



Investigation of thermo-mechanical characteristics of borax reinforced polyester composites

Ramazan Orhan^a, Ercan Aydoğmuş^a, Sibel Topuz^a, Hasan Arslanoğlu^{b,*}

^a University of Firat, Department of Chemical Engineering, Elazığ, Turkey

^b Kırşehir Ahi Evran University, Faculty of Engineering and Architecture, Department of Chemical Engineering, Kırşehir, Turkey

ARTICLE INFO

Keywords:

Borax
Polyester resin
Mechanical properties
Flame retardancy
Thermal conductivity

ABSTRACT

The aim of this study is to investigate the effect of borax added as reinforcement on the mechanical properties, flame retardancy, and thermal conductivity of polyester-based composites. The polyester-based composites were prepared by adding 5, 10, 20, and 40 wt% of borax powder into an unsaturated polyester resin. The composite samples were subjected to different types of mechanical tests such as tensile strength, flexural strength, and hardness to evaluate their performance, limiting oxygen index (LOI) test to determine flame retardancy properties. Tensile and flexural strength values of composite samples were observed to increase until the borax content of 20 wt% into polyester resin. It slightly improved the hardness values of the borax reinforced composite. The distribution of borax particles in the polyester matrix was observed by scanning electron microscopy (SEM). The thermal conductivity of the composite samples was measured experimentally using a portable thermal conductivity meter. Increasing borax content increased the thermal conductivity coefficient of composite samples. Also, the most suitable model for the effective thermal conductivity coefficient was determined by statistical analysis.

1. Introduction

The depletion of natural resources in the world leads to critical concerns in meeting global demand in the future. Maintaining a balance between future demand and sustainable supply is the next challenge. Increasing ecological and socio-economic awareness, high consumption of petroleum resources, and new environmentally friendly regulations, especially in European countries, have led researchers to research on environmentally compatible materials. The enhanced of polymers performance and their composites in different applications such as industrial and structural fields have shown good behaviour and has been a focus of significant interest by using particulate fillers to enhance the preferred properties of the polymer or by reducing the cost of the composite [1–3]. By supporting polymers that do not meet some physical or chemical properties required in the application areas with fibers of various types and proportions, composite structures that can provide the desired properties can be formed [4–6]. Natural fibers are especially preferred as reinforcement or filler in polymer composites because of their advantages such as low cost and biodegradability, but one of the biggest disadvantages of their use is their poor performance in fires [7]. However, another disadvantage of natural fibers is their hydrophilic nature,

which leads to lower interfacial bonding and surface adhesion with the matrix [6,8].

Composites comprise two main phases: continuous and particulate phases. The particulate phases referred to as reinforcing elements can be organic or inorganic and fibrous or particulate. The use of inorganic fillers is a well-known approach for improving the mechanical properties of polymers [9]. Recently, rigid inorganic particulate fillers have received special attention owing to their ability to improve the interlaminar fracture toughness of fiber-reinforced epoxy resin in composites [10]. Various studies on the use of inorganic and organic particulate fillers in composite materials have been conducted. For example, Wetzel et al. examined the mechanical and tribological characteristics of epoxy matrix composites using nano- and micro-sized ceramic fillers composed of titanium dioxide (TiO₂) and silicon carbide (SiC) with particle sizes of 300 nm and 5–10 μm, respectively, as reinforcing particles [11]. Wang et al. fabricated a polyamide 6 (PA6) composite using different thermal conductive fillers (TC fillers), such as boron nitride (BN) and aluminum nitride (AlN), in a PA6 matrix containing an aluminum diethyl phosphinate (AlPi) as a fire retardant [12]. Alsaadi and Erklig investigated the mode I and mode II interlaminar fracture with inclusion SiC and borax particulate filler of glass/epoxy-reinforced composites [10]. Pech-May et al. synthesized polyester-based composites

* Corresponding author.

E-mail address: hasan.arslanoglu@ahievran.edu.tr (H. Arslanoğlu).

<https://doi.org/10.1016/j.job.2021.103051>

Received 23 March 2021; Received in revised form 29 July 2021; Accepted 30 July 2021

Available online 31 July 2021

2352-7102/© 2021 Elsevier Ltd. All rights reserved.

loaded with carbon nanofibers and adorned with magnetite nanoparticles (m-CNF) at volumetric concentrations of 0%–3.25% by applying a constant magnetic field before polymerization [13]. Singla and Chawla studied epoxy-based composites including fly ash [14]. Uygunoglu et al. investigated the physical and mechanical properties of polymer composites with wastes that incorporating boron [15]. Wan et al. examined and compared the effects of as-synthesized graphite oxide (GO) and silane-functionalized GO (silane-f-GO) loading and silane functionalization on the mechanical properties of epoxy composites [16]. Zhang and Singh used aluminum oxide as a reinforcement to enhance the mechanical properties of commercial polyester resins [17]. Tibiletti et al. studied the thermal degradation behavior of composites prepared by incorporating nano-alumina and submicron alumina trihydrate particles into commercial polyester resin using thermogravimetric analysis and pyrolysis gas chromatography/mass spectrometry [18]. The current literature review shows that titanium dioxide (TiO₂), magnetite, alumina (Al₂O₃), graphite oxide (GO), fly ash, etc. micro and nanoparticulate fillers are used as hardened materials for composite materials.

The use of boron compounds has become prominent since the 1980s in terms of being non-toxic, eco-friendly, high thermal, and biological resistance [19]. The most abundant boron minerals in terms of reserves in Turkey, where 73% of the world's boron reserves, are Tincal (Na₂B₄O₇·10H₂O) and Colemanite (2CaO·3B₂O₃·5H₂O). Boric acid and borax are the best known boron compounds and their most important usage areas are; glass, frit, and enamel production, flame retardants, fuels, cleaning and bleaching, fibers, and composites, metallurgy, agricultural, medical and nuclear applications. Borax (Sodium Tetraborate Pentahydrate, Na₂B₄O₇·5H₂O) is a form of sodium borate containing 5 mol of water, widely used in industry. It is obtained from Tincal ore in powder or crystal form. Some usage areas and benefits of borax are as follows; when borax pentahydrate is added to molten glass intermediates, it increases its viscosity, surface hardness, and durability, so it is included in glass products for heat insulation. It is used in agriculture to increase productivity and to obtain better quality products. It is used in plaster material for heat and sound insulation in the construction sector. Borates are used as flame retardants in various materials. It is used in adjusting the viscosity of starch-based adhesives and in solvents of casein adhesives. However, additions of borax to polymer resin have been discussed in a few studies, but to better understand the mechanical properties of polyester composites using borax particles as filler, further studies are necessary related to the behavior of the tensile, flexural, hardness, non-flammability, and thermal conduction coefficient of

polyester composites with the variation of borax particles loading in the literature.

This study aims to contribute to the thermo-mechanical properties of borax-added polyester composites. For this, a polyester-based composite material was prepared by adding borax powder of 149–74 μm particle size using different ratios of 5, 10, 20, and 40% by weight to an unsaturated polyester resin. The mechanical, thermal conductivity and flame retardancy properties of the composite samples obtained were determined. The distribution of borax in the composite material was analyzed by scanning electron microscopy (SEM). These tests applied to the prepared composites were carried out with and without the inclusion of borax particles. Additionally, with the help of statistical analysis, the most suitable model for an effective thermal conduction coefficient has been developed.

2. Material and method

2.1. Materials

In this study, the unsaturated orthophthalic polyester resin was used as matrix material, the methyl ethyl ketone peroxide (MEKP, C₈H₁₈O₆) as the hardening agent, and cobalt octoate (C₁₆H₃₀CoO₄) as an accelerator in the curing process of the polyester resin. Borax powder (Na₂B₄O₇·5H₂O) provided from the Eti Holding Borax Factory in Kirka/Eskisehir was used as filling material in a polyester-based composite production. In experimental studies, the particle size of the borax particles in the range of 149–74 μm was used. Four different weight fractions were selected, such as 5%, 10%, 20%, and 40%, to examine the effect of borax on polyester composite materials. For reference, pure polyester resin samples were also prepared and tested.

2.2. Fabrication of composites

As in our previous study [20], the borax powder/polyester composites were prepared as per the hand lay-up method by pouring into mold prepared according to the standards [21]. Before manufacturing, the mold surfaces were prepared by applying to the mold release wax (Poli-vaks SV-6).

The flow chart for the production of the polyester composite is shown in Fig. 1. The ratio of cobalt octoate that provides the gelling of the polyester resin in the 100 g adhesive is 0.5 wt% and the MEKP, which ensures the hardening, is 1.0 wt%. The reaction mechanism for

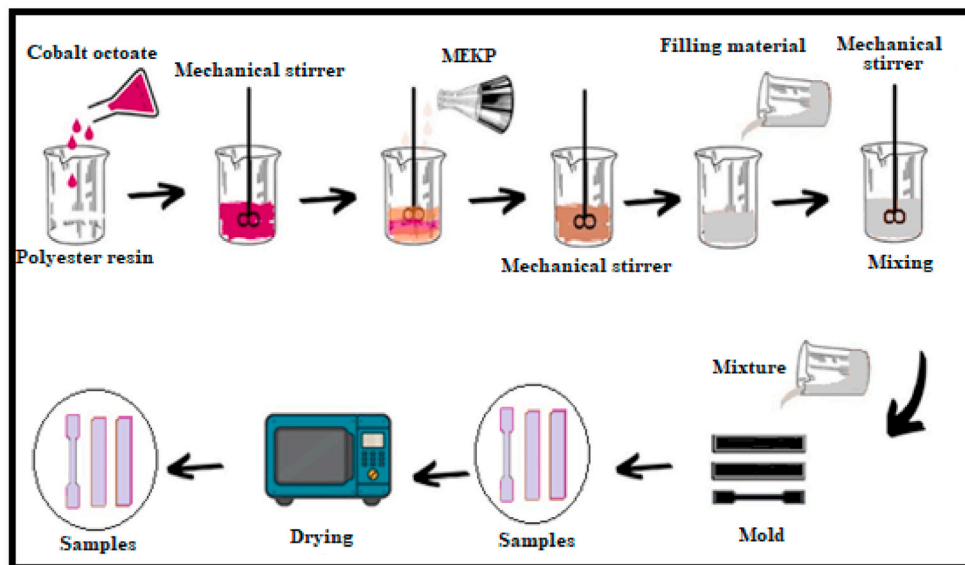


Fig. 1. Simplified flow chart for the manufacturing process of polyester composite.

the production of borax filled polyester composite (PE-B) is also given in Fig. 2. Polyester resin and prepared fillers were weighed in the proportions specified in the recipe (Table 1).

The required amount of unsaturated polyester resin was measured in a mixing cup. Accelerator and hardener were added into the polyester resin and mixed using a mechanical stirrer. After obtaining a homogeneous mixture, the appropriate amount of borax was added and was mixed thoroughly with the polyester resin. The mixture was then

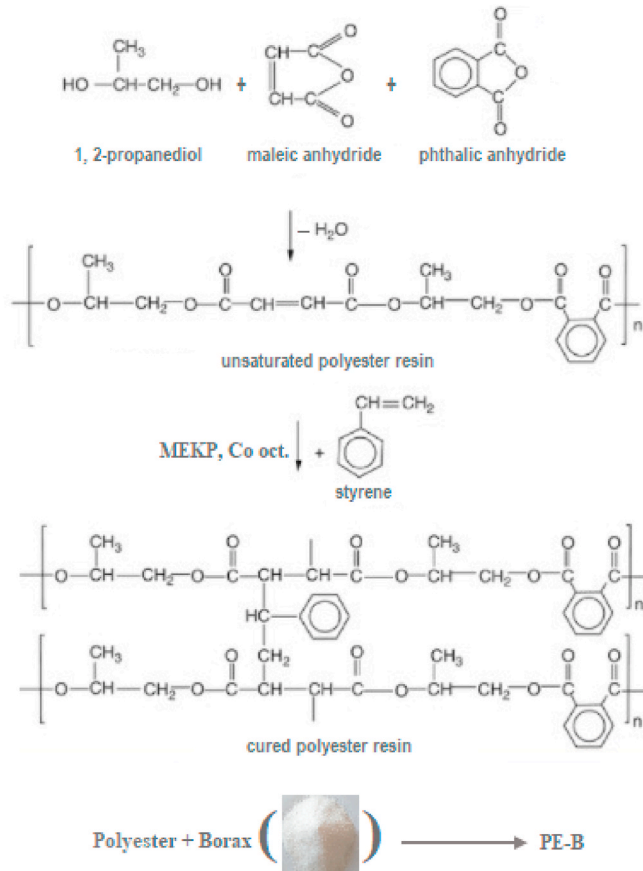


Fig. 2. Synthesis of unsaturated polyester resin, and production of borax filled composite.

Table 1

The composition of composite samples and polyester resin.

Borax content [wt%]	Polyester resin [wt%]	Cobalt octoate [wt%]	MEKP [wt%]
0	98.5	0.5	1.0
5	93.5	0.5	1.0
10	88.5	0.5	1.0
20	78.5	0.5	1.0
40	58.5	0.5	1.0

poured slowly into the mold at a distance of 30 cm above the mold, allowing extremely thin pouring a stream to reduce the trapping of air bubbles. The composition was then cured at room temperature for about 4 to 6 h. The slabs were removed from the mold and post cured in an oven at 80 °C for 1 h. Typically prepared samples are shown in Fig. 3.

2.3. Tensile test

To determine the tensile behaviour of pure polyester and composite samples, the tensile test was applied to the samples prepared according to ASTM D 638M-91a standard using a 1 kN capacity Universal tensile testing machine (UTEST Material Testing Equipment, TURKEY) at a cross-head speed of 1.0 mm/min at room temperature. Three tensile tests were performed for each sample and the tensile strength values were determined by averaging these test results. The modulus and tensile parameters were reported according to the average of these results. The modulus of elasticity (E) was calculated using the following equations:

$$E = \sigma/\epsilon \quad (1)$$

$$\epsilon = \Delta L/L_0 \quad (2)$$

where, σ is stress induced in the body (MPa); ϵ is the strain, ΔL is the change in the length of the standard sample (mm) and L_0 is the initial length of the standard sample (115 mm).

2.4. Flexural test

Flexural properties of the pure polyester and composite samples were measured according to ASTM D 790-03 test method using a Universal tensile testing machine at a cross-head speed of 1.0 mm/min at room temperature. The length, width, and thickness of the test samples were 80, 20, and 4 mm, respectively. The mean value of at least three samples of each specimen was taken into consideration. Flexural strength (σ_f) of the composite was calculated using the following relationship:

$$\sigma_f = 3PL/2bd^2 \quad (3)$$

where P is the maximum load (N); L is the support span (mm); b is the width (mm) and d is the thickness (mm).

2.5. Shore hardness test

The hardness measurement tests of the pure polyester and composite samples were performed using Shore-D hardness by the ASTM D2240 standard. The length, width, and thickness of the samples tested were 80, 20, and 10 mm, respectively. Samples were placed on the hardness measuring machine and hardness measurement was performed in 5 different regions of the composite materials (TIME TH-210 Digital Shoremetre). The average of these 5 values obtained in the calculations was used.



Fig. 3. Prepared samples.

2.6. Limited oxygen index (LOI)

Limiting Oxygen Index (LOI) is defined as the minimum concentration of oxygen required for the combustion of plastic and composite materials in a controlled atmosphere consisting of a mixture of oxygen and nitrogen [22]. The flame retardancy properties of composite samples were performed using an HC-2C oxygen index instrument (Jiangning analytical instrument company, China) according to the standard EN ISO 4589-2 with the LOI test. The dimensions of the samples prepared for this test were 100 mm × 10 mm × 4 mm (length, width, thickness respectively).

2.7. Scanning electron microscopy (SEM)

The SEM micrographs of surfaces of the pure polyester and 10%, 20%, and 40 wt% borax reinforced composites were examined using a scanning electron microscope (SEM, Zeiss EVO MA 10 Model) at an accelerating voltage of 20 kV in the secondary electron mode. To prevent the extent of sample arcing, the samples were coated with a thin layer of gold in a Denton Vacuum Desk V automatic sputter coater before scanning electron microscopy observations.

2.8. Thermal conductivity measurement

In the experimental studies, polyester mixtures with 0%, 5%, 10%, 20%, and 40% borax by weight were poured into cube-shaped (1000 cm³) molds. In this research thermal conductivity of composite samples was measured using the portable thermal conductivity meter (Thermtest TLS-100) following ASTM D5334-14. This method is gaining popularity because of the higher level of accuracy and repeatability [23,24].

The samples removed from the molds were prepared for the measurement by drilling 2.5 mm in diameter and 5 cm in depth in the central area and then the thermal conductivity coefficient values were measured using the portable thermal conductivity meter.

3. Results and discussion

3.1. Tensile strength

The change of the tensile strength of the pure polyester and composite samples produced by the weight percentage of the borax content is given in Fig. 4. The variation of the elasticity modulus of pure polyester and composite samples with a weight percentage of the borax content



Fig. 4. Variation of tensile strength of pure polyester and composite samples with weight percentage of borax.

was also obtained as shown in Fig. 5. It is seen from Fig. 4 that the added borax particles improve the tensile properties of the composite samples. The highest tensile strength was found for composite with 10 wt% borax content. The tensile strength was increased from 9.39 MPa for pure polyester to 10.77 MPa for composite with 10% borax content. It has been reported by other researchers that the composite produced by using borax as a filler improves flame retardancy and mechanical properties [7,10]. However, a decrease in the tensile strength was observed when the borax content started to increase, ie 20 and 40 wt%. Since the homogeneous distribution of filler material in composite materials is an important factor in improving the mechanical properties of the composite material, this decrease in tensile strength can be attributed to the poor distribution of added borax, particle aggregation, or pore formation [10,25,26]. As can be seen from Fig. 5, the values of elasticity modulus increased with the increasing amount of the borax addition, and the maximum value was found to be 350.72 MPa. This behavior related to interfacial bonding in the elastic limit, hence the increment was due to the stiffness of inorganic rigid particles is greater than pure polyester.

3.2. Flexural strength

The variation of flexural strength belonging to the pure polyester and composite samples is presented in Fig. 6. It is seen from Fig. 6 that the flexural strength values of the composite samples except for 40 wt% borax content are higher than the value of the pure polyester sample (from 76.17 MPa). While the flexural strength values of the composite samples initially increased with the increase of borax content, this value started to decrease after reaching a maximum at 10 wt% of the borax content. At 10 wt% the borax content (91.19 MPa), the flexural strength value was improved by 19.72%. Seki et al. reported that adding 1, 3, and 5% by weight of huntite to unsaturated polyester resin increased the tensile strength and flexural strength values of polyester by up to 3 wt% and decreased at higher waste content [26]. Therefore, it can be said that adding more borax powder into polyester composite may cause a more inhomogeneous structure in composite samples.

3.3. Hardness

In Fig. 7, the Shore-D hardness values belonging to the pure polyester and composite samples are given. Shore D hardness values were found to be 77.5 and 78.0 for pure polyester and 40% by weight added polyester composite, respectively. As a result, it has been observed that

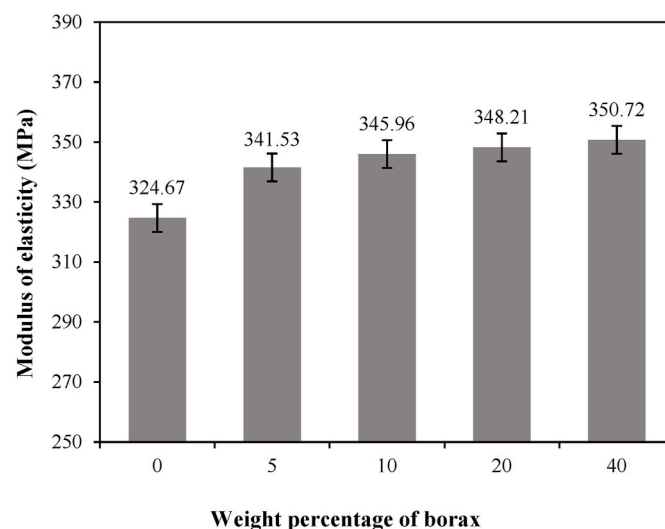


Fig. 5. Modulus of elasticity of pure polyester and composite samples with weight percentage of borax.

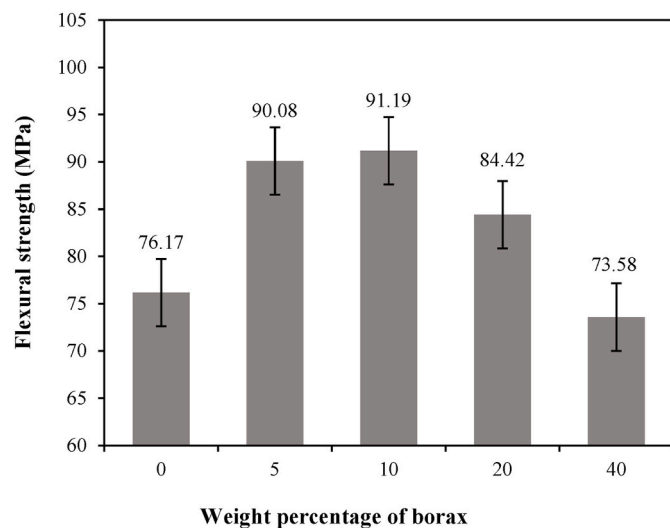


Fig. 6. Variation of flexural strength of pure polyester and composite samples with weight percentage of borax.

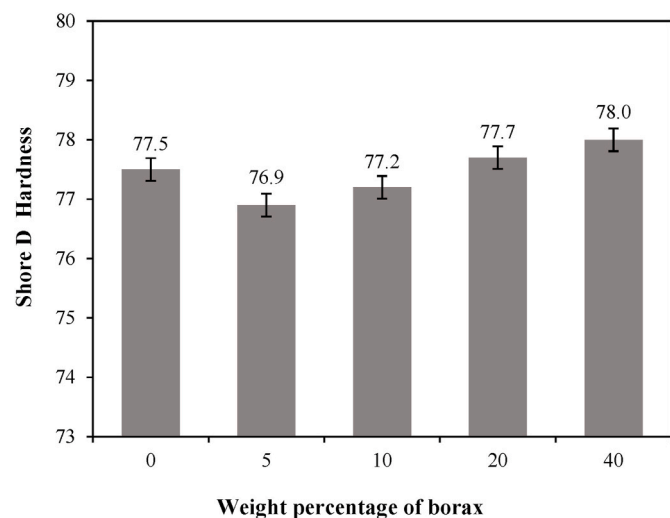


Fig. 7. Variation of the hardness of pure polyester and composite samples with weight percentage of borax.

the Shore D hardness tends to a little increase depending on the amount of borax added to the polyester resin. It has been reported in the literature that the addition of borax particles as an alkaline filler to composite materials generally improves the hardness or impact strength of the material [7,27,28].

3.4. Limited oxygen index (LOI)

It is seen from Fig. 8 that the LOI values of the composite samples increased with the use of borax according to pure polyester. LOI values of the composite samples were in the range of 22–28. These values clearly show that borax gives a flame retardant property to composite samples. Materials with LOI values less than 21 are classified as combustible, but those with LOI greater than 21 are named as self-extinguishing since their combustion cannot be sustained at ambient temperature without an external energy contribution. Materials with a high LOI value generally exhibit a better flame retardancy property [29]. It has been reported in the literature that boron and its compounds improve the flame retardant properties of the composite [7,30,31].

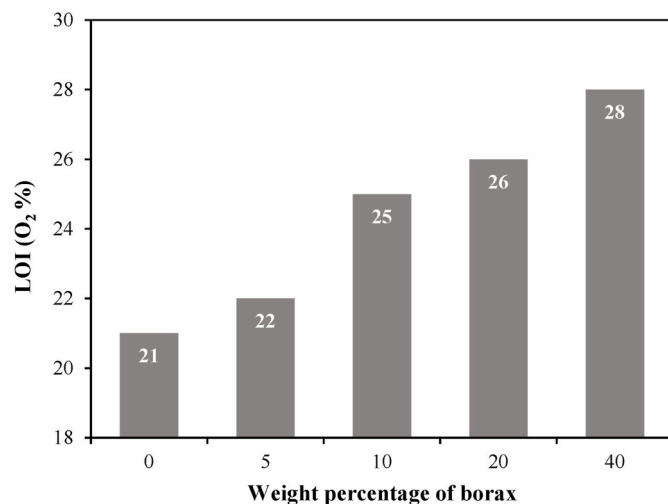


Fig. 8. LOI values of pure polyester and composite samples with weight percentage of borax.

3.5. Scanning electron microscopy (SEM)

SEM images of pure polyester and 10%, 20%, and 40 wt% borax reinforced composite materials are given in Fig. 9. It is seen from Fig. 9 that SEM micrograph of the 10 wt% borax reinforced composite material is close to pure polyester, but as the borax amount increases, 20 and 40 wt% borax reinforced composite sample has an inhomogeneous distribution and porosity. Also, increasing borax content negatively affected the surface morphology of the polyester composite and caused roughness. As a result, this inhomogeneous dispersion caused local aggregation of borax in polyester. This observation supports the decrease seen in tensile and flexural strength values with increasing borax content (especially 20 and 40 wt%).

3.6. Thermal conductivity measurement

The measured thermal conductivity values of the pure polyester and composite samples with different borax content loadings are given in Fig. 10. The thermal conductivity coefficient of the pure polyester was experimentally found to be 0.0461 W/m K (Accuracy \pm %5). When borax content is 5 wt% and 10 wt%, no obvious difference is observed among the thermal conductivities of the composites, because borax particles cannot contact each other. However, when the borax content increased and reached 40 wt%, the thermal conductivity of the composite was found to be a high value such as 0.0723 W/m K, indicating that the borax added to the polyester resin started to take effect prominently. The reason for this increase may be attributed to the higher thermal conductivity of the filling material. The thermal conductivity of most mineral fillers is approximately higher than that of thermoplastics and their incorporation considerably increases the conductivity of composite materials [32].

3.7. Statistical analysis

Parallel, series, geometric and Maxwell-Eucken model equations were used to determine the effective thermal conduction coefficient. The theoretical models were used by modified since there are great differences between the thermal conduction coefficient obtained from the experimental results and the coefficients found in the model equations. With the help of statistical analysis, it was seen that the error functions of the modified models were close to zero and R^2 values were close to one. The effective thermal conduction coefficient was expressed in the literature as a function of the porosity and the thermal conduction coefficient of solid and fluid (liquid or gas) [33,34]. In this study, when the

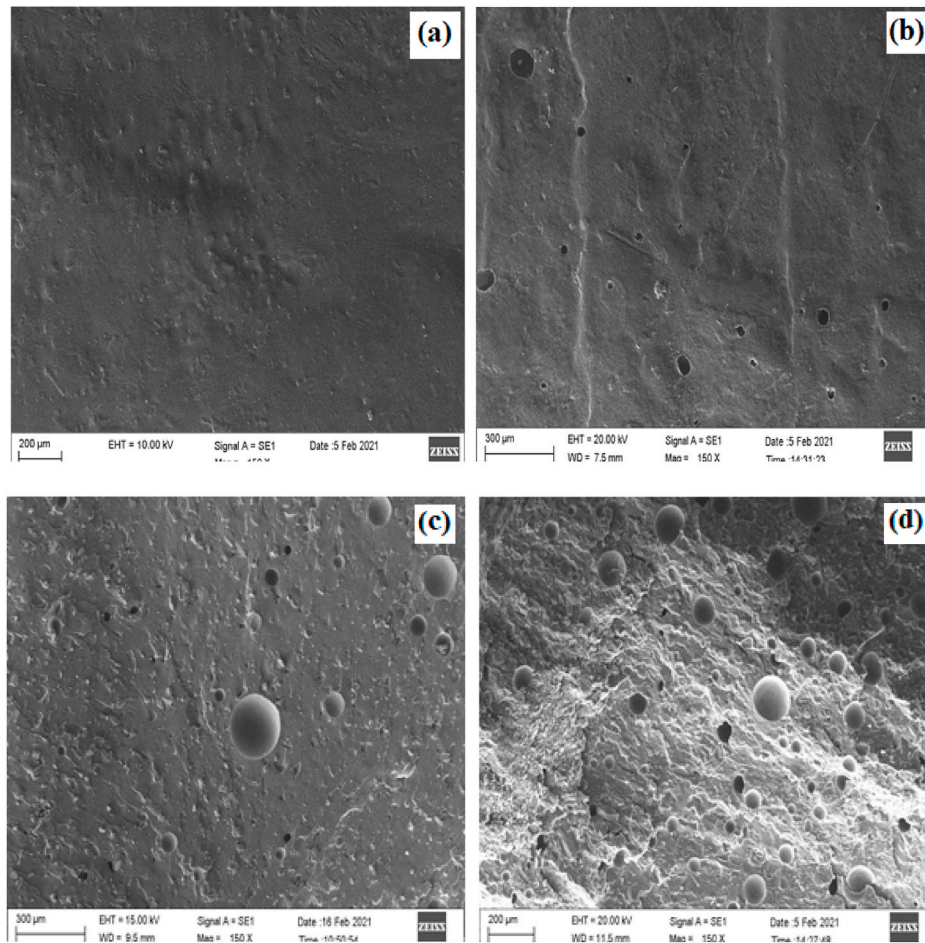


Fig. 9. SEM images of (a) the pure polyester, (b) the borax-reinforced composite of (10 wt%) (c) the borax-reinforced composite of (20 wt%), (d) the borax-reinforced composite of (40 wt%).

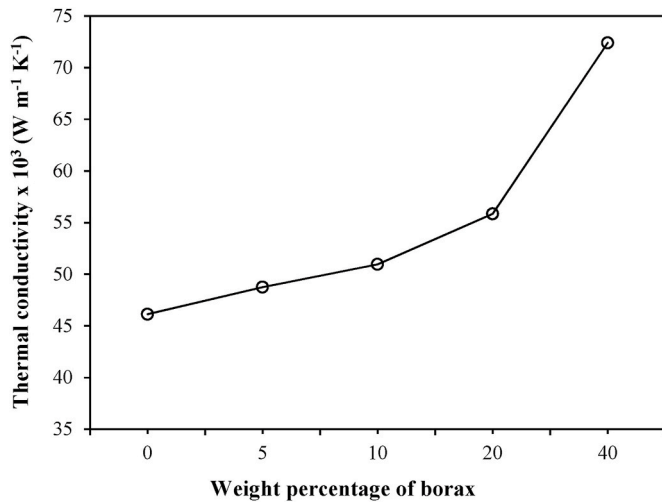


Fig. 10. Variation of thermal conductivity of polyester and composite samples with weight percentage of borax.

structure of the borax reinforced polyester composite is examined, it is concluded that many parameters affect the effective thermal conduction coefficient. Many parameters such as polyester, catalyst ratio, filler, impurities, hydrated water crystals, moisture, distribution and size of pores, composite matrix, interface resistances affect the thermal conduction coefficient. Theoretical equations have been modified to reduce the effect of these factors on model results. The modified and de-

veloped model equations obtained for polyester composites are given in Table 2.

In the model equations given in Table 2; k_c is the effective thermal conductivity coefficient, k_s is the thermal conductivity coefficient of the solid phase, k_f is the thermal conductivity coefficient of the gas phase, ϵ is the porosity, and m, n, z are the correlation coefficients.

The porosity of the samples was determined by the density method [35] and calculated using Eq. (4)

$$\epsilon = 1 - \frac{\omega \rho_b + (1 - \omega) \rho_p}{\omega \rho_{bg} + (1 - \omega) \rho_{pg}} \quad (4)$$

where; ρ_b and ρ_p are the density of the borax and polyester composite, respectively; ρ_{bg} and ρ_{pg} are the density of the borax and the polyester composite, which have zero porosity after grinding, respectively. ω is the ratio by mass of the borax content in the mixture [36].

Table 2
Modified and improved model equations for the polyester composites.

Models	Equations
1. Modified parallel model	$k_c = mk_f(\epsilon) + nk_s(1 - \epsilon) + z$
2. Modified serial model	$k_c = 1 / \left(\frac{m\epsilon}{k_f} + \frac{n(1-\epsilon)}{k_s} \right) + z$
3. Modified geometric model	$k_c = mk_f^\epsilon + nk_s^{(1-\epsilon)} + z$
4. Modified Maxwell-Eucken	$k_c = \frac{k_s(k_f + 2k_s + 2m\epsilon(k_f - k_s))}{k_f + 2k_s - n\epsilon(k_f - k_s)} + z$
5. Improved model	$k_c = \frac{\epsilon k_f^m}{(1-\epsilon)k_s^n} + z$

Table 3
Correlation coefficients obtained using statistical analysis of models.

Models	m	n	z	R^2	RMSE	SST	χ^2
1	0.52220	0.75424	0.01398	0.98910	0.00098	0.00033	2.4×10^{-6}
2	0.50202	0.52317	-0.03545	0.96748	0.00169	0.00056	7.1×10^{-6}
3	0.04795	0.29201	-0.00448	0.97333	0.00153	0.00050	5.8×10^{-6}
4	1.64114	0.00455	0.00286	0.98754	0.00108	0.00037	2.9×10^{-6}
5	-0.94799	-2.73599	0.04535	0.99985	0.00012	0.00004	3.4×10^{-8}

The effective thermal conductivity coefficient (k_e) of pure polyester, and borax reinforced polyester composite samples at a concentration of and 5–40 wt% was experimentally repeated five times. The m , n , and z coefficients were calculated by performing non-linear regression analysis with statistical analysis, considering the validation experiments of a total of 25 measurements. The modified and newly improved equations have been evaluated within the 95% confidence interval, and the most suitable model was selected where the standard deviation and error functions (SST, RMSE, and χ^2) were minimum and regression coefficient R^2 was maximum. The error functions and correlation coefficients found with the help of statistical analysis of the modified and newly improved model equations are given in Table 3. It is seen from Table 3 that the models with the minimum error functions and maximum R^2 values are compatible with the experimental results. Especially, the results of the newly improved model (5) and the modified models were found to be compatible with the experimental results.

The most appropriate model was determined by applying statistical tests such as the root mean square error (RMSE), the total sum of squares (SST), and chi-square (χ^2) to verify the reliability of the results obtained from the models.

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (M_{ei} - M_{mi})^2}{N}} \quad (5)$$

$$\chi^2 = \frac{\sum_{i=1}^N (M_{ei} - M_{mi})^2}{N - n} \quad (6)$$

$$SST = \sum_{i=1}^N (M_{ei} - \bar{M}_{mi})^2 \quad (7)$$

where M_{ei} is experimental values, M_{mi} is the values in the model, N is the number of experiments, n is the number of parameters in the model, and \bar{M}_{mi} is the average of the data in the model.

The thermo-mechanical properties of the borax reinforced polyester composite were compared with the composites synthesized using different filling materials in the literature and summarized in Table 4.

4. Conclusion

The results found for the borax reinforced polyester composite are as follows:

- The tensile and flexural strength of the composite improved significantly with increasing borax content, except for 40 wt%, and the Shore D hardness slightly increased. This decrease at 40 wt% borax reinforced composite is due to process-induced voids.
- The limiting oxygen index (LOI) test results showed that borax gave significantly the flame retardant property to the composite samples.
- It was observed that the thermal conductivity of the composite samples increased with the increase in the amount of borax.
- It has been seen that the results of the newly improved model (5) and the modified models for the effective thermal conductivity coefficient are compatible with the experimental results.

These results showed that borax as a filler can be used as a flame retardant and as a mechanical properties improver in the production of an economical polyester composite. Hence, the obtained polyester com-

Table 4

Comparison of thermo-mechanical properties of borax reinforced polyester composite synthesized in this study with other composites.

Filling material	Tests applied to composite samples and their effect	References
Borax	TS decreased by 1.88% FS increased by 5.92% IS decreased by 11.58% LOI increased by 9.5%	[7]
Huntite mineral	TS increased by 18.8% FS increased by 5.61%	[26]
Sanseveria natural fiber	TS increased by 155.2%	[37]
Bentonit	IS increased by 312% k decreased by 20% H increased by 90% CS increased by 100% k increased by about 850%	[38]
Boron compounds	TS decreased by 26.71% IS decreased by 23.12% BR decreased by 56.48%	[39]
Waste grass broom fiber	TS increased by 222%	[40]
Mica	IS increased by 590% k decreased by 24.35% TS decreased by 20% FS increased by 97% IS decreased by 430%	[41]
Borax	TS increased by 14.7% FS increased by 19.72% H increased by 0.65% LOI increased by 33.33% k increased by 56.52%	This study

TS: Tensile strength (MPa); FS: Flexural strength (MPa); IS: Impact strength (Jm^{-1}); LOI: Limiting oxygen index ($O_2\%$); k: Thermal conductivity coefficient ($Wm^{-1} K^{-1}$); H: Hardness; CS: Compressive Strength (MPa); BR: Burning rate ($mm min^{-1}$).

posite can be evaluated in construction and construction areas such as the insulation sector.

In future studies, it may be recommended to use the pressure molding system to increase the effectiveness of the method used. With the help of this system, the quality of the samples can be improved by removing the air bubbles that may occur during the synthesis of the composite.

Credit author statement

Ramazan Orhan: Conception and design of study, Analysis of data, Drafting the manuscript, Approval of the version of the manuscript to be published. **Ercan Aydoğmuş:** Acquisition of data, Drafting the manuscript, Approval of the version of the manuscript to be published. **Sibel Topuz:** Analysis of data, Revising the manuscript critically for important intellectual content. **Hasan Arslanoğlu:** Conception and design of study, Drafting the manuscript, Revising the manuscript critically for important intellectual content.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This study was financially supported by the Scientific Research Projects Unit of Firat University (FUBAP) (Project No: MF.19.12).

References

- [1] J.I. Kim, P.H. Kang, Y.C. Nho, Positive temperature coefficient behavior of polymer composites having a high melting temperature, *J. Appl. Polym. Sci.* 92 (1) (2004) 394–401.
- [2] A. Olad, Polymer/clay nanocomposites, *Advances in Diverse Industrial Applications of Nanocomposites*, Boreddy Reddy, 2011 IntechOpen, <https://doi.org/10.5772/14464>.
- [3] S. Otlés, S. Despoudi, C. Bucatariu, C. Kartal, Food waste management valorization and sustainability in the food industry, *Food Waste Recovery: Processing Technologies and Industrial Techniques*, 2015, pp. 3–23, <https://doi.org/10.1016/B978-0-12-800351-0.00001-8>.
- [4] T. Karpenja, A. Lorentzon, K. Wickholm, Sustainability Aspects in Waste Management of Biocomposites 26th IAPRI Symposium on Packaging, 2013, pp. 220–232.
- [5] R. Syafiq, S.M. Sapuan, M.Y.M. Zuhri, R.A. Ilyas, A. Nazrin, S.F.K. Sherwani, A. Khalina, Antimicrobial activities of starch-based biopolymers and biocomposites incorporated with plant essential oils: a review, *Polymers* 12 (2020) 2403.
- [6] A.M.N. Azammi, R.A. Ilyas, S.M. Sapuan, R. Ibrahim, M.S.N. Atikah, M. Asrofi, A. Atiqah, Characterization studies of biopolymeric matrix and cellulose fibres based composites related to functionalized fibre-matrix interface, *Interfaces in Particle and Fibre Reinforced Composites*, Elsevier, London, UK, 2020, pp. 29–93.
- [7] A.D. Cavdar, F. Mengelöglu, K. Karakus, Effect of boric acid and borax on mechanical, fire and thermal properties of wood flour filled high density polyethylene composites, *Measurement* 60 (2015) 6–12.
- [8] N.H. Sari, C.I. Pruncu, S.M. Sapuan, R.A. Ilyas, A.D. Catur, S. Suteja, Y.A. Sutaryono, G. Pullen, The effect of water immersion and fibre content on properties of corn husk fibres reinforced thermoset polyester composite, *Polym. Test.* 91 (2020) 106751.
- [9] M. Davallo, H. Pasdar, M. Mohseni, Mechanical properties of unsaturated polyester resin, *Int. J. Chemtech Res.* 2 (2010) 2113–2117.
- [10] M. Alsaadi, A. Erklig, A comparative study on mode I and mode II interlaminar behavior of borax and SiC particles toughened S-glass fabric/epoxy composite, *Arab. J. Sci. Eng.* 42 (2017) 4759–4769, <https://doi.org/10.1007/s13369-017-2649-1>.
- [11] B. Wetzel, F. Hauptert, K. Friedrich, M.Q. Zhang, M.Z. Rong, Mechanical and tribological properties of microparticulate and nanoparticulate reinforced polymer composites, *Proceedings of the ICCM*, vol. 13, 2001.
- [12] F. Wang, W. Shi, Y. Mai, B. Liao, Effect of thermal conductive fillers on the flame retardancy, thermal conductivity, and thermal behavior of flame-retardant and thermal conductive polyamide 6, *Materials* 12 (24) (2019) 4114 <https://doi.org/10.3390/ma12244114>.
- [13] N.W. Pech-May, C. Vales-Pinzón, A. Vega-Flick, Á. Cifuentes, A. Oleaga, A. Salazar, J.J. Alvarado-Gila, Study of the thermal properties of polyester composites loaded with oriented carbon nanofibers using the front-face flash method, *Polym. Test.* 50 (2016) 255–261, <https://doi.org/10.1016/j.polymertesting.2015.12.011>.
- [14] M. Singla, V. Chawla, Mechanical properties of epoxy resin-fly ash composite, *J. Miner. Mater. Char. Eng.* 9 (3) (2010) 199–210 <https://doi.org/10.4236/jmmce.2010.93017>.
- [15] T. Uygunoğlu, I. Gunes, W. Brostow, Physical and mechanical properties of polymer composites with high content of wastes including boron, *Mater. Res.* 18 (6) (2015) 1188–1196, <https://doi.org/10.1590/1516-1439.009815>.
- [16] Y.J. Wan, L.X. Gong, L.C. Tang, L.B. Wu, J.X. Jiang, Mechanical properties of epoxy composites filled with silane-functionalized graphene oxide, *Compos. Appl. Sci. Manuf.* 64 (2014) 79–89, <https://doi.org/10.1016/j.compositesa.2014.04.023>.
- [17] M. Zhang, R.P. Singh, Mechanical reinforcement of unsaturated polyester by Al₂O₃ nanoparticles, *Mater. Lett.* 58 (2004) 408–412.
- [18] L. Tibiletti, C. Longuet, L. Ferry, P. Coutelen, A. Mas, J. Robin, J. Lopez-Cuesta, Thermal degradation and fire behaviour of unsaturated polyesters filled with metallic oxides, *Polym. Degrad. Stabil.* 96 (1) (2011) 67–75.
- [19] K.K. Shen, S.H. Kochesfahani, F. Jouffret, Boron-based flame retardants and flame retardancy, chapter 9, in: A.B. Morgan, C.A. Wilkie (Eds.), *Fire Retardancy of Polymeric Materials*, CRC Press, 2010, pp. 207–239.
- [20] R. Orhan, S. Topuz, E. Aydogmus, Experimental and theoretical study on mechanical properties of apricot stone shell reinforced polyester composites, *Asia Pacific 3rd International Conference on Contemporary Studies*, Seoul, South Korea, vols. 1–2, 2020, pp. 198–209 June.
- [21] D. Ray, J. Rout, Thermoset biocomposites, in: A.K. Mohanty, M. Misra, L.T. Drzal (Eds.), *Natural Fibers, Biopolymers, and Biocomposites*, CRC Press, Boca Raton, FL: Taylor & Francis, 2005, pp. 291–345.
- [22] S.M. Lomakin, G.E. Zaikov, *Modern Polymer Flame Retardancy*, VSP, Netherlands, 2003, pp. 12–14.
- [23] M.T. Rahman, A. Mohajerani, Thermal conductivity and environmental aspects of cigarette butt modified asphalt, *Case Stud. Construct. Mater.* 15 (2021) e00569.
- [24] J. Byzyka, M. Rahman, D.A. Chamberlain, An innovative asphalt patch repair pre-heating method using dynamic heating, *Construct. Build. Mater.* 188 (2018) 178–197.
- [25] B.W. Jo, S.K. Park, D.K. Kim, Mechanical properties of nano-MMT reinforced polymer composite and polymer concrete, *Construct. Build. Mater.* 22 (1) (2008) 14–20.
- [26] Y. Seki, K. Sever, M. Sarikanat, A. Sakarya, E. Elik, Effect of huntite mineral on mechanical, thermal and morphological properties of polyester matrix, *Compos. B Eng.* 45 (2013) 1534–1540.
- [27] T. Farajpour, Y. Bayat, M. Abdollahi, M.H. Keshavarz, Effect of borax on the thermal and mechanical properties of ethylene-propylene-diene terpolymer rubber-based heat insulator, *J. Appl. Polym. Sci.* 41936 (2015) 1–10.
- [28] H. Demir, A.K. Ozdemir, D. Ozdemir Dogan, F. Tugut, H. Akın, Effects of boron on the mechanical properties of poly methyl methacrylate denture base material, *Eur. Oral Res.* 55 (1) (2021) 45–53.
- [29] S. Chapple, R. Anandjiwala, Flammability of natural fibre-reinforced composites and strategies for fire retardancy: a review, *J. Thermoplast. Compos. Mater.* 23 (2010) 871–893.
- [30] A.A. Borazan, D. Gokdai, Pine cone and boron compounds effect as reinforcement on mechanical and flammability properties of polyester composites, *Open Chem.* 16 (1) (2018) 427–436.
- [31] O. Polat, C. Kaynak, Use of boron oxide and boric acid to improve flame retardancy of an organophosphorus compound in neat and fiber reinforced polyamide-6, *J. Vinyl Addit. Technol.* 22 (2014) 300–310.
- [32] R.N. Rothman, Mineral fillers in thermoplastics: filler manufacture and characterization, in: J. Jancar (Ed.), *Advances in Polymer Science*, Springer, Berlin, 1999, pp. 69–107.
- [33] B. Sundén, J. Yuan, Evaluation of models of the effective thermal conductivity of porous materials relevant to fuel cell electrodes, *Int. J. Comp. Methods Exp. Meas.* 1 (4) (2013) 440–455.
- [34] K.S. Reddy, P. Karthikeyan, Combinatory models for predicting the effective thermal conductivity of frozen and unfrozen food materials, *Adv. Mech. Eng.* (2010) 1–14 2015, <https://doi.org/10.1155/2010/901376>.
- [35] Y. Bicer, C. Yildiz, The determination of porosity in the solid materials, *Firat Univ. J. Sci. Eng.* 7 (1995) 24–31.
- [36] A. Kaya, F. Kar, Properties of concrete containing waste expanded polystyrene and natural resin, *Construct. Build. Mater.* 105 (2016) 572–578, <https://doi.org/10.1016/j.conbuildmat.2015.12.177>.
- [37] K. Ramanaiyah, A.V. Ratna Prasad, K. Hema Chandra Reddy, Mechanical, thermophysical and fire properties of sansevieria fiber reinforced polyester composites, *Mater. Des.* 49 (2013) 986–991.
- [38] B. Abu-Jdayil, K. Al-Malah, R. Sawalha, Study on bentonite-unsaturated polyester composite materials, *J. Reinforc. Plast. Compos.* 21 (17) (2002) 1597–1607.
- [39] R. Kurt, F. Mengelöglu, H. Meric, The effects of boron compounds synergists with ammonium polyphosphate on mechanical properties and burning rates of wood-HDPE polymer composites, *Eur. J. Wood Prod.* 70 (2012) 177–182.
- [40] K. Ramanaiyah, A.V. Ratna Prasad, K. Hema Chandra Reddy, Thermal and mechanical properties of waste grass broom fiber-reinforced polyester composites, *Mater. Des.* 40 (2012) 103–108, <https://doi.org/10.1016/j.matdes.2012.03.034>.
- [41] M.S. Sreekanth, V.A. Bambole, S.T. Mhaske, P.A. Mahanwar, Effect of concentration of mica on properties of polyester thermoplastic elastomer composites, *J. Miner. Mater. Char. Eng.* 8 (4) (2009) 271–282.