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Utilization of synthetic based mineral filler in wood plastics composite

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ABSTRACT

Purpose: Purpose of this paper is to utilize synthetic base mineral filler in wood plastic composites (WPCs) and to determine their physical, mechanical and thermal properties.

Design/methodology/approach: Hybrid composites were produced by mixing wood flour (Turkish red pine (Pinus brutia Ten.), wax and maleic anhydride grafted polypropylene (MAPP) and polypropylene (PP) in a high intensity density mixer. The homogenous mixture was extruded using a single screw extruder with five heating zones. Extrudates were pelletized and composite samples were injection molded. Density of the samples was measured (ASTM D 792). Flexural strength (ASTM D 790), flexural modulus (ASTM D 790), tensile strength (ASTM D 638), tensile modulus, elongation at break and hardness (ASTM D22-40) were studied. Linear burning rate of the samples were also determined (ASTM D 635).

Findings: According to test results synthetic based mineral filler and wood flour can use together for better composite properties and they provide adequate mechanical properties according to ASTM D 6662.

Research limitations/implications: This article determined some of physical and mechanical properties of wood plastics hybrid composite which was manufactured with Turkish red pine flour and synthetic based mineral filler. As for the future researchers the some wood plastics composites can be manufactured by different wood flour species and in different amounts of synthetic based mineral filler.

Practical implications: Synthetic based mineral filler were added to the mixture either before extrusion or injection molding. Effect of mineral filler and wood flour amount was also studied.

Originality/value: Addition of wood flour and synthetic based mineral filler into polypropylene improved modulus values while reducing tensile strength, elongation and impact values.

Keywords: Wood plastic composite; Polypropylene; Synthetic based mineral filler; Mechanical properties; Thermal properties

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PROPERTIES

1. Introduction

Wood-plastic composites (WPCs) are emerging hybrid materials that combine lignocellulosic components, primarily wood material, and synthetic thermoplastics [1]. Wood plastic composites (WPC) are made from wood and annual plant fibre or flours, mixing with plastics materials. WPC provide better properties than resources which form itself. WPCs are mostly manufactured through extrusion and injection moulding processes, and they can be used in many different industrial sectors. The outdoor applications of WPCs, such as decking and siding, have raised concerns about their durability, including fungal resistance, ultraviolet resistance, moisture resistance, and dimensional stability [2].

Wood flour and plastic matrix constitute the main ingredients in WPC formulations [3]. Natural fibres as a renewable resource are receiving increased attention due to environmental protection issues. Many natural fibres, such as sisal, jute, wood fiber, sugarcane, wheat, and, flax straw can be used as fillers to improve mechanical properties and reduce the shrinkage of materials [4]. Wood makes an excellent functional filler, but within limits. While the heat used to melt and process plastics does not affect mineral-based fillers, it does affect wood [5]. WPC is the combination form of raw materials such as fillers (organic and inorganic), plastic, and additives. Among the raw materials, fillers are solid materials added to plastics mainly to reduce cost and improve properties [6]. The two main categories of these fillers are: 1) inorganic fillers, such as talc, mica, calcium carbonate, glass fibre, etc.; and 2) organic/natural fibres, such as wood flour/fibre, cellulose, rice hull, wheat straw, etc. [7]. The effect of inorganic fillers on the composite property strongly depends on the size, shape, content, surface characteristics, aspect ratio, and dispersion of the fillers [8]. Inorganic fillers have a higher density than wood fibre and can contribute to a third of the WPC weight [9].

2. Materials and method

2.1. Materials

The polypropylene (PP) (Petkim Petrochemical Co., Turkey) was used as the plastic matrix. Its density was 0.905 g/cm3, its melt flow index was 4.5 g/10 min (230°C/2.16 kg) and its melting Point (DSC) was 163°C. Turkish red pine (Pinus brutia Ten.) flour, supplied from a wood working atelier in the city of Kahramanmaraş, was used as natural filler. Paraffin wax (K.130.1000) as a lubricant and maleic anhydrite grafted polypropylene (MAPP) (Licomont AR 504 by Clariant) as coupling agent were used. Synthetic based mineral filler Hyperform® HPR-803i, Milliken Chemical Division of Milliken Europe, was used as mineral filler. The physical and chemical properties of synthetic based mineral filler in as follows in Table 1.

Table 1.
Hyperform® HPR-803i physical and chemical properties (Milliken, 2015)

Properties	Value and Unit
Trade name	HYPERFORM® HPR-803i
Material name	Magnesium Oxysulfate
Chemical Nature	synthetic mineral-based fibre
Fibre Length	10-30 micron
Fibre Diameter	0.5-1.2 micron
Appearance	White dust
Material Density	2.31 g/cm3
Moisture	<1.0%
Tapped Bulk Density	0.15 g/cc
Melting Point	547 K

2.2. Composite manufacturing

The Turkish red pine (Pinus brutia Ten.) wastes were granulated into the flour form using willey mill. These flours were classified and flours passing through a 40 mesh screen and retained on 60 mesh screen (0.25 mm or 250 micron) were used. The classified wood flours were dried in oven at 103°C (±2) for 24 hours. The moisture content of dried filler materials was below 1%.

In this study, wood flour and MOS content was investigated. In addition, the effect of adding MOS before extrusion and before injection was also studied. Depending on the manufacturing schedule; synthetic mineral based fiber lignocellulosic fillers, polypropylene (PP) and maleic anhydrite grafted polypropylene were mixed in a high-intensity mixer (900-1000 rpm in 2 sec.) to supply a homogeneous blend.

These blends were compounded in a single-screw extruder at 40 rpm screw speed in the temperatures of 170-180-185-190-200°C (from barrel to die) respectively. The extruded strand passed through a water bath and were cooled in water pool (23°C ±2) and then granulated into pellets by pellet machine. The pellets were dried in oven at 103°C (±2) for 24 hours. The moisture content of pellets was below 1% before the injection molding. The manufacturing schedule of the study is given in Table 2.

Table 2.
Manufacturing schedule of wood plastic composites with filled synthetic and lignocellulosic fillers

ID	PP, %	HPR use	Wood flour, %	HPR (803İ), %	MAPP, %	VAX, %
I-1	84	Before injection	0	10	3	3
I-2	88.14		2.93	2.93	3	3
I-3	74		2.93	17.07	3	3
I-4	84		10	0	3	3
I-5	74		10	10	3	3
I-6	64		10	20	3	3
I-7	74		17.07	2.93	3	3
I-8	59.86		17.07	17.07	3	3
I-9	64		20	10	3	3
E-1	84	Before extrusion	0	10	3	3
E-2	88.14		2.93	2.93	3	3
E-3	74		2.93	17.07	3	3
E-4	84		10	0	3	3
E-5	74		10	10	3	3
E-6	64		10	20	3	3
E-7	74		17.07	2.93	3	3
E-8	59.86		17.07	17.07	3	3
E-9	64		20	10	3	3

I: injection, E: extrusion.

The injection moulding machine (HAIDA HDX-88) was used for manufacturing test samples. The temperatures of injection moulding machine were from feed zone 180°C to die zone 200°C. Dried pellets were injected at an injection pressure of 5-6 MPa. Test samples were prepared in 18 different parameters (by weight 20 and 40 wt %) and five specimens were tested for each of the WPC formulation.

2.3. Composite testings

For both physical and mechanical properties, samples were conditioned at room temperature (23 ± 2°C) and relative humidity (65 ± 2%). Density of the each sample was measured by a water displacement technique according to the ASTM D 792 standard. Flexural, tensile and impact properties of all samples were determined according to ASTM D 790, ASTM D 638 and ASTM D 256, respectively. Five test samples for each group were tested. Flexural and tensile testing were performed on Zwick 10 KN while a HIT5,5P by Zwick™ was used for impact property testing on notched samples. The notches were added using a Polytest notching cutter by RayRan™. The dimensions of the specimens for flexural properties were 4 x 13 x 165 mm, for tensile strength (dogbone shape) 4 x 19 x 165 mm and for the izod impact strength (notched) 4 x 13 x 64 mm.

Horizontal burning test was accomplished according to ASTM D 635. Samples dimensions after injection molding were approximately 4 mm x 13 mm x 125 mm. Average burning rate was reported as the average of the burning rates of the samples which have burned to the mark in mm/min. For each group, ten samples were tested. Atlas HVUL2 Horizontal Vertical Flame Chamber test machine was used in this study (Fig. 1). Design-Expert® Version 7.0.3 statistical software program was used for statistical analysis. To form prescriptions, central composite design (CCD) programme was used.

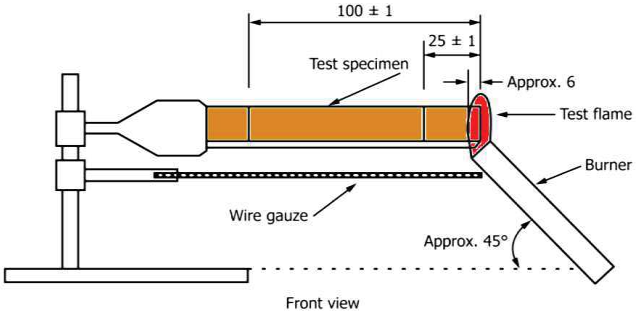


Fig. 1. Horizontal burning test procedure (adapted from ASTM D 635)

3. Results and discussion

Densities of the manufactured samples were presented in Figure 2. Fig. 2a shows the interaction graph of E-1 to E-9 (MOS were used before extrusion) and Fig. 2b shows I-1 to I-9 (MOS were used before injection).

Sample densities were between 0.91 and 1.11 g/cm^3. The MOS usage both before extrusion and before injection had significant effect on sample densities ($P<0.0001$).

Increase concentration of both wood flour and MOS had raised the density of the samples. Samples produced with MOS provided higher densities than samples produced with wood flour. Density of the composites was increased with filler 2.93, 10, 17.07, 20% rates. This increase was believed to be due to the higher cell wall density of lignocellulosic materials [10-12] and depend on higher density of MOS than the polymer and the density of lignocellulosic materials.

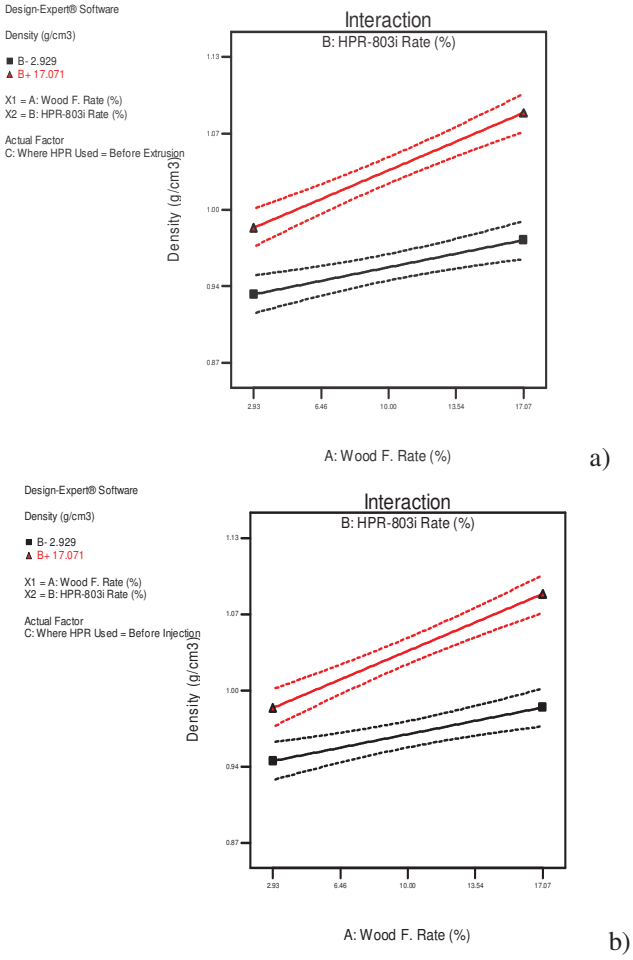


Fig. 2. Interaction graphs of density for a) before extrusion, b) before injection

In this study, flexural (flexural strength and flexural modulus), tensile (tensile strength, tensile modulus and elongation at break), impact and burning rate properties of all samples were determined. The mean values were ranged for the flexural strength from 36.27 to 49.86 MPa with group the injection moulding process and for the extrusion process was ranged from 36.78 to 56.87 MPa. Interaction graph of flexural strength and flexural modulus were presented in Figure 3. The results were showed the flexural strengths are significantly affected by MOS and WF rates and filler types ($P<0.0001$). Similar results were also reported for the flexural strength of other wood flour filled thermoplastic composites [12]. Results also showed that the place MOS was added had a significant importance on properties. E group (MOS was added before extrusion) provided better properties than I group (MOS was added before injection).

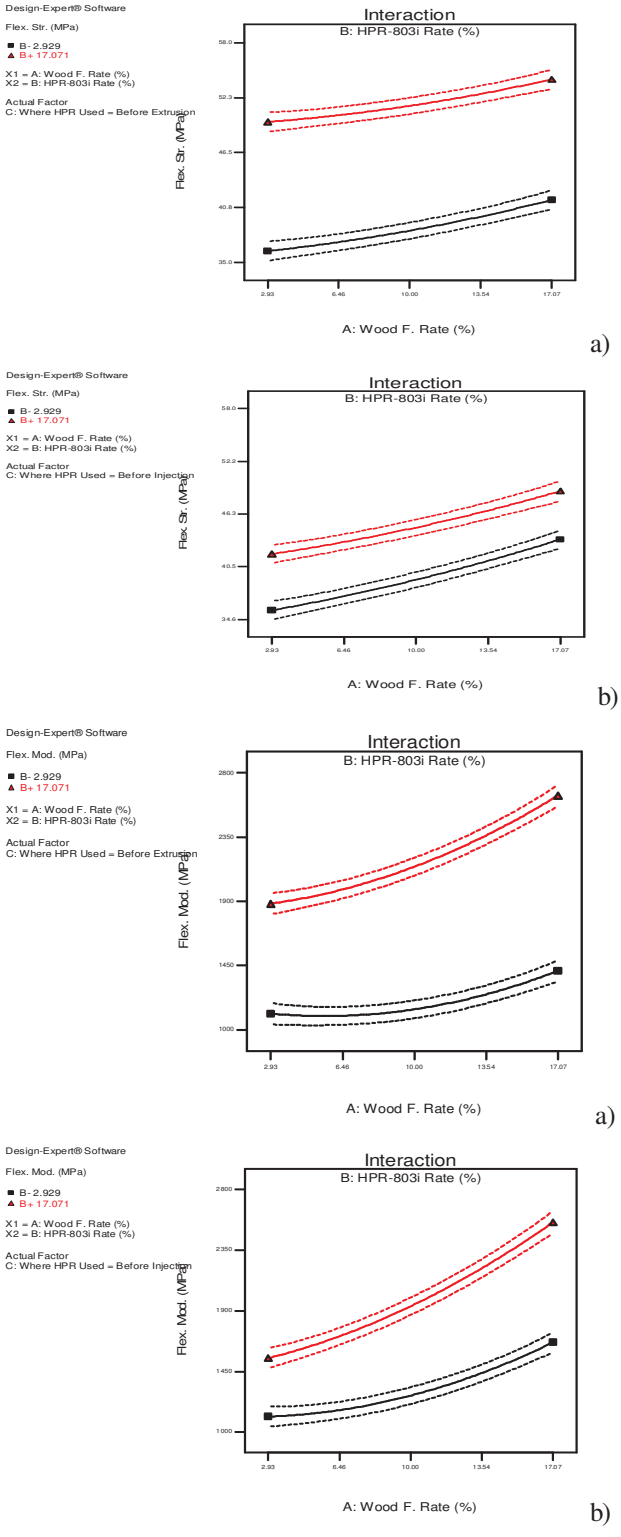


Fig. 3. Interaction graphs of flexural strength and flexural modulus, a) before extrusion, b) before injection

The highest flexural strength value was achieved at group E-6 (56.87 MPa) and the lowest was value was found at group I-2 (36.27 MPa). Interaction graph of flexural strength is shown in Figure 3a and for flexural modulus is shown in Figure 3b.

For the flexural modulus, regardless of filler type, rising filler 2.93, 10, 17.07, 20% concentration increased the flexural modulus. This increase was statistically significant (P<0.0001). There was similar flexural modulus properties were achieved with group E and group I. Synthetic based mineral filler, wood flour and polypropylene have different modulus of elasticity from each other. Lignocellulosic fillers have higher modulus of elasticity than polymer and flexural modulus increased with the rise of filler materials [12]. The highest flexural modulus value was found I-8 (2848.99 MPa) and the lowest was found E-4 (1108.43 MPa).

Tensile properties include tensile strength, tensile modulus and elongation at break. Tensile strength was significantly reduced with filler concentrations for both group I and group E samples (P <0.0001). The mean values was ranged for the tensile strength from 26.112 to 34.55 with group the injection moulding process and for the extrusion process was ranged from 25.85 to 29.28 MPa. The results were showed the tensile strengths are significantly affected by MOS and WF rates in both group I and group E (P<0.0001). Interaction graphs of the tensile properties strength were given in Figures 4 and 5.

Similar results for other wood flours filled polymer composites were also reported [11-12]. The filler has significant effect on elongation at break (Fig. 5) values for both composites (P<0.0001). Significant reduction by addition of filler in elongation at break values was determined for both polymer matrixes.

The mean impact strength values ranged from 1.70 to 2.55 (kJ/m^2) for group I and 1.96 to 4.24 (kJ/m^2) for group E. The interaction graph of impact strength was given in Figure 6. The results of the statistical analysis showed that, the rate of MOS and WF were effective on impact strength for group I and group E composites (P<0.0001). This usually arises from increasing of brittleness of the composite material [12].

The mean hardness strength values ranged from 66.12 to 75.60 (Shore-D) for group I and 66.00 to 74.14 (Shore-D) for group E. The interaction graph of hardness values was given in Fig. 7. The hardness strength of the test specimens were increased with both filler concentration in group I and group E composites.

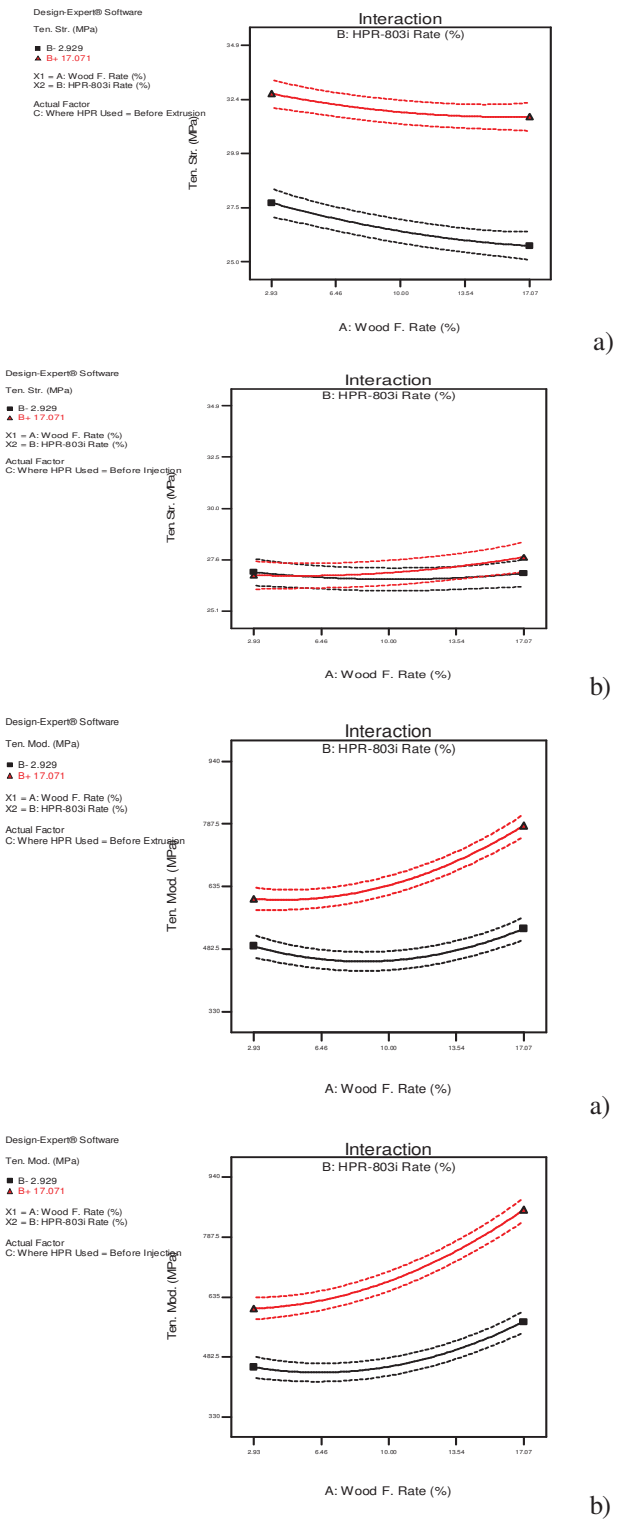
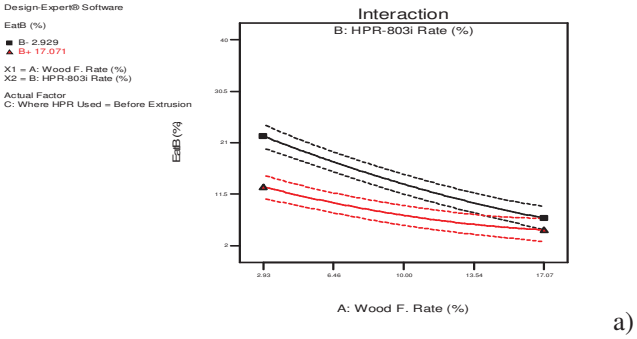
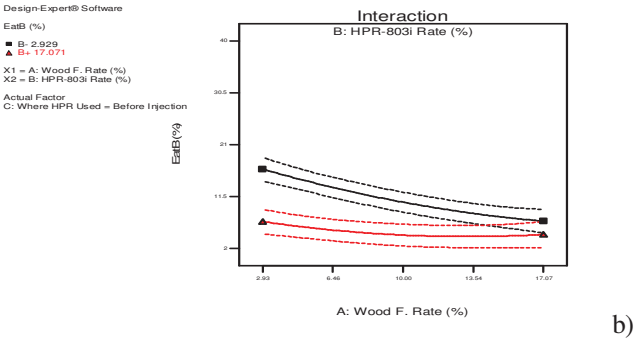


Fig. 4. Interaction graphs of tensile strength, tensile modulus, a) before extrusion, b) before injection

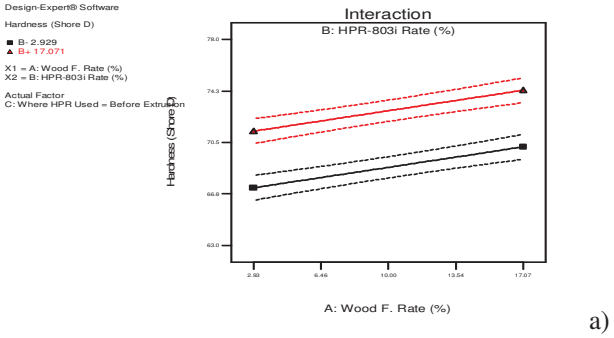


a)

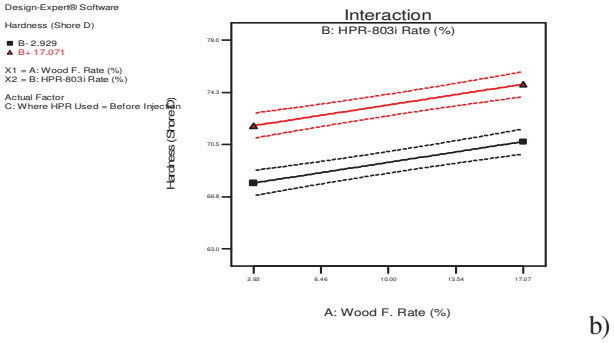


b)

Fig. 5. Interaction graphs of elongation at break, a) before extrusion, b) before injection

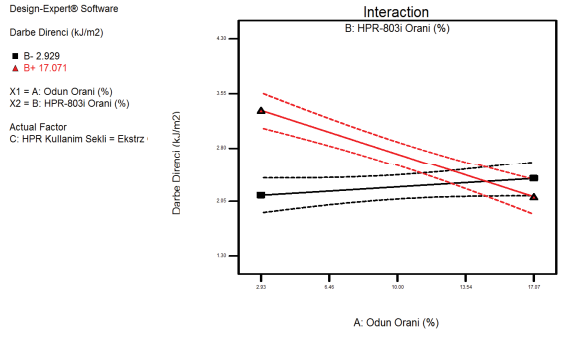


a)

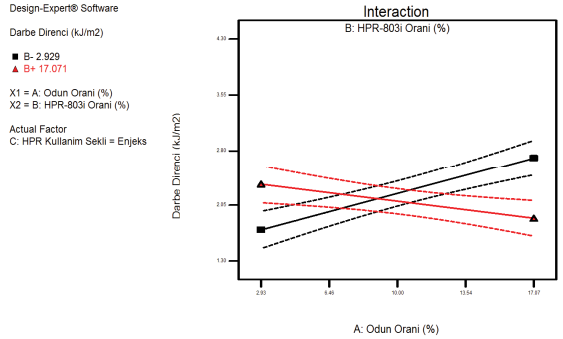


b)

Fig. 7. Interaction graphs of hardness (Shore-D) properties, a) extrusion, b) injection



a)



b)

Fig. 6. Interaction graphs of impact properties, a) extrusion, b) injection

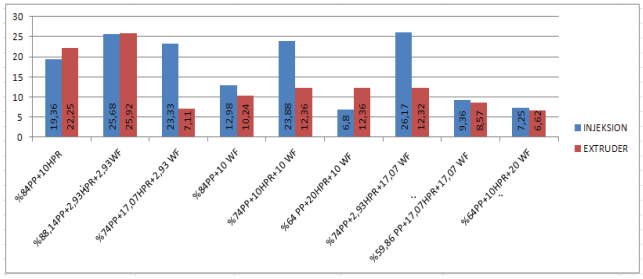


Fig. 8. Graphs of burning rate properties (mm\min)

The mean burning rate values ranged from 6.80 to 26.17 (mm\min) for group I and 6.62 to 25.92 (mm\min) for group E. The graph of burning rate values was given in Fig. 8. The hardness strength of the test specimens were increased depend on filler material rates both group I and group E. The highest burning rate value was found in group I-7 (26.17 mm/min.) and the lowest was found E-18 (6.62 mm/min.). Burning rate value was affected depend on filler material type and rates.

4. Conclusions

Polypropylene (PP) based composites including different 0, 2.93, 10, 17.07, 20% rates of synthetic based

mineral filler and wood flour were successfully manufactured by injection moulding process. MOS additive was added to the formulation before extrusion process (group E) and before injection process (Group E). Some properties of the produced composite such as density, tensile strength, tensile modulus, flexural strength, flexural modulus, elongation at break, burning rate, hardness and impact strength were determined. Addition of wood flour and synthetic based mineral filler into polypropylene improved modulus values while reducing tensile strength, elongation and impact values. According to test results synthetic based mineral filler and wood flour can use together for better composite properties and they provide adequate mechanical properties according to ASTM D 6662.

Acknowledgements

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