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Investigation of Effect of Recycled PET Powders on Recycled Polyvinyl Chloride (PVC) Composites

Geri Dönüşümlü Polivinil klorid (PVC) Kompozitlerde Geri Dönüşümlü PET Tozlarının Etkisinin Araştırılması

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ABSTRACT

Recycling is vital subject for sustainable future and environment. Plastic waste can be post-consumer and pre-consumer and need urgent recycling. Both PVC and Polyethylene terephthalate (PET) were used commonly and has important place in solid waste stream. These polymers should be reused or recycled instead of landfilling due to their valuable properties. In this study, processing type (injection molding vs compression molding) and PET filling concentration (0% and 10%) during recycled PVC composite materials manufacturing were studied. During manufacturing process, 20 phr (per-hundred-resin) DOP was utilized. Density, tensile, flexural, impact and hardness (shore D) properties of composites were determined. Results showed that samples produced with injection molding process provided superior tensile properties compared to compression molding process ones. Addition of PET powder into recycled PVC matrix both reduced the tensile strength and elongation at break values while improving tensile modulus. In the case of flexural properties, compression molding and injection molding provided higher flexural strength and flexural modulus, respectively. Impact strength was reduced with injection molding and PET presence in the matrix. Processing type did not affect the hardness of the materials. However, addition of PET in the PVC matrix increased the hardness of the samples. Future studies will be conducted to investigate the effect of using different size and shape PET fibers in recycled PVC.

Keywords: Recycled PVC, Polyethylene terephthalate (PET), injection molding, compression molding, mechanical properties and density.

ÖZET

Geri dönüşüm sürdürülebilir çevre ve gelecek için hayati bir konudur. Plastik atıklar tüketim öncesi ve sonrası oluşabilir ve acil geri dönüşüm gerektirir. PVC ve PET yaygın kullanılır ve katı atık akımında önemli yere sahiptir. Bu polimerler değerli özelliklere sahip olduğundan toprağa atılmaları yerine geri dönüşümleri sağlanıp yeniden kullanılmalıdır. Bu çalışmada, geri dönüşüm PVC kompozit malzeme üretimi enjeksiyon ve pres kalıplama yöntemleri ile PET dolgu oranları % 0 ve % 10 olarak çalışılmıştır. Üretimlerde PVC'nın %20'si kadar DOP kullanılmıştır. Kompozitlerin yoğunluğu, çekme, eğilme, darbe dirençleri ve sertlik değerleri belirlenmiştir. Sonuçlar, enjeksiyon kalıplama yöntemi ile üretilen numunelerin, pres kalıplama yöntemine kıyasla daha yüksek çekme direnci değeri sunduğunu göstermiştir. Geri dönüşüm PVC matriksi içine katılan PET tozu Çekmede elastikiyet modülünü arttırırken çekme direnci ve kopmada uzama değerlerini düşürmüştür. Eğilme özelliklerine bakıldığında, eğilme direnci pres kalıplama örneklerinde eğilmede elastikiyet modülü ise enjeksiyon kalıplama örneklerinde yüksek çıkmıştır. Darbe direnci değeri matriks içerisine PET eklenmesi ve enjeksiton kalıplama yöntemi kullanılması ile düşmüştür. Üretim yönteminin malzeme sertliği üzerine etkisi bulunmamıştır. Fakat PVC matriks içerisine PET'in eklenmesi örneklerin sertliğini arttırmıştır. Gelecek çalışmamızda geridönüşün PVC'lerde farklı boyut ve şekillerde PET kullanımının etkisi araştırılacaktır.

Anahtar kelimeler: Geri dönüşüm PVC, PET enjeksiyon kalıplama, pres kalıplama, mekanik özellikler ve yoğunluk.

1. INTRODUCTION

Polyvinyl Chloride (PVC) and Polyethylene terephthalate (PET) are among the most widely used thermoplastic plastic in the world. The most important adventure of PVC is being compatible with very various additives. Furthermore, it is used in many sectors such as automobile and construction duo to high performance and cheap cost of PVC (Kıralp et al., 2007). Similarly, PET is extensively used in industrial productions, such as beverage bottles, packaging films and textile fibers, because of its superior chemical, physical, mechanical, and (oxygen and carbon dioxide) barrier properties (Makkam, S. and Harnnarongchai, W., 2014).Therefore, the amount of waste PVC and PET is increasing day by day and increases concern about environmental issues. Therefore, recycling of PET and PVC attracts great interest.

Several studies were conducted to investigate the possible re-usage of waste thermoplastics. Won et al. (2010) studied long-term performance of recycled PET fibre-reinforced cement composites. Santos et al. (2015) investigated bio-based materials from the electrospinning of lignocellulosic sisal fibers and recycled PET. In another study, Mengeloglu and Karakus (2008) studied polymer-composites from recycled high density polyethylene and waste lignocellulosic materials. Fukushima et al. (2010) studied on dechlorination technology for municipal waste plastics containing polyvinyl chloride and polyethylene terephthalate. Colom et al. (2014) researched acoustic and mechanical properties of recycled polyvinyl chloride/ground tyre rubber composites. Utilization of waste PET and PVC would serve both to environment and economy.

Although there are several studies on using of PET and PVC in composite materials, on using of them in the same material have not been investigated extensively. In this study, recycled PVC based composites were produced using recycled PET as filler. Mechanical properties of manufactured composites were investigated.

2. MATERIAL AND METHODS

Recycled polyvinyl chloride (r-PVC) as a polymeric matrix and recycled PET as filler were used and both of them supplied by Kastamonu Integrated industry and trade limited company. They were 50-mesh size (0.297 mm). DOP were obtained from ENPAK Chemical Industry and Trade Ltd. Co., Turkey.

The composition of recycled polyvinyl chloride composites is presented in Table 1. Four different polymer composites were produced. Composite materials were produced using compression and injection moulding methods. The work flow diagram of the production of composite materials is given in Figure 1.

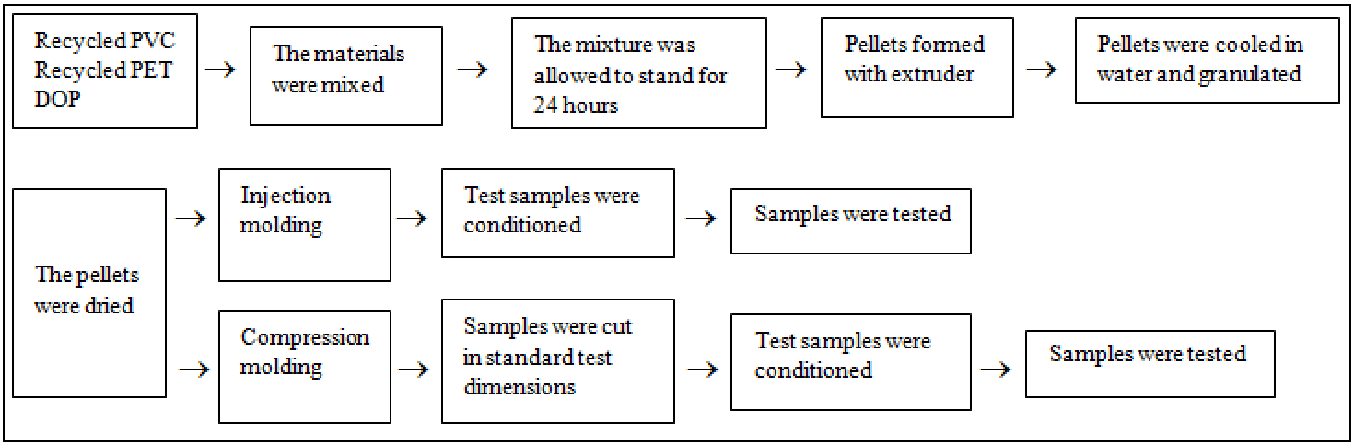


Figure 1. The work flow diagram of the production of composite materials

Recycled PVC, recycled PET powder and DOP were mixed with high-speed mixer, speed range 5–1000rpm, for 5 min and production started after 24 hours. The compounding was accomplished using a laboratory scale single screw extruder (Teknomatik, Turkey) to produce homogenous composite pellets. The extruder screw speed was set to 40 rpm and the temperature was set to 170 °C, 175 °C, 180 °C, 185 °C, and 190 °C for five heating zones. Pellets were cooled in water and granulated. Granulated pellets were dried at 105 °C for 24 h. These pellets were used for either compression or injection moulding. One half of the pellets were compressed into a 4mm-thick 175 x 160mm panels at 200 °C temperature, 100 bar pressure and 10 pressing time. Other half of the pellets were injection moulded with 102 kg/cm^{2}injection pressure and 80 mm/s injection speed to produce the test samples. The temperature used for injection moulded samples using an HDX-88 injection moulding machine was 180-200 °C from feed zone to die zone. After manufacturing, all tests samples were conditioned in a climatic room with the temperature of 20 °C and the relative humidity of 65%. Density, Tensile, flexural values and impact strengths were determined according to ASTM D 792, ASTM D 638 (5.0 mm/min), ASTM D 790 (2.0 mm/min) and ASTM D 256, respectively.

Statistical analysis was applied to see how the production method and the use of PET interacted in the composite material.

Table 1. The composition of recycled polyvinyl chloride composites

Specimen ID	PVC(%)	PET(phr)	DOP(phr)
Press I	100	0	20
Press II	100	10	20
Injection I	100	0	20
Injection II	100	10	20

3. RESULTS AND DISCUSSION

The effect of processing types and presence of recycled PET in recycled PVC matrix was investigated. Interaction graph of density of the manufactured recycled polyvinyl chloride composites was presented in Figure 2. X axis denoting the PET amount (%) while Y axis shows measured properties. Rectangular and triangle shapes present compression method and injection method, respectively. Densities of the samples were in the range of 1.13 – 1.24g/cm^3. Statistical analysis showed that processing types have significant effect on density value (P<0.0001). Compression molded samples had higher density compared to injection molded samples. In the case of PET amount, it has a significant effect also (P=0.0004). Densities of the samples were increased with the presence of PET powder in the matrix. There is a significant interaction between the factors (P=0.0275). Injection and compression methods having no PET have similar density values. On the other hand, when PET was present in the samples, compression molded samples had higher densities than injection molded ones.

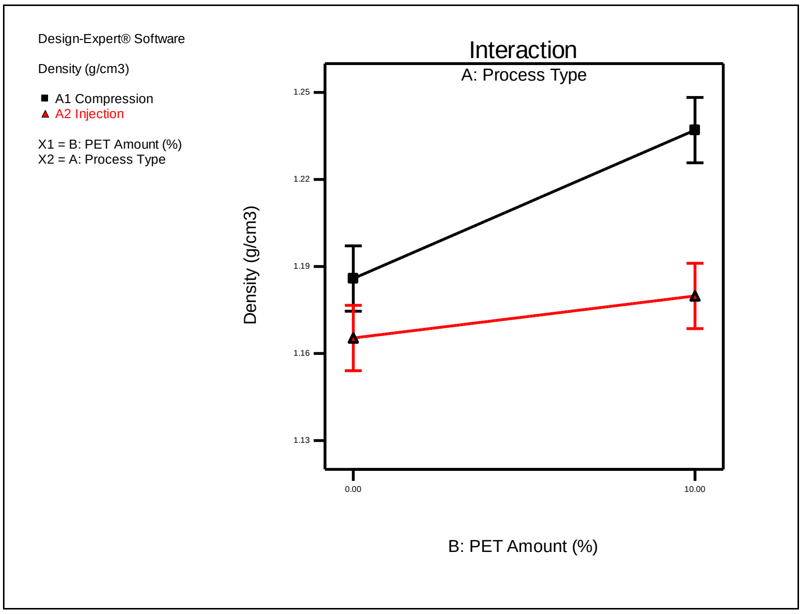
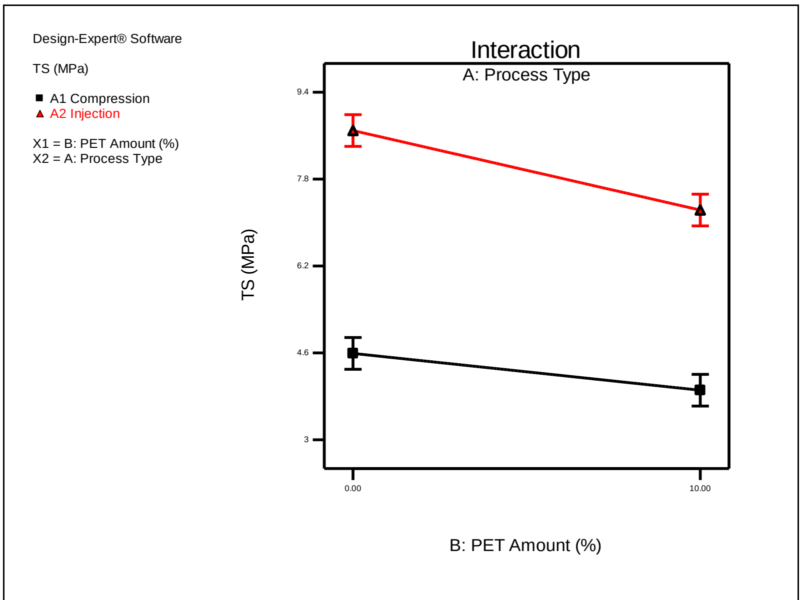


Figure 2. Interaction graph of processing types and presence of recycled PET on density

Tensile strength values of the samples were in the range of 3.04 – 9.36MPa. Figure 3a shows the interaction graph of tensile strength. Statistical analysis showed that processing types and PET amount had a significant effect on tensile strength (P<0.0001). Injection molded samples provided higher tensile strength values compared to compression molded ones. In addition, regardless of processing types, tensile strength values were reduced with the addition of 10 % PET powder in the matrix. In the case of tensile modulus, values were in the range of 37.18 – 100.86MPa (Figure 3b). Similar to tensile strength, both processing types and PET amount had a significant effect on tensile modulus (P<0.0001). Injection molded samples were outperformed the compression molded ones. It should be noted that presence of 10% PET powder in recycled PVC matrix significantly increased the tensile modulus regardless of processing methods. Elongation at break values of the samples was in the range of 7.38 – 37.66%. Their interaction graph was presented in Figure 3c. Based on the statistical analysis, both processing types and PET amount had a significant effect on elongation at break values (P<0.0001). Injection molded samples provided higher values compared to compression molded ones. In addition, regardless of processing method, elongation at break values were reduced with the addition of 10 % PET powder in the matrix.


Design-Expert® Software
TS (MPa)
A1 Compression
A2 Injection
X1 = B: PET Amount (%)
X2 = A: Process Type
Interaction
A: Process Type
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9.4
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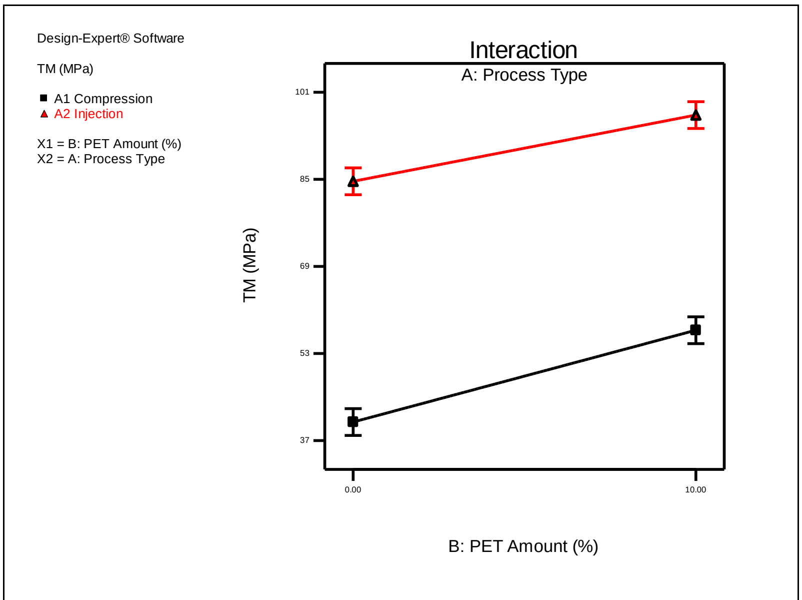
6.2
4.6
3
0.00
10.00
B: PET Amount (%)

(a)


Design-Expert® Software
TM (MPa)
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X2 = A: Process Type
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101
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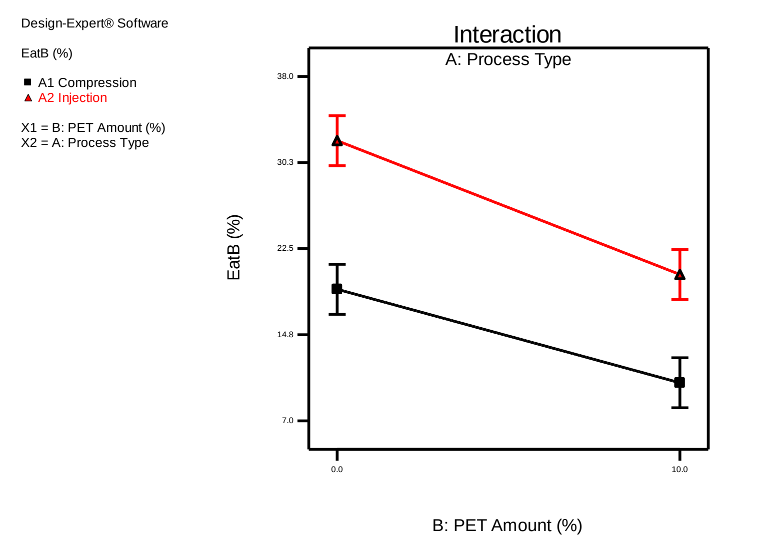
69
53
37
0.00
10.00
B: PET Amount (%)

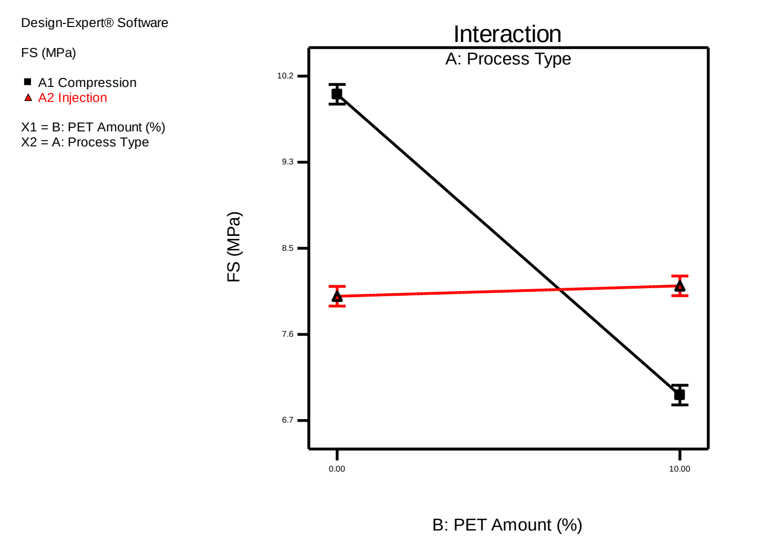
(b)



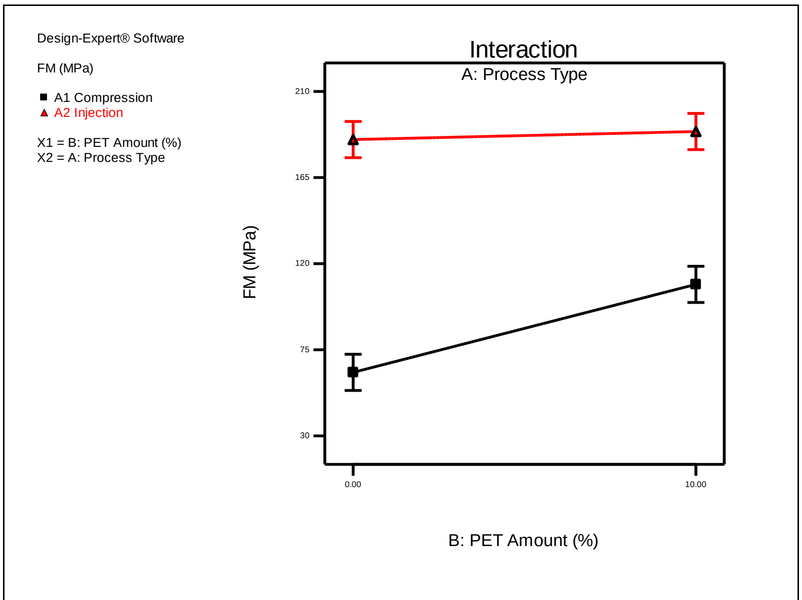
(c)

Figure 3. Interaction graph of processing types and presence of recycled PET on tensile properties; a) tensile strength, b) tensile modulus and c) elongation at break.

Flexural strength values of the samples were in the range of 6.7 – 10.0 MPa. Figure 4a shows the interaction graph of flexural strength. Statistical analysis showed that both processing types and PET amount had a significant effect on flexural strength ($P<0.0001$). Compression molded samples provided higher flexural strength values compared to injection molded ones. There is an interaction between processing method and PET amount ($P<0.0001$). Presence of PET has significantly reduced the values of compression molded samples while slightly influence the injection molded ones. In the case of flexural modulus, values were in the range of 30.95 – 202.81 MPa (Figure 4b). Processing method had a significant effect on flexural modulus. Injection molded samples provided higher flexural strength values compared to compression molded ones. Addition of PET filler increased the flexural modulus of compression molded samples. There was no significant effect of PET presence on flexural modulus of injection molded samples. Overall, injection molded samples still had higher modulus values even after PET filling.



(a)



(b)

Figure 4. Interaction graph of processing types and presence of recycled PET on flexural properties; a) flexural strength and b) flexural modulus

In the case of impact strength, produced samples were in the range of 2.74 – 7.26 kJ/m^2. Figure 5 shows the interaction graph of impact strength. Processing method has a significant effect on impact strength (P=0.0025). Compression molded samples had higher impact strength values than injection molded ones. In the case of PET amount, regardless of procession method, addition of 10% PET powder reduced the impact strength significantly (P<0.0001).

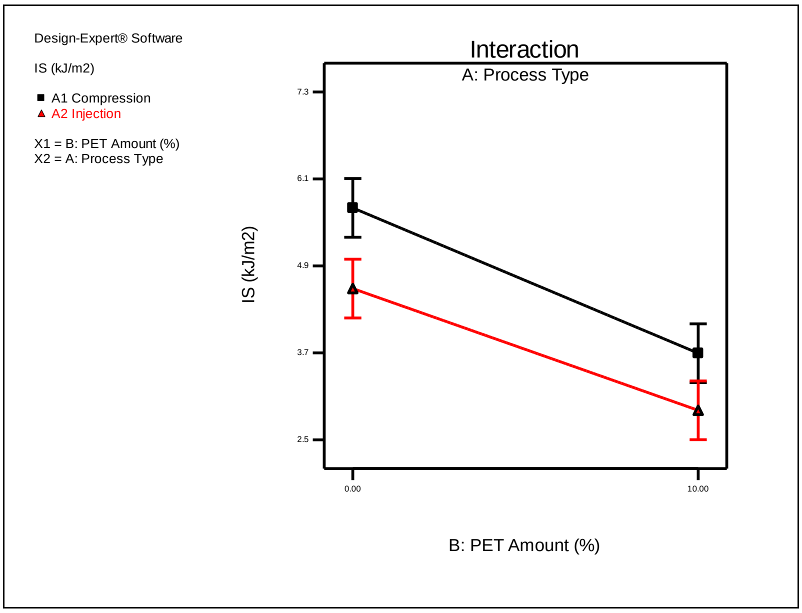


Figure 5. Interaction graph of processing types and presence of recycled PET on impact strength

Hardness of the produced samples were also evaluated and they were in the range of 54.8 – 61.2 Shore D. Processing method had no significant effect on hardness values (P=0.4718). Figure 6 shows the interaction graph of hardness. In the case of PET amount, regardless of procession method, addition of 10% PET powder increased the hardness values significantly (P=0.0002).

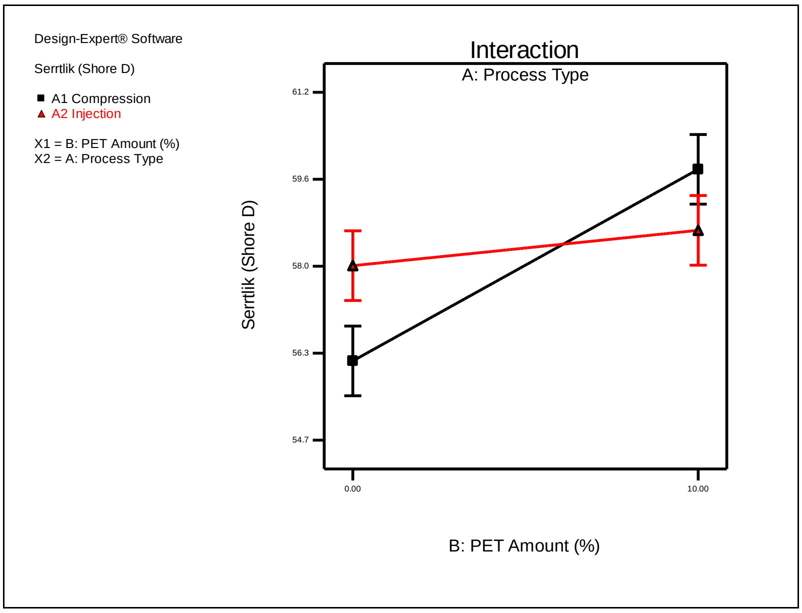


Figure 6. Interaction graph of processing types and presence of recycled PET on hardness

4. CONCLUSION

Recycled PVC composites were successfully manufactured with addition of DOP and recycled PET powder. Processing type and PET amount had a significant effect on mechanical properties. Best tensile strength values were achieved in the injection molded and no PET samples while best tensile modulus values were achieved with PET filled injection molded samples. The highest elongation at break values were measured with injection molded samples having no PET powder. In the case of flexural properties, best flexural strength and flexural modulus values were achieved with compression molding and injection molding, respectively. Best impact strength results were recorded with the compression molded and no PET powder samples. Highest shore D values were measured with PET filled compression molded samples. Future studies will be conducted to investigate the effect of using different size and shape PET fibers in recycled PVC.

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