Study Some Mechanical Properties of Binary Polymer Blends Fabricated by Friction Stir Processing

Jawad Kadhim Oleiwi[1*] **Sihama I. Salih[2*]** **Sajid Abd Alkhidhir[3**]**

* *Department of Materials Engineering, University of Technology, Baghdad, Iraq.*

** *Department of Mechanics, Babylon Technical Institute, Babylon, Iraq.*

jawadkad@yahoo.com Sihama_Salih@yahoo.com sjdbdllh@gmail.com

Abstract

Friction stir processing (FSP) is a promising technique to improve the mechanical properties of the polymer blends surface with retainment of bulk properties, in this work an attempt was done to add different ratios of polypropylene (PP), styrene acrylonitrile (SAN) and polyvinyl chloride (PVC) as a second material to the matrix plate high density polyethylene (HDPE). Mechanical properties were estimated for hardness and tensile tests were carried out to assess the performance of friction stir processed to prepared the binary polymers blends (HDPE: PP), (HDPE: SAN) and (HDPE: PVC) at depth 3 mm from the surface of (HDPE) plate. The results of the tests showed that the best values of the tensile strength, young modulus and hardness, it was obtained when adding the ratio of (15%) of the (PVC) to matrix (HDPE). The friction stir processing technique was successfully used to improve the mechanical properties of polymer surface. In view of the foregoing, it can be concluded that the friction stir processing technique, can be utilizing to repair the cracks and imperfections that are formed in polymeric materials.

Keywords: Binary polymers blends, Friction Stir Processing (FSP), Tensile strength, Hardness.

الخلاصة

تعتبر طريقة الاحتكاك والخلط تقنية واعدة لتحسين الخواص الميكانيكية لسطح الخلائط البوليميرية مع الاحتفاظ بخواص باقي الجسم، في هذا العمل جرت محاولة لإضافة نسب مختلفة من البولي بروبلين، ستيرين أكريلونيتريل والبولي فينيل كلوريد كمادة ثانية إلى البولي اثيلين عالي الكثافة (كمادة اساس). تم أجراء الاختبارات الميكانيكية (الصلادة والشد) لتقييم أداء عملية الاحتكاك والخلط لتحضير الخلائط البوليميرية الثنائية: (البولي اثيلين عالي الكثافة: بولي فينيل كلوريد)، (البولي اثيلين عالي الكثافة: ستيرين أكريلونيتريل) و (البولي اثيلين عالي الكثافة: بولي بروبلين) على عمق 3 مم من سطح (البولي اثيلين عالي الكثافة). أظهرت نتائج الاختبارات أن أفضل قيم للصلادة ومقاومة الشد تم الحصول عليها عند إضافة نسبة (15٪) من (البولي فينيل كلوريد) إلى المادة الاساس (البولي اثيلين عالي الكثافة). في ضوء ما سبق، يمكن الاستنتاج أن تقنية الاحتكاك والخلط، يمكن أن تستخدم لإصلاح التشققات والعيوب التي تتكون على سطح المواد البوليميرية.

الكلمات المفتاحية: الخلائط البوليميرية الثنائية، عملية الاحتكاك والخلط، مقاومة الشد، الصلادة.

1.Introduction

Polymers has a leading role in the industrial applications, but the increasing demand of materials for advanced applications or characterized by specific combination of properties cannot be satisfied by simple homopolymers. Because of that, there are considerable scientific and industrial interests in modifying or mixing these commodity polymers. Blending different polymers and keeping their individual properties in the final mixture is an attractive and inexpensive way of obtaining new polymeric materials

(Utracki, 2002). Polymer blends are capable of providing materials with extended useful properties beyond the range that can be obtained from single polymer (Sihama et. al, 2015). Preparing polymer blends– a mixture of at least two macromolecular substances – is an effective way to develop new raw materials (Al-Salem *et.al.,* 2009). Because of its combination of low cost, high chemical resistance, and well balanced mechanical properties, high density polyethylene (HDPE) is one of the most widely used thermoplastics or some applications, such as pipes and fittings for liquids or gas transportation (Dorigato *et.al.*, 2012). Polypropylene is a linear hydrocarbon polymer used for wide range of applications in field of automobile, aerospace, reusable containers of various parts. Polypropylene is weathered and unusually rebellious to many chemical solvents, bases and acid. Polypropylene provides better results in terms of ductile fracture, toughness strength and fatigue compare to other plastic materials (Jaiganesh *et.al.*, 2014). Poly (styrene-acrylonitrile) (SAN) is a widely used engineering thermoplastic owing to its desirable properties, which include good mechanical properties, chemical resistance and easy processing characteristics. It has many important applications, such as the fittings of mobile industry and home appliance…. etc. (Yibing *et.al.,* 2007). PVC is a thermoplastic material of large consumption by building and construction industry. PVC is popular because of its excellent impact, wear, chemical and UV resistant and easy to work with (weld, repair and paint) (Alfredo, 2008).

Improved surface properties beside the retainment of bulk properties are necessary for a component for enhanced wear characteristics. Friction stir processing as showed in Figure (1) is used to produce such surface composites (Narayana *et.al.*, 2015). Friction stir processing is an important technique for preparing surface composites. Fabricating defect free surface composites with uniform particle distribution by FSP is a challenging task (Vipin *et.al.,* 2016).

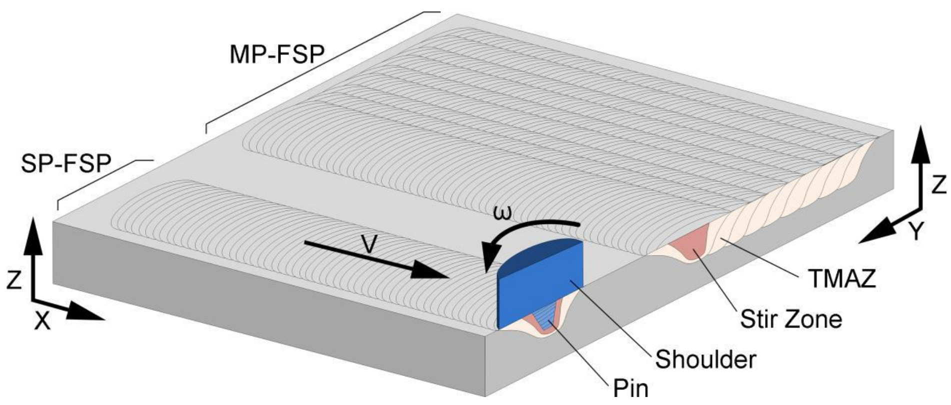

Fig. (1): Schematic diagram of FSP process (Alberto *et.al.*, 2017).

FSP is based on the concepts of friction stir welding (FSW) (Hoyos *et.al.*, 2016) and requires a cylindrical rotating tool with a concentric pin and shoulder that is punched in the material and traversed along the line of interest. The friction between the rotating tool and the workpiece produce a localized heating becoming the material easily plastically deformable. The material undergoes intense plastic deformation at high temperature resulting in significant grain refinement. FSP allows for a precise control of the required microstructural refinement. In addition, the versatility of the FSP is not only limited to produce deformations along a line (Chen *et.al.,* 2016) but to modify the microstructure along extensive sheets as well (Johannes and Mishra, 2007) or even being used as a surface modification technique to modify locally the composition (Kurt *et.al.,* 2011), (Rajan *et.al.,* 2016). It is noted that FSP polymers and polymeric composites are still much less studied than FSP metals and metallic composites (Nandan *et.al.,* 2008). For this reason, this study was conducted promote information in this area.

The aim of this work is to identify the possibility of manufacturing binary polymer blends by friction stir processing technique in specific locations of the polymer surface, according to the required dimensions and depths, furthermore improving the mechanical of the polymer surface, treatment of defects and cracks on the surface of the polymer and increase surface resistance to the occurrence of such defects or cracks.

2. Materials and Methods

I. Materials Used

Four types of polymeric materials (HDPE, PP, PVC AND SAN) were used in this study. High density polyethylene (HDPE) was produced from the General Company of Chemical Industries in Zafarania/ Baghdad, the trade name of the HDPE is "2200J/MITSUI" has density (0.968 g/cm3) and melt flow rate of (6 g/10min). Polypropylene (PP) was supplied from Sabic Company, Saudi Arabia, and has a trade name of "520 LPP", has melt flow rate of (10g/10min). PVC was provided by the General Company of Chemical Industries in Zafarania (Baghdad), was the product of Bandar E Mam Center (suspension type, K value = 70 Iran) and it is having apparent density and viscosity index are 120 and (0.46 g/cm3) and 120 respectively. SAN was supplied from the general Company of Chemical Industries in Zafarania / Baghdad. These materials were selected for the work of three groups of binary polymers blends according to the percentages shown in Table (1) where different percentages of (PP), (SAN) and (PVC) were added as a secondary material to (HDPE) sheet which is considered as a basic material.

Table 1: Formulation of the samples.

Blends	Binary polymer blends ratios				
HDPE:PP	100:0	90:10	85:15	80:20	75:25
HDPE:SAN	100:0	90:10	85:15	80:20	75:25
HDPE:PVC	100:0	90:10	85:15	80:20	75:25

II. Experimental Procedure

Blending process used friction stir processing (FSP) technique, as shown in Figure (2) in three stages; for the purpose of configuring the process, at first stage a special slot with different depths (0.9 mm, 1.1 mm, 1.3 mm, 1.5 mm) was processed in the middle of (HDPE) sheet, each one has the same surface area (8 mm width, 150 mm Length). In the same measurements, slices were cut from (PP), (SAN) and (PVC) sheets and then installed in the slot which prepared on the surface of (HDPE) sheet, Figure (3) shown a schematic diagram of shoe tool. The stainless-steel material was selected to performed a tool for friction stir processing, the tool consists of two main parts, the shoulder is 20mm diameter, the pin is 14mm diameter with 3mm height, Rotation and linear speed selected are (492 rpm, 24 mm/min) respectively, the plunge depth was 0.5 mm and dwell time was 30 second. The process of (FSP) was performed on the vertical milling machine by adding a backing pleat and supports made of medium carbon steel for the purpose of attaching and installing polymer sheet.

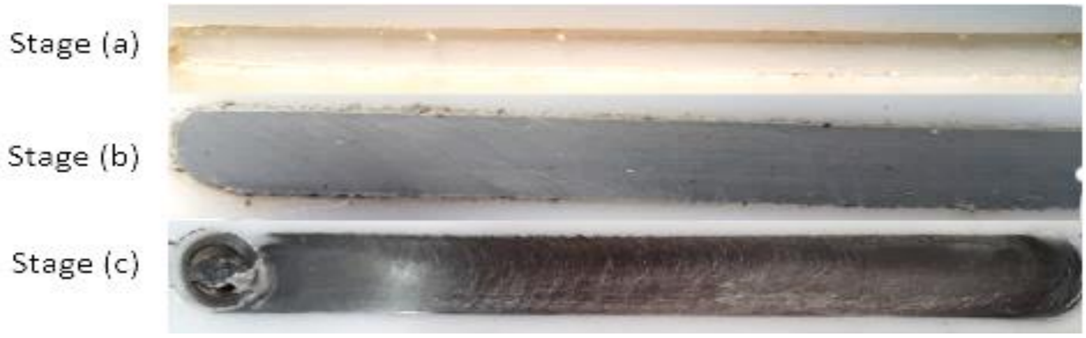

Fig. (2): Illustrated three stages of FSP technique.

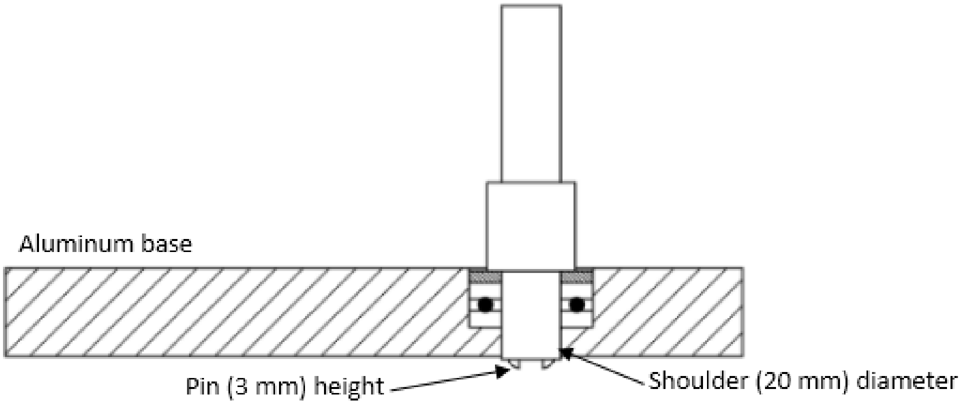

Fig. (3): Schematic diagram of shoe tool

3. Mechanical Testing

Tensile testing machine, controlled by a computer (model WDW 200 E) made in China, was used to determine the tensile strength of the selected samples at a constant crosshead speed of (5 mm/min) at room temperature. Longitudinal tensile samples were prepared from the FSP zone by vertical milling machine and extracted from the sheets of each group of binary polymer blends according ASTM D638-03 standard. Tensile strength was the average of five values of parallel samples tested. Hardness test carried out at room temperature, by a durometer D scale ASTM D 2240, with specimen dimension are (10 × 10 × 4) mm. The reported values for hardness are the average of ten readings for each specimen in different regions.

4. Results and discussion

I. Tensile properties

Tensile properties for three groups of polymer blends, which were produced through friction stir processing technique, depending on the percentage of minor material contained in the blend, homogeneous distribution of minor materials in the blend and bond strength at the interface between the matrix and minor materials

Figures (4), (5) and (6), were showed the tensile strength, young's modulus and elongation at break respectively for three groups of polymer blend ((HDPE: PVC), (HDPE: PP), (HDPE: SAN)). From Fig. (4), it was noticed that the tensile strength of the matrix (HDPE) increased with addition of PVC to it by friction stir processing (FSP) technique, whereas addition, PP or SAN it will lead to decreasing the values of tensile strength for these binary polymer blends. As well as it was observed that, the first polymer blend (HDPE: PVC) having higher values of the tensile strength as compared with their counterpart of the other groups samples of binary polymer blends (HDPE: PP) and (HDPE: SAN) and this result related to the natural of molecular structure of these polymers, as well as, this behavior is linked to the compatibility between the constituents of polymer blends (Sihama *et.al.*, 2015). As shown in Figures (4), (5) and (6) that the tensile strength, young's modulus and elongation at break values of matrix (HDPE), which not processed by FSP technique, were measured to be (16.319MPa), (1.94GPa) and (2.543%) respectively. The results indicated that the tensile strength value of the (HDPE: PVC) with (15%) ratio of PVC as a minor content was significantly higher compared to the other binary polymer blends samples. According to the results a (53.2%) increase was observed as compared with the base material (HDPE) value. While as mentioned earlier there is a significant reduction in tensile strength when adding (PP) and (SAN) to (HDPE) to produce (HDPE: PP) and (HDPE: SAN) binary polymer blends at all ratios. The low values of tensile strength obtained indicated the low chemical affinity between the (PP), (SAN) and (HDPE) domains.(Kunori and Geil, 1980) reported that the tensile failure of a polymer blend resulted from the adhesion between the matrix and dispersed phase through a crazing or de-wetting effect (Kunori *et.al.*, 1980).

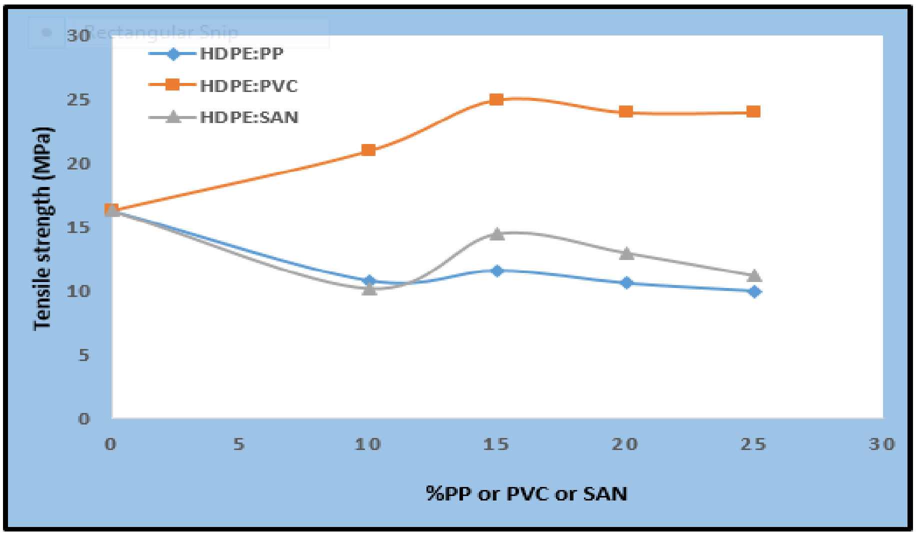

Fig. (4): Tensile strength for binary polymer blends (PE: PP), (PE: SAN) and (PE: PVC) as a function of second materials [(PP), (SAN) or (PVC)] content in blend.

From Fig. (5) and Fig. (6), it was noticed that the young's modulus and elongation at break respectively for three groups of polymer blend ((HDPE: PVC), (HDPE: PP), (HDPE: SAN)), it was increasing with addition of a minor materials PVC, PP and SAN by friction stir processing (FSP) technique to HDPE as a matrix, except, the value of elongation at break for binary polymer blends (HDPE: PP) it was decreased with addition of a minor material (PP) to the matrix (HDPE). From test results of young's modulus and elongation at break reported that there a considerable increase in values, the highest value observed at the addition of 15% ratio of PVC increases the value of (young's modulus) from (1.94 GPa) to (6.1 GPa), an increase of (214.4%) as compared with base material (HDPE). As well as obtaining the highest elongation at break value when adding 15% ratio of (SAN) as a minor material to the matrix (HDPE) where the increase reached (442.6%) relative to the matrix polymer. Nishar Hameed *et.al.*, found the comparative pattern, where the Poly(styrene-co-acylonitrile) was utilized to adjust diglycedyl ether of bisphenol-A type epoxy resin. The blends showed extensive changes in mechanical properties (Hameed *et.al.*, 2008).

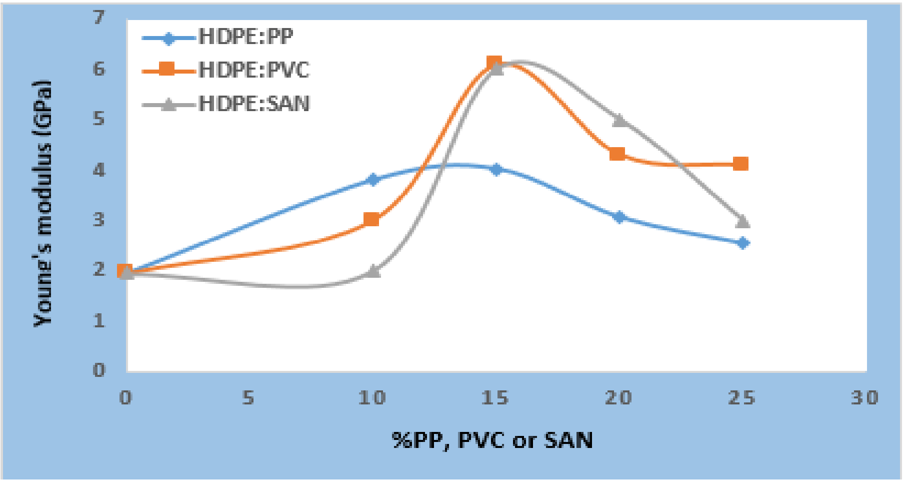

Fig. (5): Young's modulus for binary polymer blends (PE: PP), (PE: SAN) and (PE: PVC) as a function of second materials [(PP), (SAN) or (PVC)] content in blend.

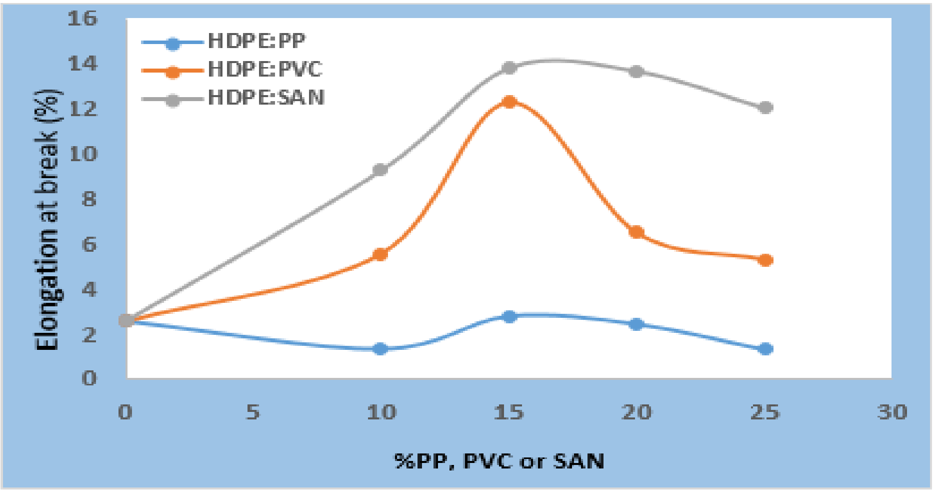

Fig. (6): Elongation at break for binary polymer blends (PE: PP), (PE: SAN) and (PE: PVC) as a function of second materials [(PP), (SAN) or (PVC)] content in blend.

II. Hardness

Figure (7) illustrates the hardness of the binary polymer blends fabricated by FSP technique. As shown from this figure, there is a significant improvement in the hardness of the binary polymer blends compared with that of the base polymer. Such an increase can be attributed to concerning to molecular structure which provides considerable steric hindrance and thus make polymeric material rigid and relatively strength (Sihama *et.al.*, 2015). After FSP technique, the scattering of (PP, SAN or PVC) polymers as secondary materials within the FSP nugget zone is considered that the pin stirring could efficiency disperse the minor polymers in a reasonably uniform manner. Beside foregoing it was found that the test results indicated that the hardness value (62) of the (HDPE: PVC) with (15%) ratio of PVC as a minor content was significantly higher compared to the other samples of binary polymer blends and the hardness of matrix material (HDPE) (53). And according to the results it was observed that the ratio of increase in hardness values was reach to (16.98%) as compared with the base material (HDPE) value.

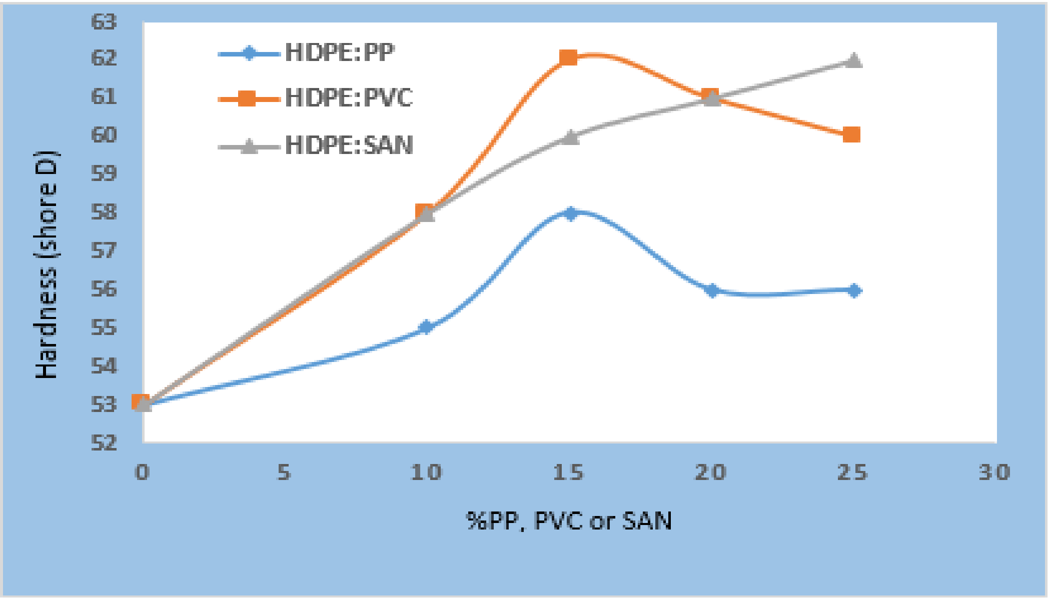

Fig. (7): Hardness for binary polymer blends (PE: PP), (PE: SAN) and (PE: PVC) as a function of second materials [(PP), (SAN) or (PVC)] content in blend.

Conclusions

In this study, some of the mechanical properties of the (HDPE) plate have been improved through the addition of different percentages of (PVC), (PP) and (SAN) and (PVC) as secondary materials to (HDPE) as a base material, by employing heat assisted friction stir processing technique.

The results showed that the highest increase in the tensile strength, young's modulus and hardness when adding (15%) ratio of PVC as a secondary material by friction stir processing technique to the basic material (HDPE), these values increased from (16.319 MPa, 1.94GPa and 53) to (25 MPa, 6.1 GPa and 62) respectively. The lowest value it was obtained for (elongation at break) when adding (25% PP) as a secondary material for the manufacture of a binary polymer blend (HDPE: PP). The value of (elongation at break) decreased from (2.543%) to (1.298%) with a percentage decrease (95.9%) as compared to the base material (HDPE). As indicated by the outcomes acquired, and that show the achievement of the friction stir processing technique to arrangement the constituents of the various polymeric materials by blending for different types of thermoplastic polymeric materials by this technique, without any defects can accrue along these lines. In view of the foregoing, it can be utilizing from the technique of the friction stir processing, to be an effective to repair the cracks and imperfections that are formed of polymeric materials.

References

Alberto Orozco-Caballero, Marta Álvarez-Leal, David Verdera, Pilar Rey, Oscar A. Ruano, Fernando Carreño, 5 July 2017," Evaluation of the mechanical anisotropy and the deformation mechanism in a multi-pass friction stir processed Al-Zn-Mg-Cu alloy." Materials & Design. Volume 125, pages 116-125.

Alfredo Campo E., 2008,"Selection of Polymeric Materials". William Andrew Publishing/Plastics Design Library.

Al-Salem SM, Lettieri P, Baeyens J, 2009: Recycling and recovery routes of plastic solid waste (PSW): A review. Waste Management, Vol. 29, No. 10, pp. 2625-2643.

Chen Y., Ding H., Cai Z., Zhao J., Li J., 2016, " Effect of initial base metal temper on microstructure and mechanical properties of friction stir processed Al-7B04 alloy. " Mater. Sci. Eng. A. 650, pp 396–403.

Dorigato A. & D'Amato M. & Pegoretti A., 2012, "Thermo-mechanical properties of high density polyethylene – fumed silica nanocomposites: effect of filler surface area and treatment". J. Polymer, 19:9889

Hameed, N., Sreekumar, P. A., Thomas, P. S., Jyotishkumar, P., Thomas, S., Sci. 2008, "Mechanical properties of poly (styrene-co-acrylonitrile)-modified epoxy resin/glass fiber composites." J. Appl. Polym. 110, 3431-3438.

Hoyos E., López D., Alvarez H., 2016," A phenomenologically based material flow model for friction stir welding." Mater. Des. 111, pp. 321–330.

Jaiganesh, Maruthu, Gopinath. , 2014, "Optimization of process parameters on friction stir welding of high density polypropylene plate" Procedia Engineering 97, pp. 1957 – 1965.

Johannes L.B., Mishra R.S., 2007, "Multiple passes of friction stir processing for the creation of superplastic 7075 aluminum." Mater. Sci. Eng. A. 464, pp. 255–260.

Kunori, T., and Geil, P.H., 1980, "Morphology property relationship in polycarbonate based blends. II. Tensile and impact strength." J. Macromol. Sci. Phys., B 18(1), pp. 135-175.

Kurt A., Uygur I., Cete E., 2011, "Surface modification of aluminum by friction stir processing." J. Mater. Process. Technol. 211, pp. 313–317.

Nandan, R.; DebRoy, Bhadeshia T.; H.K.D.H., 2008," Recent advances in friction-stir welding—Process, weldment structure and properties." Prog. Mater. Sci., *53*, 980–1023.

Narayana Yuvaraj, Sivanandam Aravindanb, Vipina. , 2015, "Fabrication of Al5083/B4C surface composite by friction stir processing and its tribological characterization." J. Mater. Echnil; 4(4): pp. 398-410.

Rajan H.B.M., Dinaharan I., Ramabalan S., Akinlabi E.T., 2016, "Influence of friction stir processing on microstructure and properties of AA7075/TiB2 in situ composite." J. Alloys Compd. 657, pp. 250–260.

Sihama E. Salih, Jawad K. Oleiwi, Rawaa A. Abdle Amear, 2015,"Comparing Effect of Adding LDPE, PP, PMMA on the Mechanical Properties of Polystyrene (PS)." Eng. & Tech. Journal. Vol. 33 part (A). No, 6, pp. 1950- 1961

Sihama E. Salih, Kadhum M. Shabeeb and Rula F. Hasan, 2015, “Comparative study of some properties of two groups’ binary polymer blends prepared by a twin-screw extruder,” Eng. & Tech. Journal, Part (A), Vol. (33) N. 8, pp. 1971-1985

Sihama Issa Salih, Jawad Kadhim Oleiwi, Rawaa Adnan Abdle Ameer, 2015 " Evaluation of addition ABS and EPDM effect on the mechanical properties of ternary polymer blends." International Journal of Materials Science and Applications. Vol. 4, No. 1, pp. 39-46.

Utracki L.A. , 2002, Introduction to polymer blends, Polymer Blends Handbook, L. A. Utracki (ed), Kluwer Academic Publishers, Dordrecht.

Vipin Sharma, Yashpal Gupta, V. Manoj Kumar B. & Ujjwal Prakash, 2016,"Friction Stir Processing Strategies for Uniform Distribution of Reinfo- rcement in a Surface Composite."Material and Manufacturing Processes Journal. Volume 31; pages 1384-1392.

Yibing Cai, Yuan Hu, Junfeng Xiao, Lei Song, and Weicheng Fan., 2007, " Morphology, Thermal and Mechanical Properties of Poly (Styrene-Acrylonitrile) (SAN)/Clay Nanocomposites from Organic-Modified Montmorillonite". Polymer-Plastics Technology and Engineering, 46: pp. 541–548.