficiency} = \frac{\text{Tensile Strength of Weld Joint}}{\text{Tensile Strength of Material Without Weld}} \times 100\% \quad (1)$$

4. Results and Discussion

The friction welding butt joint were used to analyze the relationship between the joint efficiency with different friction time and rotational speed, the appearance is shown in Figure 3.

(a) (b) (c)

Figure 3: Friction-welding results at (a) 605 *rpm,* (b) 820 *rpm* (c) 1220 rpm

Table 2 compares the results obtained from the preliminary analysis of friction welded ABS ter-polymer and as received (without welding) ABS samples.

Table 2: Experimental results of tensile testing of ABS ter-polymers

No. of test	Friction Time (*sec.*)	Friction Speed (*rpm*)	Peak stress (*MPa*)	Time before fracture (s)	Efficiency of joint %	Fracture locations
1	15	605	0.041	1.08	0.28	Weld joint
2	15	820	1.51	4.2	10.32	Weld joint
3	15	1220	0.66	1.2	4.511	Weld joint
4	30	605	0.257	1.8	1.76	Weld joint
5	30	820	0.056	0.9	0.383	Weld joint
6	30	1220	1.836	0.3	12.55	Weld joint
7	60	605	2.522	1.2	17.24	Weld joint
8	60	820	1.184	0.6	8.1	Weld joint
9	60	1220	0.204	0.06	1.394	Weld joint
As received	-	-	14.63	2.4	-	Shoulder

The results of the correlational analysis of friction time and frictional speed of the three different cases are summarized in figure 4.

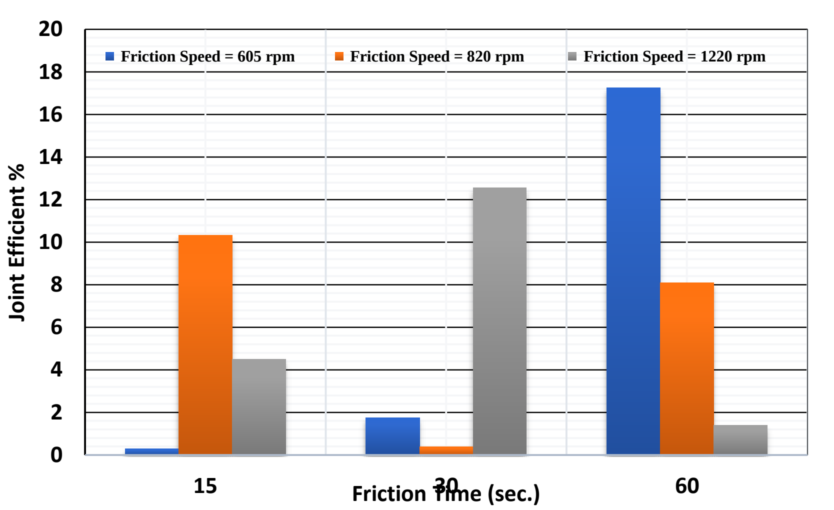

Figure 4: Relation between friction times and joint efficiency by the effect of friction speed.

A first case (at 605 rpm) of results show a positive correlation between joint efficiency and friction time in which the joint efficiency is 0.28% and this value slightly increased at 30 seconds while by increasing the friction time to 60 seconds, the joint efficiency significantly increased to 17.24 %. However, joint efficiency appeared to be less affected by increasing friction speed, as it can be seen from the graph (above). A strong relationship between joint efficiency and friction speed has been reported in the literature, these results reflect those of [13] who also found that the effect of increasing the flow temperature the tensile strength will increase and the welding interface has become rougher. Comparing the two set results, it can be seen that, no significant difference between the two cases was evident. In the second case (820 rpm) with compared to the first case the joint efficiency fluctuated which is reduced from 10.32% to 0.383% and then this value is significantly increased to 8.1%. This pattern is reversed when friction speed is increased to 1220 rpm. However, this result has not previously been described. Taken together, these results suggest that there is an association between friction speed, time and joint efficiency. A possible explanation for this might be that due to its melting point of ABS because it has no true melting point in which friction welded ABS has more time for melting due to its physical property has a melt flow 18-23g/10min. However, these results were not very encouraging. It can thus be suggested that ABS ter-polymer can be successfully weld at 60 second and 605 rpm as a peak tensile strength is obtained (2.522 MPa).

The next section of the study was concerned with average burn-off length during the friction welding. Therefore, the length of material before and after friction welding has been measure, hence the burn-off length is calculated by equation (2) and the results are shown in Table 3.

$$\text{Average burn-off length } (mm) = \text{Length before test} - \text{Length after test} \quad (2)$$

Table 3: Average burn-off length of friction welded butt joint of ABS ter-polymers

No.	Friction Time (*sec.*)	Friction Speed (*rpm*)	Length before welding (*mm*)	Length after welding (*mm*)	Average burn-off length (*mm*)
1	15	605	32	30	2
2	15	820	32	28	4
3	15	1220	32	26	6
4	30	605	32	24	8
5	30	820	32	26	12
6	30	1220	32	24	8
7	60	605	32	16	16
8	60	820	32	19	13
9	60	1220	32	13	19

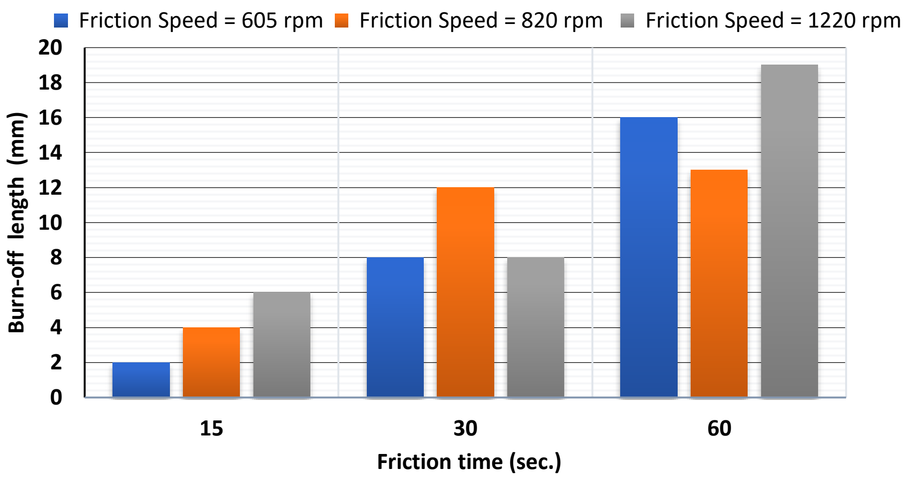

Figure 5: Relation between friction time and burn-off length under the effect of friction speed.

The burn-off is representing as a function of shortening length after friction welding. From the graph above we can see that the burn-off length is increased with increasing friction time in each three different cases. This finding is consistent with that [19] who states that welding parameters are significantly influences the microstructure of the weld joint. Weakly bonded joint related to shorter friction time, lower friction pressure, and lower upsetting pressure, to achieve higher strength, the friction time should be held as short as possible.

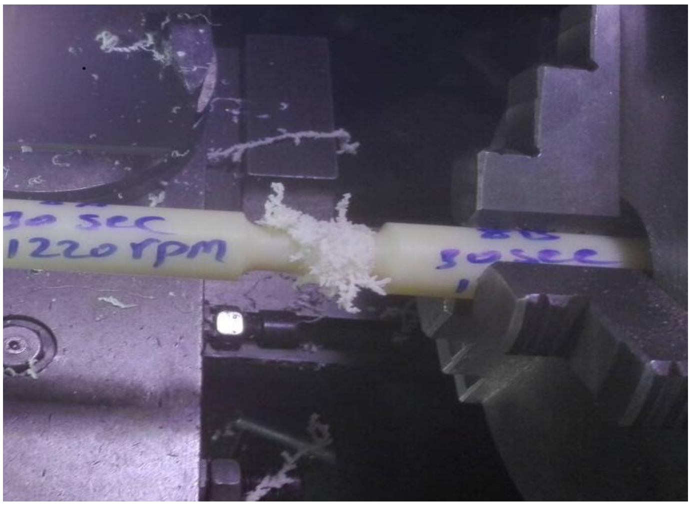

Figure 6: Burn-Off Length Operation During Welding

What is surprising is that all the welded specimens are fractured at the weld interface as shown in figure 7. There are several possible explanations for this result. In reviewing the literature, a possible explanation for this result is due to its mechanical property which is elongation at break is 2.5-40% as compared to the as received ABS specimen is fractured in the shoulder as shown in figure 8.

Figure 7: Welded ABS terpolymer of specimen at fracture

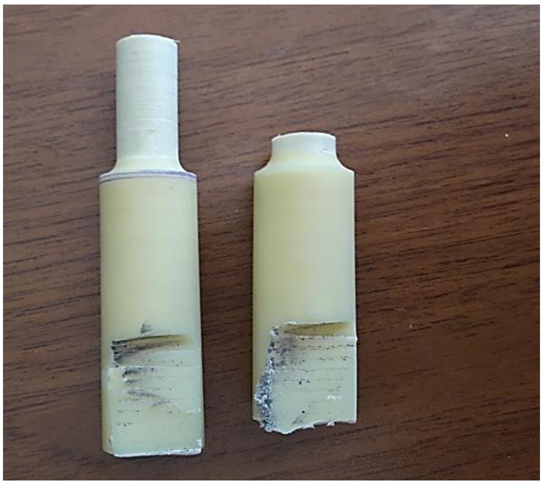

Figure 8: Fracture Location of Specimen as Received

The deformation rate depends on heat generated at the weld interface during friction welding, which depends on friction pressure and burn-off length which is low generated heat rate occur due to low friction pressure and low sufficient time for adjusting the materials to heat up, this reduces the temperature gradient as shown in Figure 9. Furthermore, finer grain rate and low density will induced in the weld joint because of low heat [14; 19].

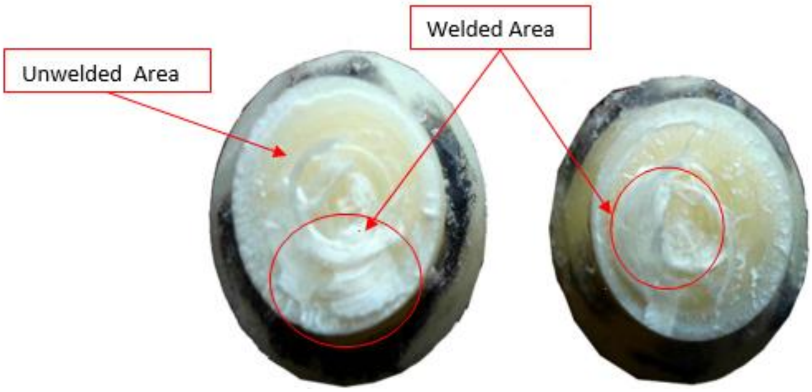

Figure 9: Welded ABS ter-polymer specimen at fracture

5. Conclusions

The aim of the present research was to examine the joint efficiency of ABS polymer under the effects of friction speeds and times. The results of this investigation showed that the most obvious finding to emerge from this study is that the optimal joint efficiency was obtained 17.24 % at 60 seconds in 605 rpm. While burn-off length was 2 mm at 15 seconds and 605 rpm. The research has also shown that the burn-off length was increased with increasing tensile strength of ABS. These findings suggest that in general the deformation rate depends on the heat generated at the weld interface during friction welding. Hence, these findings have significant implications for the understanding of how the temperature gradient at the weld joint is reduced due to the insufficient friction time and friction speed for adjusting the materials to heat up.

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