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RESEARCH ARTICLE - MECHANICAL ENGINEERING

Thermal and Mechanical Analysis of Polyvinyl Chloride (PVC) to Polyethylene (PE) Bonding via Friction Stir Spot Welding Process

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Abstract

This study investigates the thermal and mechanical behavior of friction stir spot welding (FSSW) for joining dissimilar thermoplastics, Polyvinyl Chloride (PVC) and Polyethylene (PE). Given the inherent differences in polarity, crystallinity, melting temperatures, and surface energies, bonding between PVC and PE presents significant challenges. The experimental work involved applying FSSW under varying process parameters (rotational speed and dwell time), followed by tensile shear testing and infrared-based thermal analysis. The results revealed that the rotational speed had a dominant effect on peak interfacial temperature, reaching up to 137°C, which exceeds the crystalline melting range of both materials (PVC: 75–105°C; PE: 130–135°C), facilitating localized melting, which promotes effective molecular inter diffusion at the weld interface. Taguchi-based DOE analysis confirmed that optimal parameters (1700 RPM and 2 min dwell) produced the highest joint strength and temperature. Tensile shear strength results also indicated that appropriate heat input and tool interaction facilitated robust bonding without external adhesives or surface treatments. This research offers valuable insights into optimizing polymer-to-polymer welding conditions, paving the way for scalable, environmentally friendly joining methods suitable for packaging, automotive, and biomedical applications.

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Keywords: Friction Stir Spot Welding; Thermal Analysis; Mechanical Analysis; Polyvinyl Chloride (PVC); Polyethylene (PE).

1. Introduction

Welding is a technique of fusion joining that involves a process of inter-molecular diffusion adhesion [1]. Polymer welding is an assembly method among several known assembly techniques such as friction stir spot welding, hot press welding, laser welding, and/or gluing. This welding process applies to thermoplastics, which have rheological or softening characteristics during melting [2].

In materials engineering, joining polymers has grown in importance, particularly as the need for lightweight, corrosion-resistant, and reasonably priced structures in industries like packaging, automotive, and medical devices increases. [3, 4]. Polyvinyl chloride (PVC) and polyethylene (PE), two of the most widely used polymers, each have unique benefits in terms of mechanical qualities, machinability, processability, and chemical resistance. [5, 6]. However, because these two different polymers have differing melting temperatures, thermal conductivities, and surface energies, joining them presents substantial difficulties [7, 8].

Typical joining techniques like mechanical fastening and adhesive bonding frequently have problems with aging, stress concentrations, and environmental deterioration [9, 10]. To overcome these restrictions, polymer welding methods such as hot plate welding, ultrasonic welding, friction stir welding, and laser welding have been thoroughly investigated [10-13]. For PVC-to-PE joining, in particular, welding techniques that use localized heating at the interface are considered promising [14, 15].

Nomenclature & Symbols			
PVC	Polyvinyl Chloride	DSC	Differential Scanning Calorimetry
PE	Polyethylene	TGA	Thermogravimetric Analysis
FSSW	Friction Stir Spot Welding	DOE	Design of Experiments

The weldability of PVC and PE is greatly influenced by their surface properties. Because PVC is polar, it has comparatively greater adhesion properties than non-polar PE, which usually requires surface treatments like chemical modification, plasma, or corona discharge to strengthen adhesion the binding [16-18]. Additional complications are introduced by the mismatch in their thermal behavior, where PE has a lower melting point and a higher thermal expansion than PVC [19, 20].

Strategies to enhance direct polymer-to-polymer bonding have been the subject of numerous investigations. To enable good PVC-to-PE couplings, methods such as the use of compatibilizers, interlayers, or altered welding parameters have been proposed [21–23]. By regulating the heat input and contact pressure, hot plate welding with ideal temperature profiles has been shown to produce reasonably robust connections between PVC and PE [24, 25]. Furthermore, novel methods like laser transmission welding (LTW) have surfaced, enabling accurate energy deposition but necessitating careful material optical matching [26, 27].

To characterize the resultant joints and gain insight into the bonding mechanisms at molecular level, mechanical testing (such as tensile lap shear tests), thermal analysis (DSC, TGA), and morphological investigations (SEM, FTIR) are commonly used [28, 29]. Furthermore, stress distributions and welding parameters for different polymer joints have been predicted using finite element modeling [30, 31].

Even with these developments, it is still technically difficult to create PVC and PE joints that are dependable, long-lasting, and repeatable. To overcome the inherent material variances, more study is needed to create reliable processing methods, surface activation approaches, and hybrid joining procedures [32].

This study aims to methodically examine friction stir spot welding techniques in order to produce dependable and highly durable polymer-to-polymer junctions, given the difficulties involved in combining PVC and PE. The study seeks to fill in the knowledge gaps in existing joining technologies by examining the impacts of welding settings, interfacial changes, and joint morphology. In the end, it is anticipated that the results will aid in the creation of joining methods that are optimal and allow for the scalable, effective, and long-lasting production of multi-material polymeric structures for industrial uses.

2. Experimental Work Procedure

2.1. Material and specimen

The PVC and polyethylene (PE) plastic polymers were used because of the high importance of their applications in manufacturing. They were welded with a 4 mm thickness employing the FSSW process, as illustrated in Fig. 1, which indicates the dimensions of the bonded samples and welding zone. Polymers should be tested with the FTIR test, DSC, and TGA tests to ensure the type of polymer. They are also displayed in Figs. 2 and 3, respectively. The mechanical properties for the PVC and PE tensile test before bonding are listed in Table 1. The parameters employed for joining the samples by FSSW are based on the parameters listed in Table 2. Therefore, all the parameters were within the acceptance criteria of the spot-welding process. Each welding condition listed in Table 2 was repeated at least three times to ensure repeatability and account for variability in joint performance. The reported tensile shear strengths represent the average of these repetitions, with the standard deviation included to reflect data uncertainty. Coefficients of variation (CV%) were also computed to evaluate the relative dispersion among repeated trials, ensuring a quantitative understanding of consistency. The reported tensile shear strengths represent the average of these repetitions, with standard deviation included to reflect data uncertainty. For each set of experiments, the mean shear strength was calculated along with the standard deviation (±SD) to provide a statistical metric of consistency. Coefficients of variation (CV%) were also computed to evaluate the relative dispersion among repeated trials.

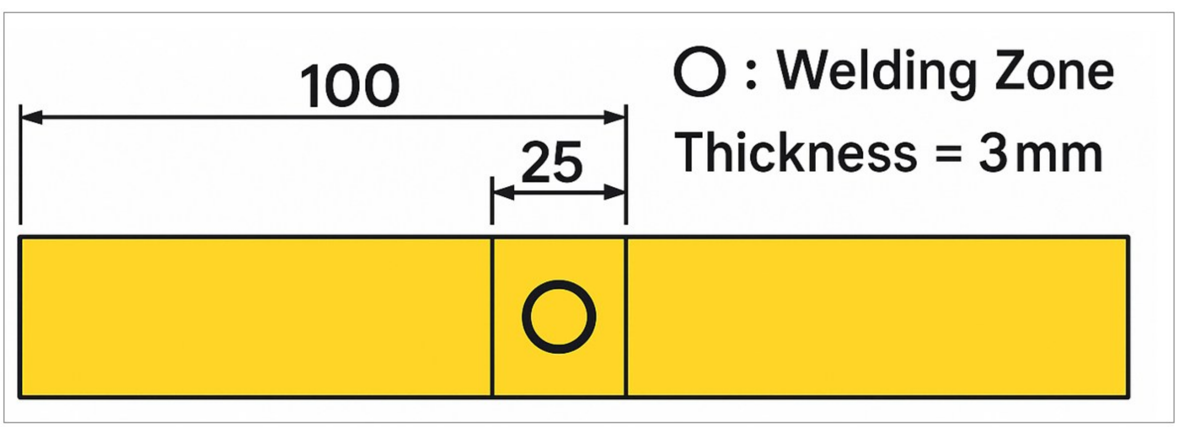
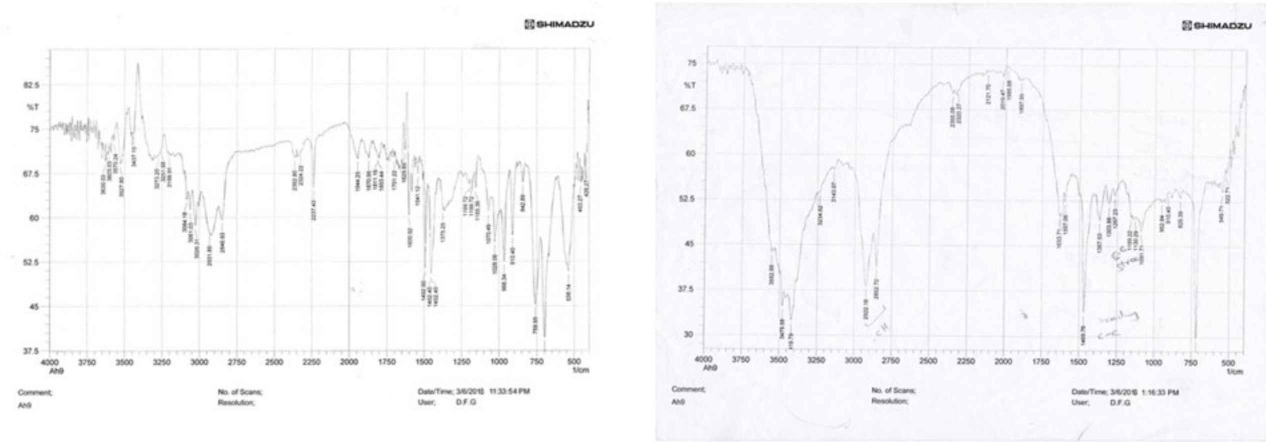


Fig. 1. The sample preparation and Schematic of the welded sample and the welding zone

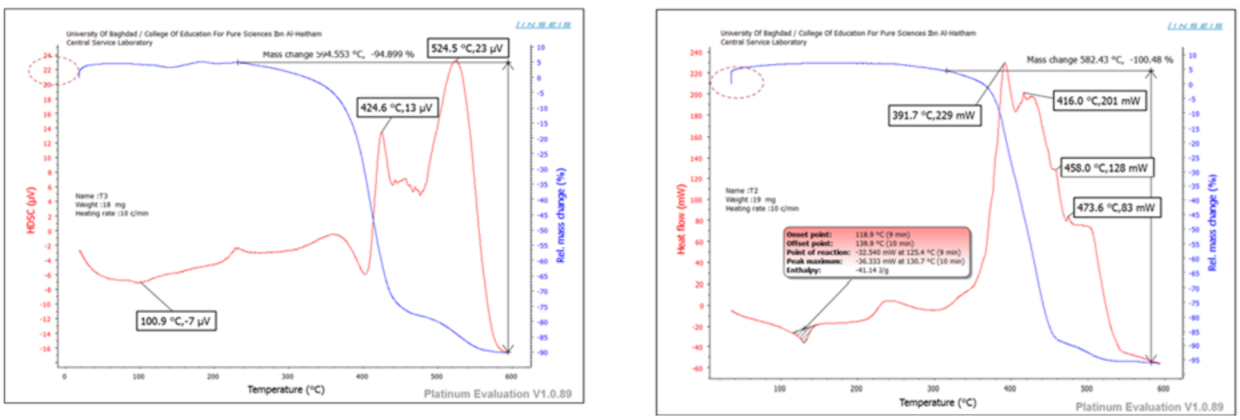
In this research, two types of polymers were used: polyethylene (PE) and polyvinyl chloride (PVC). The polyethylene (PE) and polyvinyl chloride (PVC) polymers were tested by FTIR, DSC, and TGA tests. To identify and ensure the type of these polymers, infrared spectroscopy (FTIR) was used. This type of test provides the general structure of the materials. From the DSC test, the melting point of the polymers was determined to be 119-140°C for PE, while for PVC, the FTIR test was sufficient to specify this type of polymer due to the chloride content in its structure.



FTIR for PVC

FTIR for PE

Fig. 2. The FTIR chart test for PVC and PE



DSC and TGA for PVC

DSC and TGA for PE

Fig. 3. DSC and TGA charts of PVC and PE before joining

Table 1. Mechanical properties of PVC and PE polymers

polymer	Tensile strength, σu, (MPa)	Yield strength, σy, (MPa)	Elongation%
PVC	53	48	21
PE	11	9	51

Table 2. Process parameters used for joining PVC to PE by FSSW

Sample No.	RPM	Time (min.)
1	900	1
2	1300	1.5
3	1700	2
4	1700	1
5	900	1.5
6	1300	2
7	1300	1
8	1700	1.5
9	900	2

All samples are joined by FSSW and tested by shear tensile test. The PE plastic polymer was placed on the PVC polymer with a joint of (25x25) mm, supported by a fixture to connect the PVC and PE samples. Fig. 4 shows the samples that are welded. During the FSSW process, both PVC and PE sheets were clamped securely in a custom-designed fixture mounted on the milling machine table. The fixture consisted of flat steel plates with rubber padding to prevent thermal damage and slippage. This ensured precise alignment and minimized movement during tool engagement and plunge.

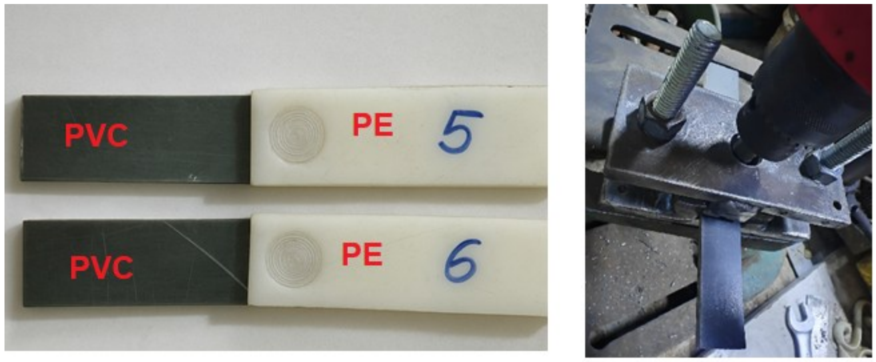


Fig. 4. The samples that are welded

2.2. Tensile shear strength

Tensile shear test of FSSW samples has been done by a tension test device with a 100 kN maximum capacity. The lap joints of the samples which were tested had dimensions: 25 mm wide and 100 mm long. To prevent slipping and bending in the tensile shear test, two shims were placed in the opposite direction as shown in Fig. 5. The crosshead velocity of the tensile shear test was 10 mm/min. The uncertainty in the tensile force measurement was estimated at ±1% of the measured value based on the calibration of the universal testing machine with a 100 kN capacity. Temperature measurements using the IR thermometer had an accuracy of ±1.5°C, and all values were verified through thermocouple readings.

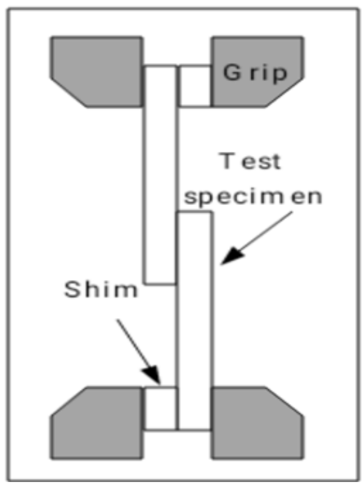


Fig. 5. Schematic clamps and specimen of shear force test

2.3. Thermal analysis results during FSSW

Due to the friction between the tool and the component's parts, FSSW causes greater plastic deformation in the immediate area of the process tool. As a result, the temperature rises both inside and outside the process region. The microstructure of the processed zone is directly impacted by the temperature distribution inside it. However, the maximum plastic deformation caused by the translation and rotation of the processing tool makes it extremely difficult to monitor the temperature within the processed area. Therefore, an infrared thermometer was fixed on the milling machine to record the temperatures inside the treated area using FSSW. By recording the reflected infrared ray, which is similar to any other ray in electromagnetic radiation but has a lower frequency, an IR thermometer can determine the temperature in any area. As seen in Fig. 6, the reflected infrared ray was positioned along the weldment joint for this investigation.

Fig. 6. Presents the Infrared Ray Thermometer

3. Results and Discussion

3.1. Tensile shear strength

The welding process parameters have a significant impact on the welded joints' shear strength. The Design of Experiments (DOE) approach, which explains the influence of different processing parameters on the mechanical properties of the joints, was used to systematically evaluate the shear-tensile force results of the test. The results of the shear-tensile tests performed on the welded samples are shown in Fig. 7, emphasizing the variations in strength performance under different conditions.

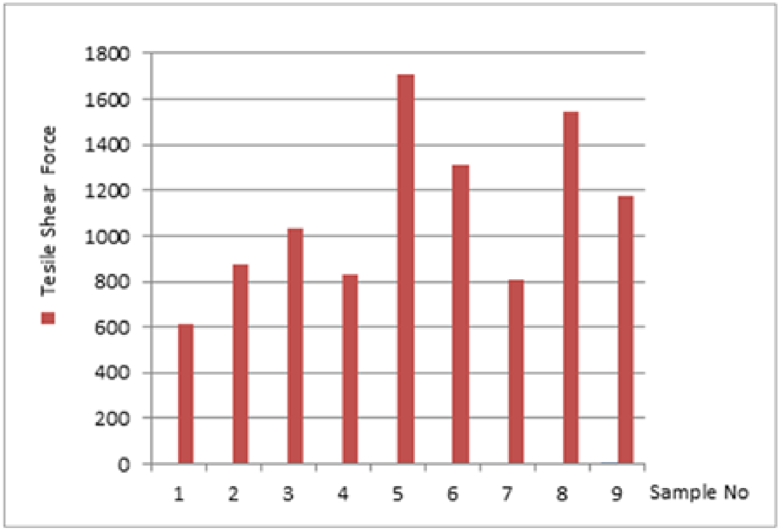


Fig. 7. Results of shear-tensile force test

The Minitab program used the Taguchi analysis approach to analyze the shear force to determine the ideal parameters and investigate how the joining parameters affected the joint's strength. This approach yields better shear force results. The impact of rotational speed and time on joint strength is shown in Fig. 8, which is called the main effects plot of means. The shear force (joint strength) will increase as the processing time is increased from one minute to one and a half minutes, but it will decrease after two minutes. Additionally, the joint strength dropped when the tool's rotational speed was increased from 900 rpm to 1300 rpm; However, the shear force (joint strength) improved when the rotational speed was increased further to 1700 rpm.

Fig. 8. The impact of rotational speed and time on joint strength

3.2. Thermal analysis results

Samples of friction stir spot welding process were used for the heat distribution analysis. The welded samples were exposed to the reflected infrared rays. The temperature of the nine welded samples, as determined by a thermocouple, is displayed in Table 3. The thermocouple showed that the temperature increased radially outward from the weld center for the PVC/PE joint. The temperature increased radially outward from the weld center. For the PE side, the highest observed temperature (~137°C) was found at the treated regions outside the border, suggesting localized melting. This behavior suggests that the PE matrix changed into an amorphous state as a result of the thermo-mechanical input from the FSSW tool, which improved its capacity to create a solid-state connection with the softened PVC surface. For dissimilar polymers with different heat reactions to form a robust joint, this thermal behavior is essential. Adequate fusion is made possible by the efficient regulation of tool rotation speed, plunge depth, and dwell duration, which guarantees that the interfacial temperature is higher than the melting range of both polymers.

Table 3. The results of the temperature, which are recorded by the thermocouple

Sample no.	Temperature
1	91.3
2	113.2
3	137.2
4	129.9
5	97.8
6	128.4
7	119.7
8	133.8
9	101.1

The main effects plot shows how two important process parameters rotational speed (RPM) and dwell time (minutes) as in Fig. 9 affect the maximum temperature produced during the Friction Stir Spot Welding (FSSW) of PVC and PE polymers. It is based on a Design of Experiments (DOE) analysis.

Effect of Rotational Speed: The temperature increases sharply with the tool's rotational speed. At 900 RPM, the interface temperature is about ≈97°C, but it rises to ≈120°C at 1300 RPM and peaks at almost ≈137°C at 1700 RPM. This pattern emphasizes how important rotational speed is in the production of frictional heat because higher RPM increases the kinetic energy at the tool-workpiece interface, increasing friction and plastic deformation, which raises the interface temperature. This is necessary to ensure that the local temperature rises above the crystalline melting points of PE (130–135°C) and PVC (75–105°C), which promotes effective bonding.

Effect of Dwell Time: Dwell time exhibits a positive correlation with temperature, albeit less so than speed. The temperature rises from about ≈113°C to ≈123°C when the duration is extended from one minute to two minutes. This slight increase suggests that extended tool contact permits heat to build up in the weld zone, aiding in the diffusion and softening of polymers over the interface. Its impact is less significant than rotational speed, though.

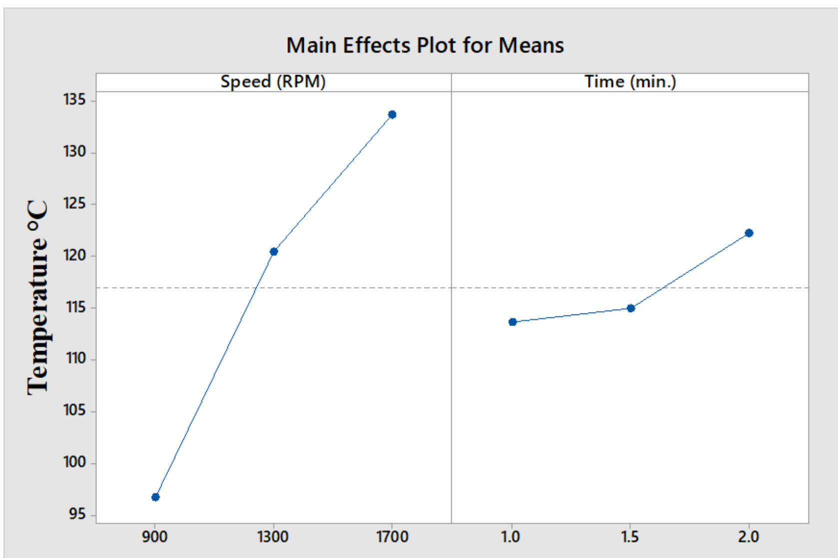


Fig. 9. The impact of rotational speed and time on joint affects the maximum temperature produced during the Friction Stir Spot Welding (FSSW)

4. Conclusion

Because of their disparate physicochemical characteristics, including polarity, melting temperature, and surface energy, joining different polymers, especially PVC and PE, remains a substantial engineering problem. In order to assess joint quality and comprehend the underlying bonding mechanisms, mechanical testing, heat analysis, and morphological characterization have proven essential. Despite significant advancements, problems such as interfacial defects, thermal degradation, and environmental aging continue to impede the development of dependable PVC-PE connections. Future studies should concentrate on developing new compatibilizer systems specifically suited to improving interfacial adhesion, investigating hybrid joining processes that combine mechanical and thermal techniques, and optimizing surface activation techniques (such as chemical functionalization and plasma treatment).

Overall, advancing the understanding and technology of PVC-to-PE joining will open new pathways for multi-material lightweight structures, contributing significantly to sectors demanding high performance, sustainability, and cost efficiency.

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References

[1] H. Kaddour, M. H. Miloud, O. C. El Bahri, and L. Abdellah, "Mechanical behavior analysis of a Friction Stir Welding (FSW) for welded joint applied to polymer materials," Unpublished report, 2019, https://doi.org/10.3221/IGF-ESIS.47.36.
[2] Pereira, Miguel A. R., Ana M. Amaro, Paulo N. B. Reis, and Altino Loureiro. "Effect of Friction Stir Welding Techniques and Parameters on Polymers Joint Efficiency—A Critical Review" *Polymers* 13, no. 13: 2056, 2021, https://doi.org/10.3390/polym13132056.
[3] T. Karger-Kocsis, "Joining of polymer–polymer and polymer–metal hybrid structures: recent advances and future challenges," Adv. Eng. Mater., vol. 22, no. 11, pp. 1–15, Nov. 2020, doi: 10.1002/adem.202000305.
[4] R. Habibi, "Review on welding techniques for thermoplastics and polymeric composites: Fundamentals and developments," J. Thermoplast. Compos. Mater., vol. 33, no. 8, pp. 1154–1184, 2020, doi: 10.1177/0892705719835037.
[5] M. Ebnesajjad, Handbook of Adhesives and Surface Preparation, 1st ed. Norwich, NY, USA: William Andrew, 2010.
[6] M. Goodwin, "Properties and applications of PVC," in Plastics Additives and Testing, 1st ed. Amsterdam, Netherlands: Elsevier, 2012, pp. 65–90.
[7] S. L. Osswald, Polymer Processing Fundamentals. Munich, Germany: Hanser Publishers, 2018.
[8] J. P. Dear, "Surface Energy Considerations in Polymer Joining," J. Mater. Sci., vol. 34, no. 20, pp. 5005–5010, Oct. 1999.
[9] M. D. H. Nguyen, "Surface Treatment Techniques for Adhesive Bonding of Thermoplastics," Int. J. Adhes. Adhes., vol. 74, pp. 100–110, 2017.
[10] G. Wypych, Handbook of Polymers, 1st ed. Toronto, Canada: ChemTec Publishing, 2012.
[11] A. Benatar and T. Gutowski, "Ultrasonic welding of PEEK graphite APC-2 composites," Polym. Eng. Sci., vol. 29, no. 23, pp. 1705–1721, Dec. 1989.
[12] M. Bachmann, "Laser welding of polymers," Optik & Photonik, vol. 2, no. 3, pp. 42–46, 2007.
[13] P. Potente, "Friction welding of plastics," Polym. Eng. Sci., vol. 31, no. 9, pp. 693–700, Sep. 1991.
[14] C. Ageorges and L. Ye, "Fusion bonding of polymer composites: Theoretical understanding and experimental investigation," Compos. Part A Appl. Sci. Manuf., vol. 32, no. 2, pp. 160–170, Feb. 2001.
[15] B. J. L. Jansen, "Hot plate welding of dissimilar polymers," Weld. J., vol. 81, no. 3, pp. 45–52, Mar. 2002.
[16] C. Dang, "Improving adhesion between polyethylene and PVC through plasma treatment," Appl. Surf. Sci., vol. 264, pp. 32–38, 2013.
[17] A. Yasuda, "Plasma surface treatment of polymers," Surf. Coat. Technol., vol. 169–170, pp. 955–960, Feb. 2003.
[18] F. L. Matthews, Joining Fibre-Reinforced Plastics. Berlin, Germany: Springer, 1999.
[19] E. P. Plueddemann, Silane Coupling Agents, 2nd ed. Boston, MA, USA: Springer, 1991.
[20] I. S. Kim, "Thermal and mechanical behavior of PE/PVC laminated composites," Polym. Test., vol. 25, no. 4, pp. 470–476, 2006.
[21] M. Chabert, "Compatibilization of PE and PVC blends using functionalized polymers," Polym. Eng. Sci., vol. 41, no. 7, pp. 1245–1251, Jul. 2001.
[22] R. A. Shanks, "Welding of immiscible polymer blends," J. Mater. Sci., vol. 28, pp. 1235–1242, 1993.
[23] L. S. Schadler, Polymer Nanocomposites: A Small Part of the Story. New York, NY, USA: Springer, 2007.
[24] H. Potente, "Hot plate welding of polymers: Process technology and applications," Weld. J., vol. 80, no. 4, pp. 50s–56s, Apr. 2001.
[25] B. Levy, "Temperature control during hot plate welding," Weld. Res. Suppl., vol. 76, pp. 123–130, 1997.
[26] T. Stambaugh, "Laser transmission welding of thermoplastics," Ind. Laser Solut. Manuf., vol. 19, no. 4, pp. 24–29, 2004.
[27] P. Eyerer, "Laser welding of thermoplastics: Mechanisms and process parameters," J. Mater. Process. Technol., vol. 84, no. 1–3, pp. 140–147, Oct. 1998.
[28] R. Ebnesajjad, Surface Treatment of Materials for Adhesive Bonding, 1st ed. Norwich, NY, USA: William Andrew Publishing, 2006.
[29] K. N. Strafford, "Analysis of bond strength in welded plastics," J. Appl. Polym. Sci., vol. 23, no. 5, pp. 1145–1150, 1979.
[30] A. H. Behravesh, "Finite element modeling of friction welding of polymers," J. Reinf. Plast. Compos., vol. 25, no. 17, pp. 1825–1835, 2006.
[31] L. Ye, "Numerical simulation of fusion bonding of thermoplastic composites," Compos. Sci. Technol., vol. 57, no. 12, pp. 1607–1615, Sep. 1997.
[32] S. B. Warner, Modern Plastic Materials and Processing. Upper Saddle River, NJ, USA: Prentice Hall, 1990.