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Friction welding of multi-shape ABS based components with Nano Zno and Nano Sio_2 as welding reinforcement

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Abstract. Due to the high usage of ABS in industries, such as aerospace, auto, recreational devices, boat, submarines, etc., the purpose of this project was to find a way to weld this material, which gives advantages, such as affordable, high speed, and good connection quality. In this experimental project, the friction welding method was applied with parameters such as numerical control (NC) machine with two different speeds and three cross-sections, including a flat surface, cone, and step. After the end of the welding process, samples were then applied for both tensile and bending tests of materials, and the results showed that, with increasing the machining velocity Considering of samples, the friction of the surface increased and then caused to increase in the surface temperature. Considering mentioned contents, the melting temperature of composite materials increased. This can give a chance to have a better combination of Nanomaterial to base melted materials. Thus, the result showed that, with increasing the weight percentage (wt %) of Nanomaterials contents, and machining velocity, the mechanical behavior of welded area for all three types of samples were just increased. This enhancement is due to the better melting process on the welded area of different Nano contents; also, the results showed that the shape of the welding area could play a significant role, and by changing the shape, the results also changed drastically. A better shape for the welding process was dedicated to the step surface.

Keywords: ABS; bending; cone shape; flat shape; friction welding; frictional joint of polymer; Nano Sio_2; Nano Zno; polymer welding; step shape; tensile

1. Introduction

Polymers are huge molecules that consist of many atoms (Wypych *et al*. 2018). Polymers are divided into three main groups: thermoplastics, thermosets, and elastomers (Soroush and Grady 2019). According to the mechanical and chemical properties, thermoplastics are used in many industrial applications, such as pipes and transmission equipment, electrical equipment, coatings, fittings, and other materials (Shrivastava 2018). for this reason, the connections and how to connect these materials were considered (Stütz *et al*. 2018, Magar HSCaRB 2017). The main focus of welding is on the welding of thermoplastics (Rey-Vinolas *et al*. 2019, Wypych *et al*. 2018). Due to the variety of heating and bonding of plastics, there are many types of welding in the industry (Singh *et al*. 2016). Welding standards are fully described in ISO 472. In this standard, the term “plastic welding” is referred to every process (Li *et al*. 2017, Nan *et al*. 2019, Schmicker *et al*. 2014) used

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to connect two non-metallic materials (Schmicker *et al*. 2014, Winiczenko *et al*. 2017, Won *et al*. 2018, Zarghani *et al*. 2018) to the surface to be treated. In Plastic friction welding moving range are 1 to 2 mm (Kumar *et al*. 2018). The heat generated by the friction welding process would melt the two samples over the edges and create typical and prevalent layers to strengthen the welding joints (Nan *et al*. 2019). Moving two pieces of work to create friction in this method can be linear or circular (Stütz *et al*. 2018, Huang *et al*. 2019). ABS polymer or acrylonitrile butadiene styrene (Gun'ko 2019, Sindu 2018) is a thermoplastic polymer. This is material obtained from styrene polymerization acrylonitrile in the presence of polybutene and has an amorphous structure (Mura *et al*. 2019). ABS is one of the most used plastic materials in industries, which has an affordable price and its mechanical, thermal, and chemical properties (De Bilbao 2011). Nanoparticles of Silica are also used in this project due to its high stability, low toxicity and applicability, and a wide range of molecules and polymers (Rostamiyan *et al*. 2015). Zinc nanoparticles are applied on a relatively high electric semiconductor, water-insoluble and biocompatible, and its slip resistive that can be used in different tasks depending on the conditions. Bending test is a kind of mechanical test of materials which the resistance of the material to bend is measured. This test was performed by a universal testing machine in a three-point flex test. during the bending test, upper surface of materials face the pressure behavior and the lower area face the tension because the tension force is usually less than the Pressure force, fracture or cracking would occurs from the lower part.Tensile test is one of the destructive tests of material science, which a single-axial pull-up sample is studied to failure. The test results are typically used to select a substance to control quality and to predict how a substance reacts under other types of forces. in similar investigations in friction welding of polymeric samples obtained results showed that, according to recent researches, the use of metals powdered at the sample surfaces would increase bond strength (Schmicker *et al*. 2014, Kumar *et al*. 2018, Mura *et al*. 2019, Srinivasa *et al*. 2015). in this project, nanoparticles used on the surface can replace the metal powder. Thus, different cross-section type was used to achieve better results.

2. Experimental details

2.1 Material characteristics

The mechanical properties of ABS, Sio_2 and Zno are mentioned in Table.1. pure ABS is purchased from the National Petrochemical Company located in Mulla Sadra St, Tehran. in this experiment, two types of nanoparticles were purchased from US Research Nanomaterials, Inc. in Houston, TX, USA, 77084, USA. The amount of nanoparticles consumed is 0.7% of the total weight of samples. The silica nanoparticles have a purity of 99% and a size of 20-30 nm, and zinc nanoparticles of 99% purity and 10-30 nm particle size.

Table 1 Material mechanical properties

Material	True Density	Molding Shrinkage	Pyrolysis Thermal Degradation	Flexural Modulus
ABS	1.01 - 1.21ρ (Mg/m^3)	8%	210°C	75.84 MPa
Material	True Density	APS	SSA	Crystal Phases
Sio_2	2.4 g/cm^3	20-30 nm	180-600 m^2/g	single crystal
Zno	5.606 g/cm^3	10-30 nm	20-60 m^2/g	single crystal

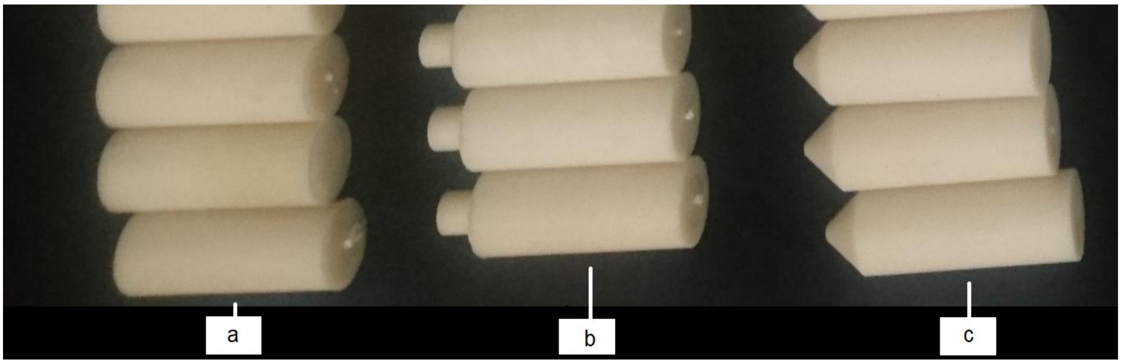


Fig. 1 Flat surface (a) Step surface (b) Cone surface (c)

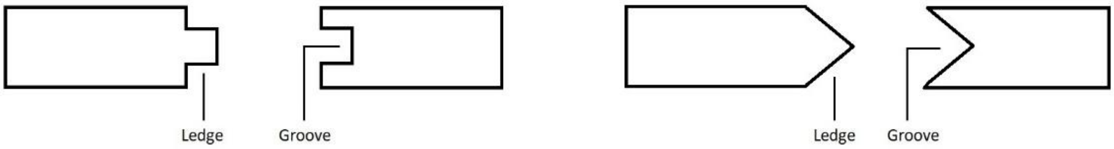


Fig. 1.1 Shape of the flat and cone surface

2.2 Behavioral and experimental procedures

In this test, a TN50D lathe machine is used to provide the required feed rate and rotation force. A fixture designed to hold the piece on the desk of the lathe machine in the proper position. According to the test requirements, it can be easily configured and quickly and accurately swapped samples. A sample with a circular surface is fixed for a friction welding process, and then the second sample is moved with a fast rotating motion. The half-melt material is formed between the two pieces, the rotation is stopped, and the pressure continues to complete the joint. All samples with a length of 40 mm and a diameter of 22 mm were readied for the welding process. The samples were cut by a lathe machine in the desired dimensions and prepared on different surfaces (flat, cone, step), as shown in Fig. 1. The diameter of the ledge for the step surface was selected, the other half of the original samples were 11 mm in diameter, and the groove was drilled by a lathe machine so that the forces and welding behavior could be applied equally on the tow sample sides. The length of the step ledge and groove is 10 mm, and the angle of the cone surface is 45° and 10 mm in length for the same reason as shown in Fig. 1.1. samples with three different surface shapes (flat, cone, step), two rotational speeds (1000, 2000 rpm), 0.05 mm/round feed rate in 15 seconds without nanoparticles and with Sio_2, Zno nanoparticles welded. At first, the samples without nanoparticles were attached to the lathe machine spindle and the other sample attached to the fixture, then Tangent two surfaces of samples and turn the machine on; after the device arrived at the top speed as been arranged, it quickly triggered the automatic feed rate to begin the welding process. The time in all samples is constant, from the start moment until the end of the welding process. after the time has elapsed, the machine stops wholly and immediately abandoned in the same conditions until it gets entirely cooled. For the step and cone shape samples, which have a ledge, the ledge is attached to the lathe machine spindle, and samples have a groove attached to the fixture. These levels are implemented for all samples in the same way. Samples readied to weld, which can be indicated in Fig. 2.1, Fig. 2.2, Fig. 2.3, and welded samples can be observed in Fig. 3.1, Fig. 3.2. after the

(a)

(b)

(c)

Fig. 2 (a) Flat surface ready to welding, (b) Cone surface ready to welding, (c) Step surface ready to welding

Fig. 3 (a) Shows the samples during welding process

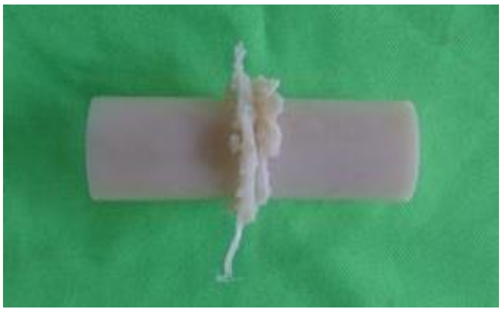
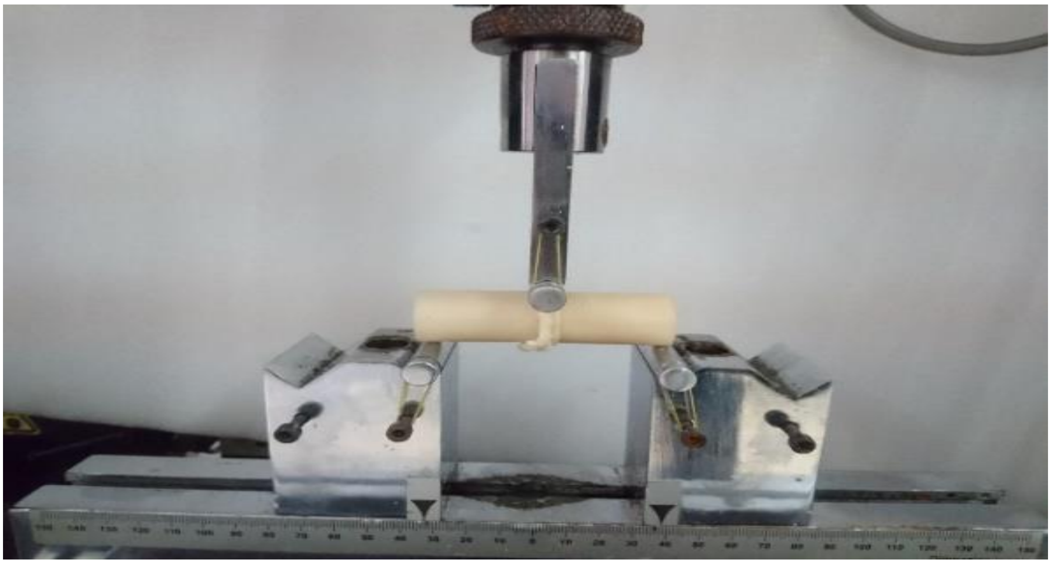
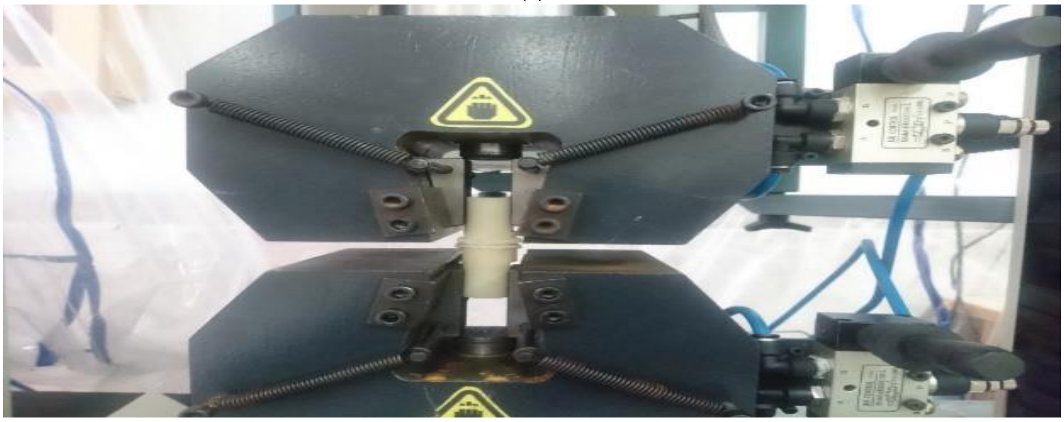


Fig. 3 (b) Shows the welded samples

welding operation, the Bending and Tensile test were conducted, as shown in Fig. 4, Fig. 4.1. The test was repeated three times, and according to the ASTM D5934 standard, the bending test speed was performed at 0.5 mm/min, and the tensile test was selected according to ISO 37 standard.



(a)



(b)

Fig. 4 (a) Welded samples under bending test (b) Welded samples under Tensile test

3. Conclusion and discussion

3.1 Bending test

3.1.1 Pure ABS

As shown in Fig. 5, according to the fact, force and extension variations in neat samples, no deformation, and concentration of stress were observed, and all the factors that cause sudden surface or area changes in the surface in these samples have not existed, no damage or machining process has not applied on these samples, so samples assumed to be constant and uniform. With this assumption, the samples are placed under mechanical tests. According to the diagram, the extension/force variations were analyzed. Since the sample is made of pure ABS (without addition of Nano particles and not welded), the elastic region is in average condition, in 3.87 mm extension

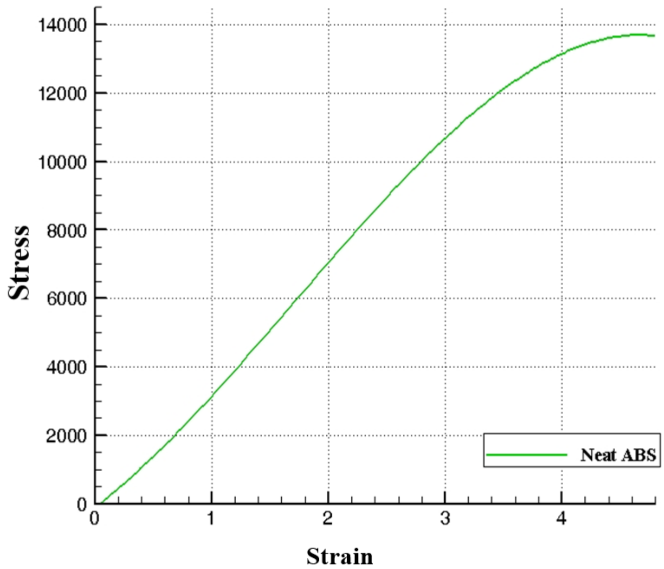


Fig. 5 Pure ABS bending test result

and 12937.46 (N) force, elastic zone ended. These data showed that ABS samples are in normal condition with good elastic levels, and samples before that point return to the initial state. The important thing is that forces in this area do not seriously damage the samples. Engineering design is essential, and calculating the safety of the design in the critical point is one of the topics that must be studied. in another glance, samples reached their ultimate limitation in an extension of 5.10 mm and a force of 12986.65 (N) and naturally failed. In engineering design, engineering piece is in different working conditions. to prevent unexpected failures and possible problems for further engineering or industrial application, the samples must be tested. Understanding the limitations of samples in working conditions and failure points can predict the sample's behavior and lead to better design in future usage in different industries.

3.1.1.2 Flat surface without nanoparticles

As seen in Fig. 6(d), the welding ABS at the speed of 1000 RPM and a speed of 2000 without a nanoparticle were mentioned; the lower speed of the welding process creates more rigid material, which failed in a lower state of strength than higher welding speed. According to this point, this method can be used in situations where elasticity is essential. It must be mentioned that the main reason can make better bonding in the polymeric chain; this chain can hold the whole structure and prevent to fail. Also, the rotation speed can play an essential role in the strength of this bonding; increasing the speed the mold zone temperature increases and increasing the mold zone can result in better bonding in thermoplastic structure. From results refined from related figures, it can be obtained that by strengthening the bonding structure, both force and extension increased; it also can be concluded that, at lower speeds, less temperature is generated and eventually increases; the temperature at higher speeds leads better melting on the surface. As shown in Fig. 6.3, the sample welded at a lower rotation speed has 4715.8 N force and 3.50 mm extension; welded samples in higher rotation speed have a force of 5107.4 N, an extension of 3.35 mm reaches the yield point and enters the plastic region. The welded samples at lower rotation speed suffered an unexpected

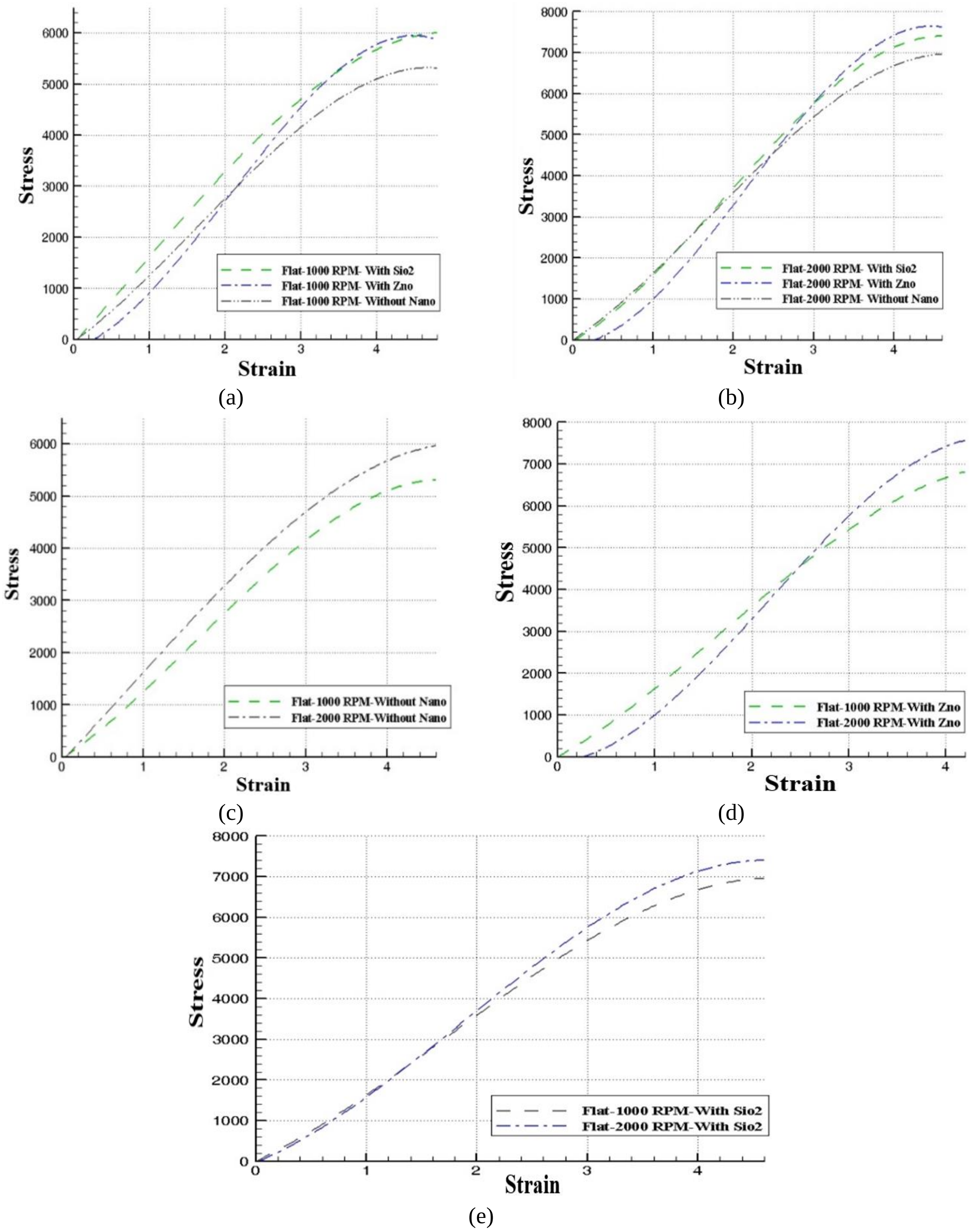


Fig. 6 (a) Shows the machining parameters in terms of the different rotation speeds in Flat surfaces, (b) shows the machining parameters in terms of the different rotation speeds in Flat surfaces, (c) samples with Flat surfaces without nanoparticles under bending test, (d) samples with Flat surface with Zno nanoparticles under bending test, (e) samples with Flat surface with Sio_2 nanoparticles under bending test breakage, which is lower than higher welding speed, so faster rotation speeds in the friction welding improved the fracture point that is due to the higher temperature, the mechanical results of melted welding surface in higher speed was more significant than the lower one.

3.1.1.3 Flat surface with Zno nanoparticles

As shown in Fig. 6(d), based on experiments conducted on the mechanical properties of nanoparticles of zinc oxide, found that the extension increased, while by characterization of samples with Zno, the mechanical strength and extension in the elastic region has increased; it has also displaced yield point and also allows better working performances in industrial usage. Due to the extension observed in the samples, the yield point has occurred in a higher extension, and in this area, the samples showed more elastic behavior than samples without nanoparticles. A deeper study shows that when higher rotational speeds were adopted, the surface of the samples was well melted and combined with nanoparticles, and these nanoparticles were placed in the welding point as a filling agent.

3.1.1.4 Flat surface with Sio_2 nanoparticles

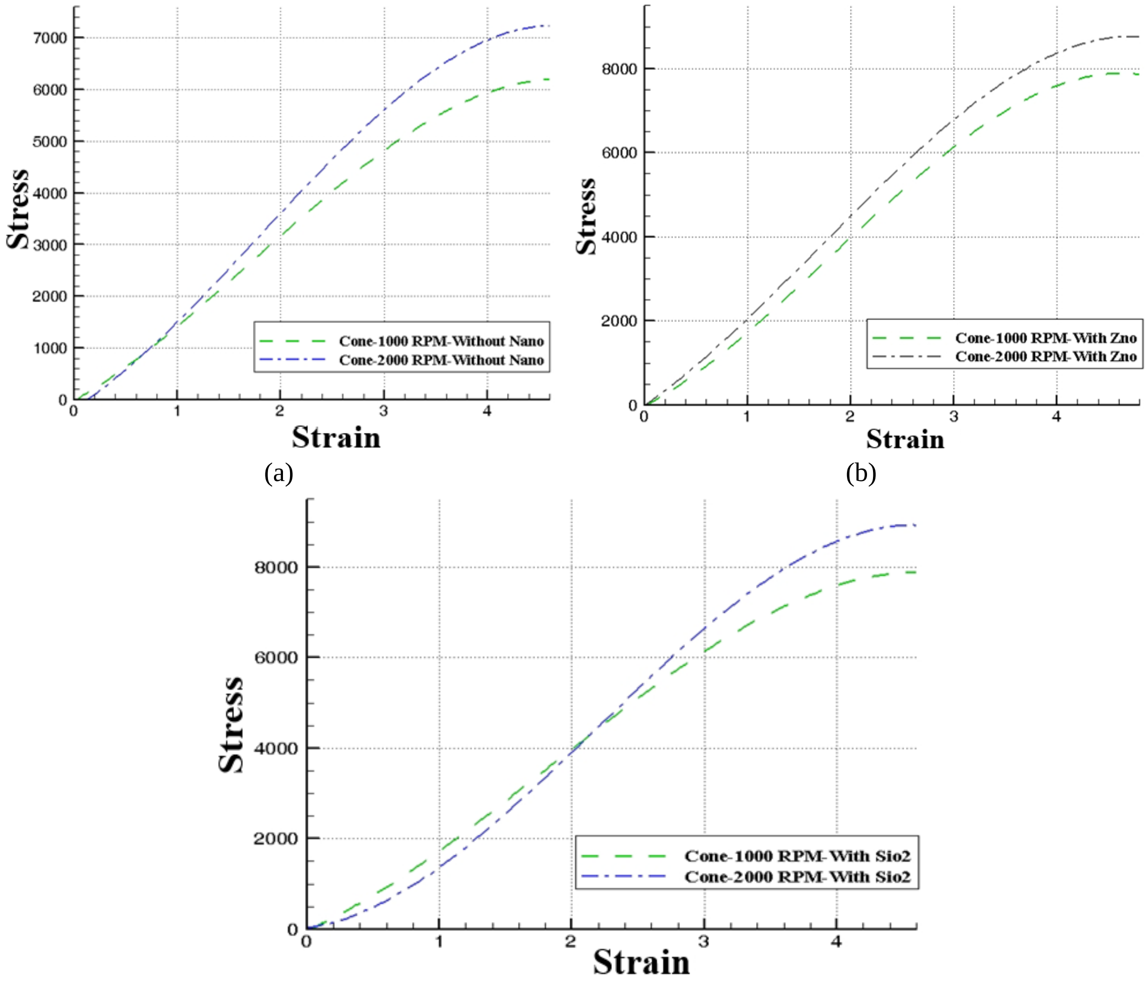
As shown in Fig. 6(e), samples with Sio_2 particles have a stronger strength than welding with Zno and without nanoparticles. Welded samples at the rotational speed of 1000 RPM in force of 6498.7 N and an extension of 3.79 mm, the samples with a rotational speed of 2000 RPM in 7114.19 N force 3.97 mm extension entered the plastic region. The Sio_2 nanoparticles are integrated with the ABS structure due to their adhesion and crystalline properties. The nature of Sio_2 nanoparticles is to complete and strengthens the bonding of chaining. Here nanoparticles will combine with the mold of thermoplastic, and size of the nanoparticle will be added to this chain. In the polymeric chain attached, some micro cracks fail or even unattached parts. The role of nanoparticles here is essential; this particle will be added and cover the unattached area fail in the polymeric chain nanoparticles will strengthen the chain and try to hold the structure in early or unexpected failures. In order to boost the behavior of the materials, nanoparticles will increase more in terms of extension and force. Which improves the welding and boosts performance. A different view of the Sio_2properties can be concluded that cracks will appear on the surface during the welding process (as seen in Fig. 12 (e)). These cracks are filled with these nanoparticles and prevent the pre joint failure.

3.1.2 Cone surface without nanoparticles

As shown in Fig. 7(a), the most important thing is the increase of the fracture point proportion on the flat surface samples. It means that surface type in friction welding significantly affects its resistance. As can be seen, samples without nanoparticles uniformly have reached the yield point. This suggests that the samples faced a minor problem in the welding process. Also, yield points have been increased and improved so that the samples with a higher rotation speed increased the force level to 6869.5 N and the other samples improved their force level to 5868.98 N. Regarding the parameters equivalence, except the velocity of the rotation of mentioned figure, the behavior of the components is the same. However, this should be considered that the higher velocity causes higher temperatures and also results in better integration of the surfaces connection, which itself leads to an increase in the fail and breakage point, and also cross-sectional interactions with each other, resulting in increased friction, heat and melting, which ultimately resulted in a better connection.

3.1.2.1 Cone surface with Zno nanoparticles

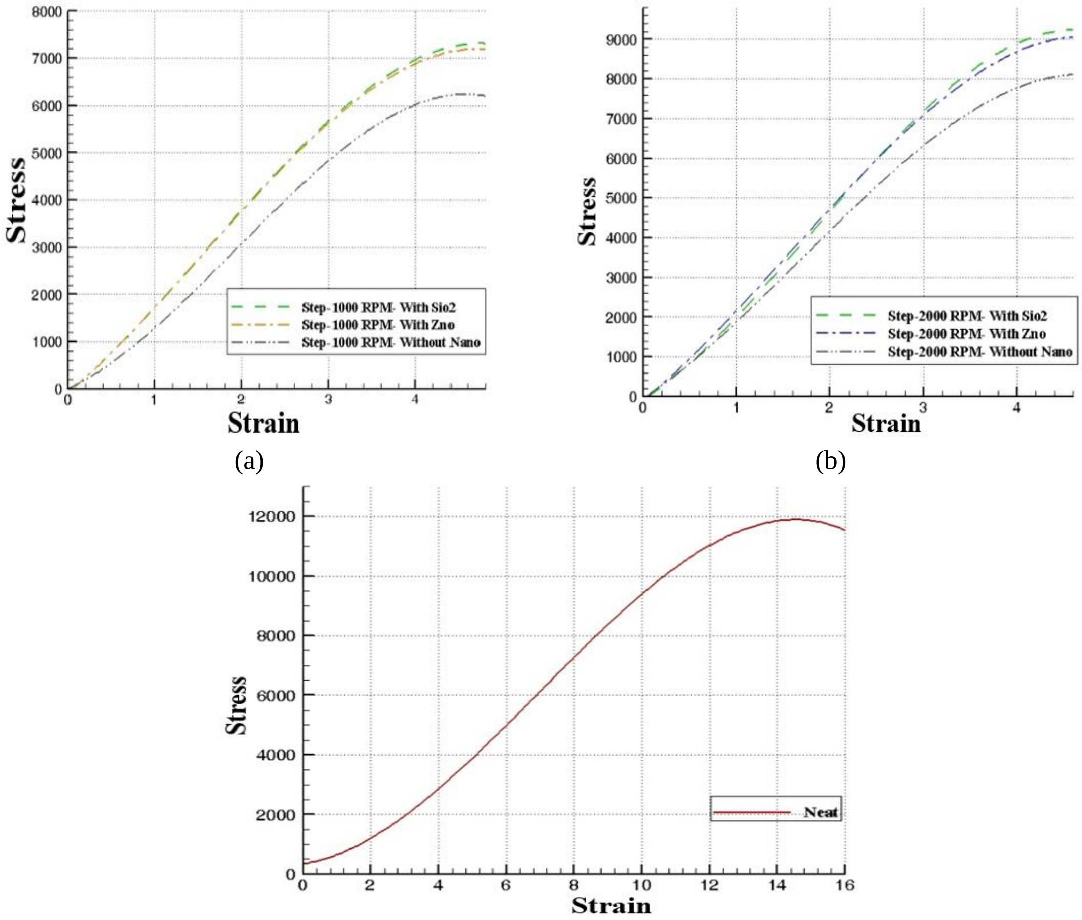
As mentioned in Fig. 7(b), the cross-sectional type has improved the resistance of the weld, and



(c)

Fig. 7 Samples with Cone surface without nanoparticles under bending test, (b) samples with Cone surface with Zno nanoparticles under bending test, (c) samples with Cone surface with Sio_2 nanoparticles under bending test

the use of zinc nanoparticles in this type of cross-section has assisted in increasing mechanical resistance. The yield point is reached a higher level (7665.69 N). Also, at 2000 RPM speed, due to the welding process temperature, the fracture failure will occur at a higher tensile point (8485.2 N) than the samples with the speed of 1000 RPM. Adding Zno in the structure will improve the adhesion in the polymeric chain. Zno nanoparticles will give a chance to improve the extension of this polymeric chain. Zno Nanoparticles will be transferred to the Porous space between these chains. Porous spaces are given and potential incidence in polymeric molding Porous. This thermal gaps can only be covered with Nanosize particles such as Zno. Nanoparticles can strengthen the structure that holds structure with external force will be loaded. This nanoparticle tries to cover the gaps or even give more elasticity to the structure.



(a) (b)

(c)

Fig. 8 (a) Shows the machining parameters in terms of the different rotation speed in Step surfaces, (b) shows the machining parameters in terms of the different rotation speed in Step surfaces, (c) Pure ABS Tensile test result

3.1.2.2 Cone surface with Sio_2 nanoparticles

As seen in Fig. 7(c), found that a failure point at the force of 8921.04 N will be surveyed by the behavior and slope tensile figures at 2000 RPM. It shows that the welding is carried out well under normal conditions due to the properties of the Sio_2 particles such as adhesion and higher strength, the chains between the sides, increase the intermediate resistance of the piece, regarding parameters can be seen in Fig. 7(a-c). An increase in yield points for samples reinforced with Sio_2 particles is more significant than samples with samples reinforced with Zno particles. Results in samples at the rotation speed of 2000 RPM with a yield point of 8567.02 N. samples manufactured at 1000 RPM rotation speed have a 7498.66 N yield point. With consideration, the yield point can be realized that the elastic region is larger than the plastic region.

3.1.3 Step surface without nanoparticles

The welding process type and method are shown in Fig. 8(a). it can be assumed that the samples with a speed of 1000 RPM have a higher yield point than the 2000 RPM. The samples with higher speeds and lower speeds have a more petite and more elastic region. Also, the less plastic area in some parts is 10 mm linked inside each other, which causes relative strength, temperature, and pressure applied to the samples to increase the friction at the surface. The friction level, the heat, and sample melting level increase more than the other samples with lower speed of welding, at a rate of 2000 RPM seen that this behavior was increased. one of the factures is the stress and growing stress and force and area. When the area is greater than the spreading force, whole stress will lower. When the molding state increases, many chances will be attached or make a bonding structure. This extension can be depended on the area; when the molding temperature rises, many chances of bonding will be provided for the polymeric chain. More area better polymeric chain considering these terms found that the reason for the improvement in mechanical behavior was the welding speed.

3.1.3.1 Step surface with Zno nanoparticles

As seen in the conditions of non-nano particles welding in Fig. 8(b), similar behavior in nanoparticle welding and the properties have been observed, which nanoparticles can cause to improve the performance of the nanocomposite joints, these advantages as well in Fig. 8.4 are observed. According to the mentioned figure, the yield point of samples is the same, but there's a significant difference in the failure points, which suggests that the plastic region is less than the elastic region. The peak resistance of the pieces before the final failure is 7859.08 N for the force of speed at 1000 RPM and 8755.4 N for speed of 2000 RPM. This resistance increases because nanoparticles are mixed with ABS in the welding area. The effect of nanoparticles where can be essential to improving the bonding structure. As a result, it can improve welding. The molding process can create Porous spaces during welding presence of oxygen.

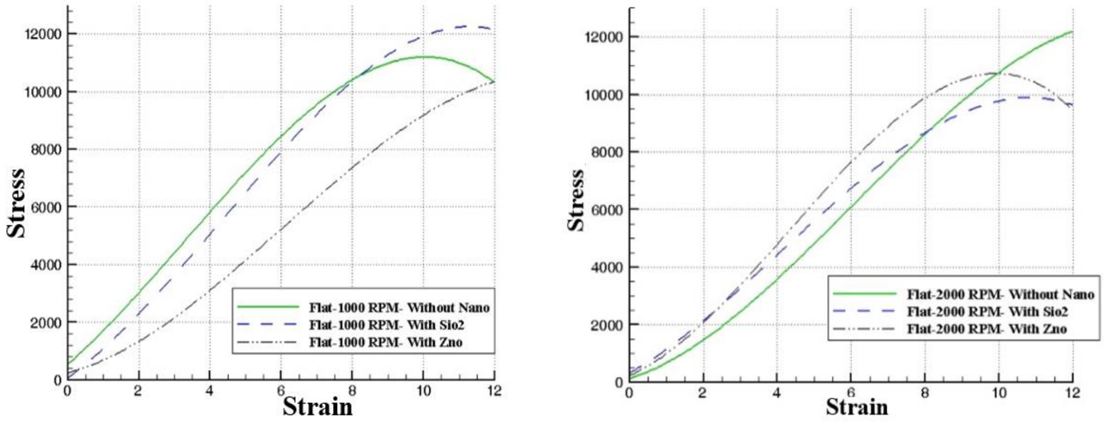
3.1.3.2 Step surface with Sio_2 nanoparticles

As shown in Fig. 8 (a-b) with experiments performed at the step surface welding, as been noted, the friction has a significant effect on the welding process. Sio_2 nanoparticles have been able to increase the resistance of fracture toughness due to the filling role; because the particles are created on the ledge surface, the melting point of the component is welly mixed in all directions, also indicating the reason for the increase in fracture resistance, as well the residual force during welding operations absorbed and filled with Sio_2 nanoparticles. Also, prevent crack growth, which improves the mechanical properties of the samples. Generally, Nano Sio_2 can be added to crystalizing structures created during the molded process. Nano Sio_2 welly distributed and placed between the gaps at a higher rotation speed. By increasing the presence of nanoparticles extension, which depends on the properties of this polymeric chain. As a result, Nano Sio_2 can cover the polymeric chain and enhance the mechanical properties, and rotation speed must also be considered.

3.2 Tensile test

3.2.1 Pure ABS

As can be seen in Fig. 9, the pure ABS in the tensile test faced the maximum force level of about 12000 N. The uniform behavior of the graph shows that the sample is followed the Hooke's law, which before the yield point and after the forced removal, it returns to its original state, but when the yield point reached to the near of 12 mm extension, the sample entered the breakage area and then ultimately failed. Regarding the sample status, it can be said that samples are placed in standard



(a) (b)

Fig. 8 (d) Shows the machining parameters in terms of the different rotation speeds in Flat surfaces, (e) shows the machining parameters in terms of the different rotation speed in Flat surfaces

conditions, which can be applied to various industrial applications and applications.

3.2.1.1 Flat surface without nanoparticles

As shown in Fig. 9 (a-b) sample without nanoparticles at a lower rotation speed has a lower yield point fracture than the higher speed. It also indicates that the welded and non-welded samples are almost in one condition, which means they can withstand an equal force but fail in the first state of extensions. The lower speed samples have weaker strength than the higher speed because the friction and the velocity are the factors that increase the heat, and heat is an essential parameter in the friction welding process.

3.2.1.2 Flat surface with Zno particles

In Fig. 8(d-e), the samples have been failed in pre-states of the mechanical test, although using zinc nanoparticles, due to their performance, can change the result in the tensile test and enhance the mechanical behavior higher yield point is observed. This fact is due to the property of the zinc particles, it must be mentioned that the fracture point in this sample with the rotation speed of 2000 rpm has an extension of 10 mm, and the sample with the rotation speed of 1000 rpm has a maximum extension of 12 mm.

3.2.1.3 Flat surface with Sio_2 particles

As shown in Fig. 9(c), which used silica particles, showed a different performance. The samples failed in the 11 mm extension areas, but the significant behavior of the curve is that the samples start at two different speeds with the same conditions and completely follow the Hooke's law. It also withstands the force close to pure force to the yield point. Silica nanoparticles fill in pores (as seen in Fig. 10) during welding, strengthening the sample material structure.

3.2.2 Cone surface without nanoparticles

As shown in Fig. 9 (d-e), in samples without nanoparticles on the cone surface, according to the friction conditions, the behavior of the samples in the yield points is the same, but the curvature behavior has changed, and the welding sample with higher speed has more resistance than the sample with lower speed of welding. The sample runs at a faster speed following Hooke's law and has a higher yield point. As a result, more friction on the cone surface has led to higher mechanical results and behavior.

3.2.2.1 Cone surface with Zno nanoparticles

The performance of nanoparticles in Fig. 9 (d-e) shows that they are uniformly placed on the ABS surface and, by the better combination, have been able to keep two samples at two different speeds along with each other up to the yield point. This can also be concluded that the samples were able to withstand a more tremendous amount of force due to their higher mixing speed.

3.2.2.2 Cone surface with Sio_2 nanoparticles

Regarding the Fig. 9 behavior (d-e), it can be expected that nanoparticles have been involved in these changes. So that different behavior can be achieved for each sample at the beginning of the test. For example, at a speed of 1000 rpm, it can be concluded that the sample first suffered a slight extension, and pores (as seen in Fig. 10(d)) that may have been created during welding are filled with nanoparticles, and ultimately the sample can withstand the force. After the yield point, the sample with some resistance has been able to last at higher extension and force levels. However, comparing the two speeds at the rate of 1000 and 2000 rpm, as seen can be concluded that the samples with a welding speed of 2000 have a higher yield point and breakage point, which has happened in the 10.5 mm extension.

3.2.3 Step surface without nanoparticles

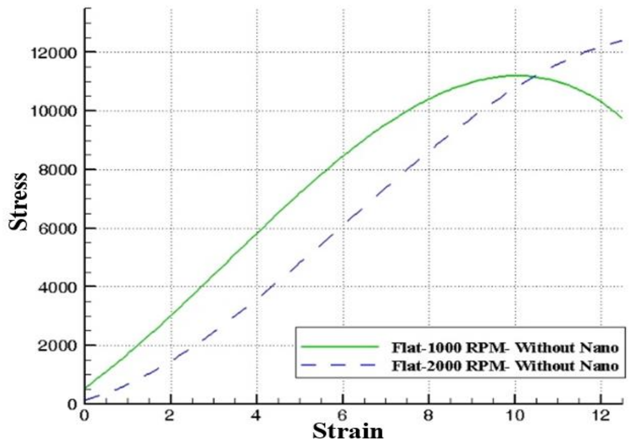
As seen in Fig. 9 (d-e), In step surface shape samples, due to the friction created at several different points, the behavior of nanoparticle samples is somewhat similar to each other. The samples follow the standard and have uniform conditions and fully follow the Hooke's law, then reach the yield point in the extension region of 8 mm, and subsequently fall under the load force uniformly. In a sample with less speed, the behavior of the graph is somewhat unstable, so the low speed interferes with the performance of the sample under inappropriate temperatures since it requires more temperature for the melting to connect the edges.

3.2.3.1 Step surface with Zno nanoparticles

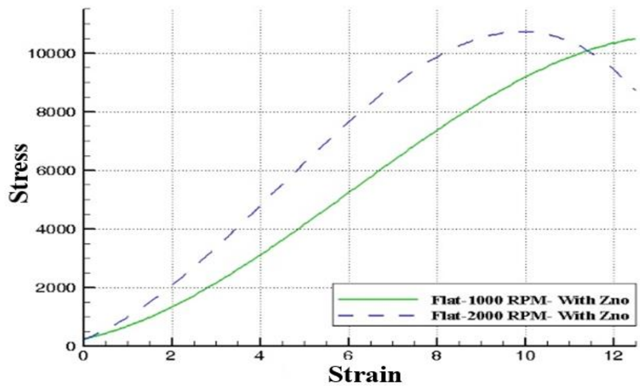
In Fig. 9 (f-g), due to the use of zinc nanoparticles, it can be seen that they showed better force resistance than without nanoparticles, which suggests that using nanoparticles gives an advantage over without nanoparticles samples. As shown in Fig. 9 (f-g), the higher speed was shown, the better result in this research.

3.2.3.2 Step surface with Sio_2 nanoparticles

As seen in Fig. 9 (f-g), According to the sample at a rate of 2000 rpm and the cross-section of the step with higher friction than the previous two levels, as well as the speed used in this sample and the higher temperature, edges can be connected better which welding process can finish and caused to better bonding and attachment of ledge to the groove of samples. It also showed relatively similar mechanical behavior to the Neat samples and had the same performances. This suggests that the adhesion properties of the ABS are provided by the silica nanoparticles, which can withstand a greater force than the pure sample; also, the yield point is higher. However, in the lower-speed samples, which means 1000 rpm, the same behavior at higher speeds was not found, considering



(a)



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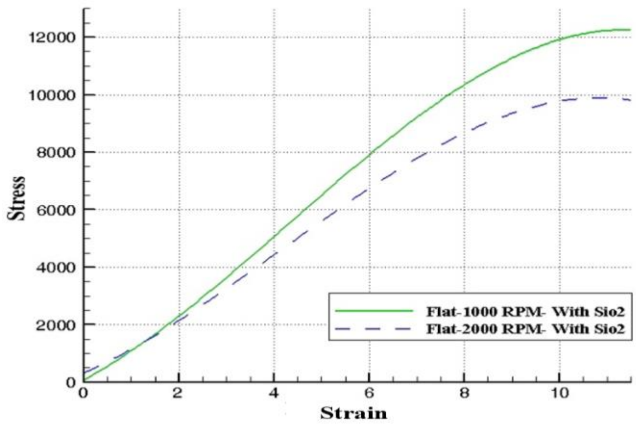
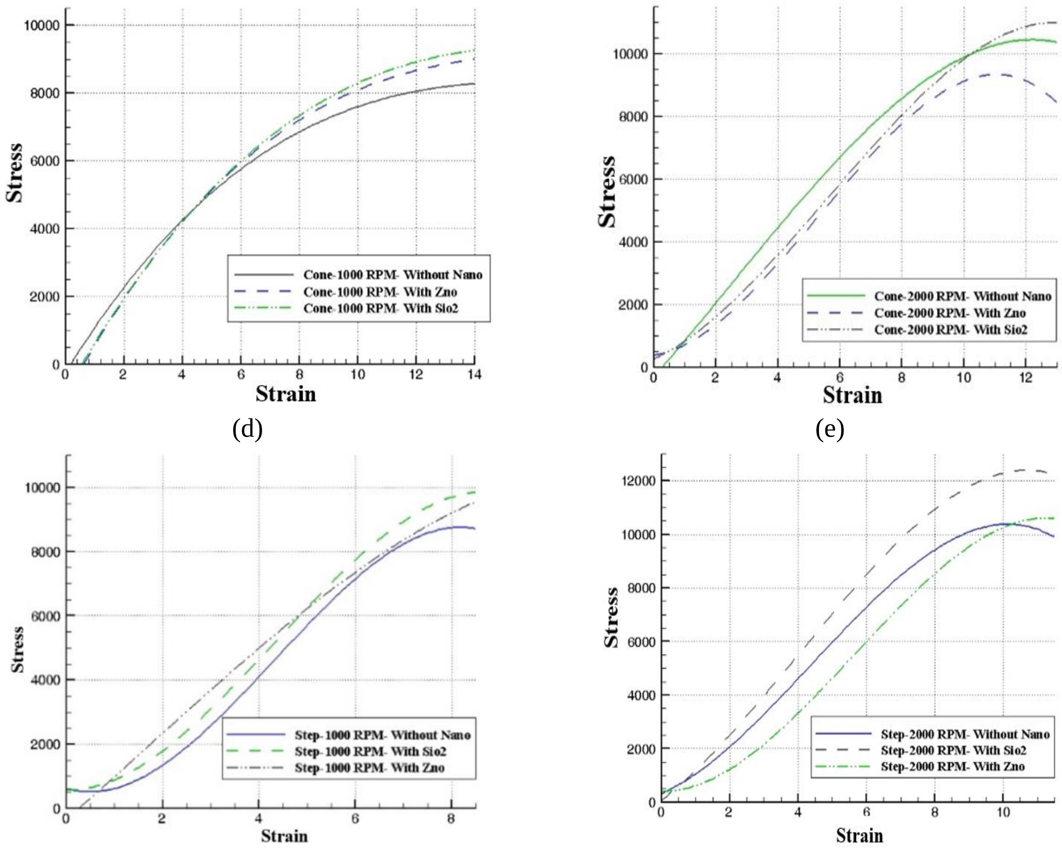


(c)

Fig. 9 (a) Samples with Flat surface without nanoparticles under Tensile test, (b) samples with Flat surface with Zno nanoparticles under Tensile test, (c) samples with Flat surface with Sio_2 nanoparticles under Tensile test, (d) shows the machining parameters in terms of the different rotation speed in Cone surfaces, (e) shows the machining parameters in terms of the different rotation speed in Cone surfaces, (f)shows the machining parameters in terms of the different rotation speed in Step surfaces, (g) shows the machining parameters in terms of the different rotation speed in Step surfaces



(d) (e) (f) (g)

Fig. 9 Continued

Nano-silica particles, which suggests that different friction welding parameters have different parameters for good bonding.

4. S.E.M photograph

After end of the test, samples were taken for S.E.M imaging. Can be seen in the Fig. 10 (a-h), nanoparticles stick to the ABS texture and are located in the joint layer of the weld. In some places, they have accumulated alongside each other. As seen in Fig. 10 it is clear that the rotation direction and the friction force the ABS layers are removed from the surface, and the layers are in the direction of the spindle rotation of the machine.

5. Conclusions

After conducting the tests and analyzing all the components that have been examined, the results are described below:

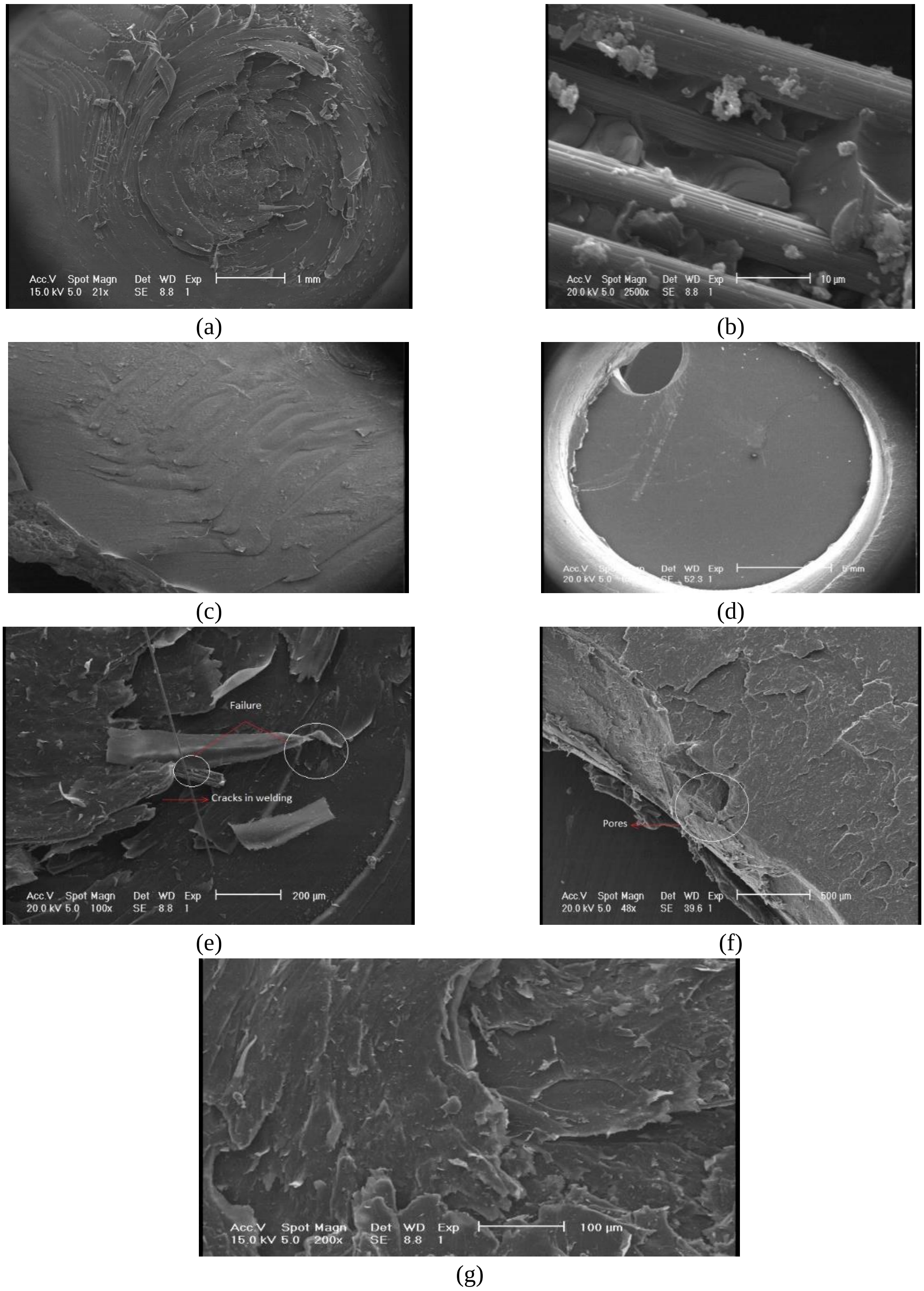


Fig. 10 (a) SEM shot on the welding area (b) Presence of Nanoparticles on welding area, (c) shows the SEM shot of ledge area, (d) shows the SEM shot of groove area, (e) shows the SEM shot of groove area, (f) shows the SEM shot of micro cracks, and sample failure on welding area, (g) shows the SEM shot of Pores on welding area

The rotation speed is an essential factor in the welding process because it increases with the temperature, which causes the melting process to occur, which is a significant factor in the friction welding process. At the speed of 2000 RPM, which was the highest rate of speed used in this project, better results even in samples without nanoparticles were observed. Another parameter that affected the welding quality was the surface type. It was found that increases in the cross-sectional contact area can increase the welding surface, making the joint stronger.

It was concluded that the step surface is the optimum design because it connects two different welding directions. This means better welding was achieved with more contact area and rotation speed. The step surface was analyzed, and the highest connection quality was recorded for the cone surface because the greater friction to the flat surface was observed due to the unique properties of any type of nanoparticles used in this project. According to the results, samples without nanoparticles differed substantially from those used. In samples where nanoparticles were used, higher quality and more resistance were found, and Nano Sio_2 showed better mechanical behavior than Zno nanoparticles due to their intrinsic properties. Also, this subject showed that Nano Sio_2 and step shape surface enhanced the mechanical behavior.

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