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RESEARCH ARTICLE

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Determination of mechanical performance of boric acid filled polypropylene based polymer composites

Hüseyin Ünal[1]*, Salih Hakan Yetgin[2], Sinan Köse[3]

[1] Sakarya University of Applied Sciences, Faculty of Technology, Metallurgy and Materials Eng. Department, 54050, Sakarya, Türkiye, ORCID: 0000-0003-0521-6647*
[2] Tarsus University, Faculty of Engineering, Department of Mechanical Engineering, 33400, Mersin, Türkiye, ORCID: 0000-0002-6068-9204
[3] Tarsus University, Vocatıonal School Of Technıcal Sciences at Mersin Tarsus Organized Industrial Zone, Department of Machinery and Metal Technologies, 33100, Mersin, Türkiye, ORCID: 0000-0002-6224-3388

Abstract

Polypropylene (PP) polymer, which is one of the indispensable materials of our daily life and stands out with its lightness, low cost and chemical resistance properties in the industry, was used. In industrial applications where the properties of polymers without additives are not sufficient, composite materials are produced by adding some additives to the polymer. In this experimental study, the mechanical properties of composites produced by adding boric acid (BA) to PP polymer at 5 wt.% (PP/5BA), 10 wt.% (PP/10BA) and 15 wt.% (PP/15BA) ratios were investigated. the effect of both BA filler and optimum BA filler ratio on mechanical properties were investigated. In the production of PP/BA composites, granules were first produced in an industrial twin screw extruder. Then, PP/BA composite tensile and impact test specimens were moulded on a conventional injection moulding machine. As a result, it was observed that the tensile modulus, tensile and yield strength of the composite materials decreased with increasing boric acid filler content in PP polymer. Depending on the boric acid filler content, the tensile strength decreased by an average of 18.3% and the breaking strength decreased by 14.8%. The lowest tensile modulus was obtained with a value of 2713 MPa at 10wt.% boric acid filler addition. The impact strength increased slightly at 5 wt.% boric acid filler addition and decreased at 10wt.% and 15wt.% boric acid filler addition.

Keywords: Polypropylene; boric asit; mechanical properties; composite

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* Corresponding author. Tel.: +90 264 295 6490
E-mail address: unal@sakarya.edu.tr

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1. Introduction

Nowadays, polymer-based composite materials (PCMs) are widely used in different industrial applications due to their high mechanical properties, low density and ease of industrial production. Polypropylene (PP) polymer is a semi-crystalline thermoplastic polymer and is one of the most promising and widely used polymers for the production of structural PCMs. Polypropylene (PP) is one of the important thermoplastic materials with low density (0.90 g/cm^3), easy processability, high strength, excellent chemical resistance, high thermal stability and low cost/price. Due to these properties, PP polymer is used in many industrial areas such as the automotive industry, health sector, food sector, construction sector and space sector [1]. In order to produce polymer composites, some additives are added to the polymer main matrix and the desired properties are tried to be obtained. These additives can sometimes be macro-sized minerals such as talc, calcite, kaolin, glass balls, titanium dioxide, copper powders, and sometimes nano-sized clays or metal powders. One of these additives is boric acid additive. Boric acid (H_3BO_3 or $B(OH)_3$), also called boracic acid or orthoboric acid, is obtained by the reaction of white powdered colemanite ore with sulfuric acid or borax with a mineral acid. Boric acid is used in the production of single-filament glass fibre (textile type glass fibre). BA which is used as a binder in ceramics, increases fracture and scratch resistance against physical impacts and improves chemical resistance. One of the most important properties of BA is the basic form of borate-based flame retardants used to reduce the degree of ignition of combustible materials. In addition to its uses in nuclear energy, medical sector, anti-bacterial and cleaning purposes, it is a good lubricant for metal and ceramic surfaces and plays an important role in controlling the coefficient of friction [2].

PCMs with different fibre (glass, carbon, aramid) and particle additions are produced for improve properties (mechanical/thermal) of polymers, which have a wide range of applications in industry and daily life. There are lots of studies in the literature in which the properties of fibre and particle filled polymer materials are determined and investigated [3], [4], [5]. In recent years, studies on the production and properties of BA-added composites with different polymer types have been intensified. Cheewawuttipong et al [6] reported the addition of boron nitride (BN) to PP polymer increases thermal conductivity, storage modulus and loss modulus. It was stated that the degree of crystallisation of PP polymer increased with increasing amount of BN. Visakh et al [7] reported that the 50% decomposition temperature (T_{50}%) increased, and the non-flammability property improved in epoxy composites filled with BA at different rates (1-10 wt.%). Celiker et al [8] characterized the mechanical and thermal properties of BA and paper mill sludge filled polyester. In their study, the highest flexural strength (21.83MPa) was obtained when 5 wt.% paper mill sludge and 3 wt.% BA were used. It was also stated that the thermal conductivity coefficient of polyester composites decreased with the addition of BA and paper mill sludge. Pehlivanlı [9, 10] examined the thermal conductivity values of PP composites produced by addition of BA (between 0.5-2.5 wt.%) in the form of particles with low thermal conductivity to PP polymer. As a result of the study, it was stated that the addition of BA decreased the heat conductivity coefficient of PP polymer. Özdemir et al [11] examined surface and mechanical behaviors of poly(methyl methacrylate) (PMMA) composites with borax, BA and colemanite addition. The highest flexural strength was obtained in 3 wt.% borax group and 1 wt.% colemanite group. Morover, the highest impact strength value was recorded in the 1 wt.% colemanite group, the difference between the 1 wt.% colemanite group and the control group was statistically significant. Cavdar et al [12] examined the effect of boron-based flame retardants (BbFRs)/high density polyethylene (HDPE) composites with impregnated spruce wood powder (WF). As a result of the study, it was reported that borax filled samples showed better mechanical properties than boric acid filled samples. A 19% improvement in the modulus of elasticity was observed at 40% fibre loading compared to control specimens. In their study, it was stated that borax in particular has the potential to be used as a flame retardant in wood plastic composites. Kırbas et al [13] examined the microstructure and physical properties of BA filled rigid polyurethane (PU). In their study, 5 wt.%, 10 wt.% and 15 wt.% BA was added to PU polymer material by weight. With the addition of BA, it was determined that there was a 57.2% decrease in thermal conductivity and 67.8% decrease in density compared to PU material. It was also observed that BA addition supported the formation of the cell structure of the polyurethane polymer. Awada et al [14] used BA filler in their study to improve the homogeneity and mechanical properties of cellulose fibres and polyvinyl alcohol (PVOH) based composite. The effect of BA on the mechanical properties of cellulose fibres under different pH values was investigated. The presence of BA under alkaline conditions further improved the mechanical properties of cellulose fibres. Aydın et al [15] investigated the tribological and mechanical properties of BA filled unidirectional glass fiber and carbon fiber added polyester composites. As a result, the wear resistance increased between 5% and 50%, tensile strength improved up to 32% depending on the amount of BA filler.

As can be seen in the literature, while there are studies examining mechanical, thermal and conductivity properties of boric acid filled polymer-based composites, there are a limited number of studies using polypropylene polymer as a matrix, where light weight, high chemical resistance and cheapness are prioritized in the industry. In this study, polypropylene based polymer composites filled with boric acid at different ratios (5-10-15 wt.%) were produced. The mechanical behavior of these composites was analyzed and optimum BA filler ratio was determined. With the results obtained, it is aimed to shed light on the literature about the usability of PP/BA composites in the industry.

2. Material and method

Boric acid filler material with a particle size of 150 μm for composite production was obtained from ETI Bank A.S./Turkey without surface treatment. The polymer main matrix material Polypropylene is a medium molecular weight PP homopolymer with a density of 0.905 g/cm^3, a melting temperature of 163 ^{o}C, a hardness of 94 HRR and a melt flow index value of 4.7 g/10 min, supplied from Petkim/Turkey with the code MH-418. The test specimens were first extruded in granule form and then injection moulded to produce PP-based composites filled with H_3BO_3 at different ratios (i.e. 5-10-15 wt.%). The temperature distribution during the extrusion process was set as 205-230 ^{o}C. Screw speed was set as 80 rpm. Injection heater temperatures were set at 200-230 ^{o}C from the feed unit to the head. No mould heater was used in the mould and the approximate mould temperature was around 40 ^{o}C.

Tensile tests have been made in a Zwick Roell Z-020 machine under climate-controlled room temperature, 50% humidity conditions and a tensile speed of 5 mm/min with ASTM D638 standard. Tensile strength, yield strength, yield strength, modulus of elasticity and elongation values of the material were determined as a result of the tensile test. At least five tensile test specimens were used for each polymer composite material composition in tensile tests. The arithmetic average of each five specimens was taken and the average values were given in the strength, modulus of elasticity and % elongation graphs. For the tensile test specimens, the average margin of error in the tensile and yield strength graphs was found to be between 2-4%, while the elastic modulus and impact strength were found to be between 2-5%.

Impact tests have been made in Zwick B5113 impact machine under climate controlled room temperature and 50% humidity conditions with ASTM D256 standard. The impact test specimens were printed in 4x10x80 mm3 dimensions in an injection moulding machine in accordance with ASTM standard. Then, a V-notch was made in the center of the 10 mm part of the specimens with a depth of 2 mm at an angle of 45^{o}. Izod impact test method was used for impact tests. In the experiments, the impact energy of the specimens was determined in joules and the izod impact strength value was automatically determined by the device by dividing the value obtained by the remaining area of the specimen after the notch. At least five test specimens were used for each material composition in the experiments and the arithmetic average of the five specimen values was taken and the average values were given in the graphs. The average margin of error in the graphs for impact test specimens was determined to be between 2-4%.

3. Results and discussion

The change in the modulus of elasticity of unfilled PP polymer and PP polymer composites filled with BA at different ratios depending on the amount of boric acid filler shows in Figure 1. As seen in the figure, while the modulus of elasticity of unfilled PP polymer was around 3173 MPa, a decrease in the modulus of elasticity was observed with the increase in the BA filler ratio. This decrease was 6.6% at 5 wt.% BA addition, 16.9% at 10 wt.% BA additions and 15.8% at 15 wt.% BA addition. The lowest modulus of elasticity was obtained with a value of 2713 MPa at 10% BA addition. It is thought that the reason for the possible decrease in the elasticity modulus is due to the release of water vapour due to the heat generated during the injection process and the formation of a porous structure in the polymer. Nazarenko et al. [16] also stated that BA releases water in the endothermic reaction during heating from 70 to 350 °C.

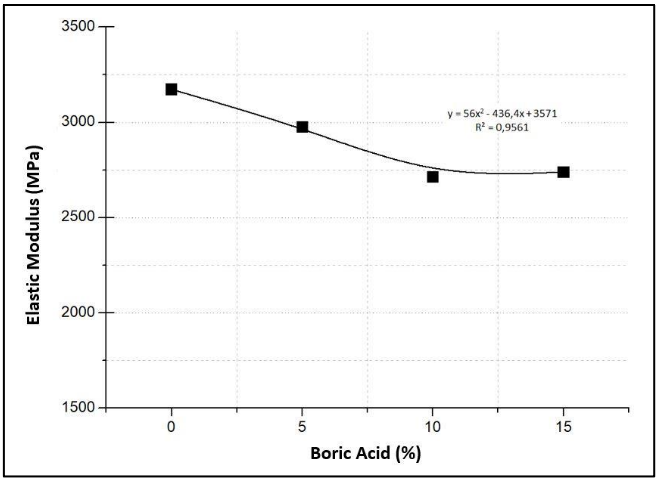

Fig. 1. Variation of elastic modulus of unfilled PP and PP composites containing BA at different ratios according to BA filler ratio.

Figure 2 shows the variation of tensile and yield strength of PP/5BA, PP/10BA and PP/15BA composites with unfilled PP polymer depending on BA filler ratio. As can be seen in the figure, yield and tensile strength of the composites decreased with the incensement in the BA filler ratio added to the PP polymer. The tensile strength of unfilled PP polymer was 35.4 MPa, it decreased by 4.23% to 33.9 MPa with 5 wt.% BA addition, by 16.9% to 30.2 MPa with 10 wt.% BA addition and by 11.8% to 31.6 MPa with 15 wt.% BA addition. Similarly, the tensile strength of the unfilled PP polymer was determined as 35.2 MPa. When 5%, 10% and 15% BA fillers were added to the unfilled PP polymer base matrix, the tensile strength values decreased by approximately 7.5%, 19.3% and 17.6%, respectively, and values of 32.7 MPa, 29.5 MPa and 29.9 MPa were obtained, respectively. As explained in the modulus of elasticity, the reason for the possible decrease in tensile strength and breaking strength can be explained by the formation of water vapour caused by the heat generated during injection moulding and boric acid filler. The water vapour formed during injection moulding will form a porous structure within the polypropylene polymer sample. This will cause the strength values of the composite to decrease. In previous studies, it has been explained that the strength increase in composite materials is related to the quality of the interfacial bond that allows stress transfer from polymer to filler element. Improvement of the interfacial bond generally results in improved strength values. Moisture/water vapour present in the composite structure may cause deterioration of the interfacial bond quality and thus decrease the composite strength [17] [18] [19]. Uygunoglu et al. [20] stated that high particle volume causes pore formation in mixtures and therefore compressive strength decreases. As is known, filler/matrix interfacial bond significantly affects the mechanical properties of polymer composites. A strong interfacial bond between the filler and the matrix increases the mechanical properties of the composite by providing efficient stress transfer [21]. However, a weak filler/matrix interface bonding will only give low composite strength. Ozdemir et al. [22] stated that the decrease in tensile strength was due to both lubricating effect of BA and the increase in the amount of filler in the composite.

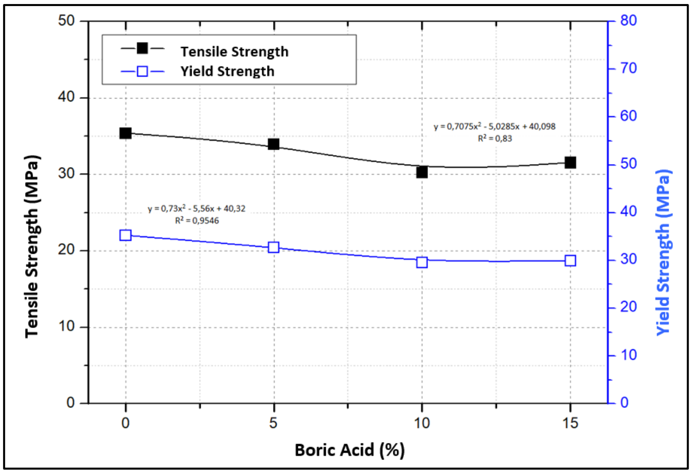

Fig. 2. Variation of tensile and yield strength of unfilled PP and PP composites containing BA at different ratios according to BA filler ratio.

Figure 3 shows the changes in % elongation and impact strength of unfilled PP polymer and PP composites filled with BA at different ratios depending on the amount of boric acid filler. As can be seen in the figure, it is observed that the elongation values change in an increasing and decreasing manner depending on the amount of BA filler. At 5 wt.% BA filler amount, the % elongation increased by 24.3%, while at 10 wt.% BA filler content it decreased by 18.7% compared to the unfilled PP polymer. At 15 wt.% BA filler content, the % elongation increased by 5.4% compared to the unfilled PP polymer. Impact strengths of the unfilled PP polymer and PP/BA composites showed a similar behavior to the elongation, i.e. increasing and decreasing. The impact strengths of unfilled PP polymer and PP/BA composites were obtained between 5.2 and 6.4 kJ/m^2. The impact strength increased by 20.7% with the addition of 5 wt.% BA while the impact strengths at high BA amounts (10 wt.%-15 wt.% BA) were obtained at the impact strength values of the unfilled PP polymer. Water vapor affects the polymer physically, chemically or in terms of plasticization and may cause bond breakage at the reinforcement/matrix interface [23, 24]. Additionally, although the decrease in the strength values of BA filled PP composites is thought to be due to the plasticization of the PP polymer phase, this contributed to almost preservation of properties such as impact strength and elongation.

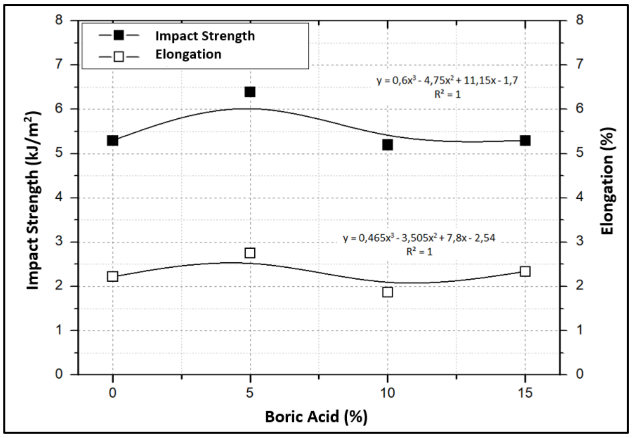

Fig. 3. Variation of % elongation and impact strength of unfilled PP and PP composites containing BA at different ratios according to BA filler ratio.

4. Conclusions

The mechanical properties of PP polymer without filler and PP composites with BA filler were investigated and the following results were obtained.

The mechanical properties of PP-based composites decreased due to the addition of BA to the PP polymer. Modulus of elasticity of PP polymer decreased depending on the BA filler ratio (5-10-15 wt.%). This decrease in the modulus of elasticity was obtained at 6.6%, 16.9% and 15.8%, respectively, depending on the BA filler rate. The addition of BA to PP polymer also decreased tensile and yield strength values of PP/BA composites. Elongation and impact strength values also showed increasing and decreasing changes depending on the amount of BA. The impact strengths of PP polymers and composites were obtained between 5.2 and 6.4 kJ/m^2. Before the BA filler is added to the polymer based materials, it must be dried in an oven at high temperatures to prevent the formation of water and/or water vapour in the composite. It should be ensured that the interface bond between polymer base matrix and filler material is strong.

Conflict Of Interest

The author declares no conflict of interests.

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