



## Valorization of boron derivatives in polyurethane-based foams for reduced ignitability and thermal conductivity

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### ARTICLE INFO

#### Article history:

Received September 16, 2024

Accepted October 30, 2024

Available online December 31, 2024

#### Research Article

DOI: 10.30728/boron.1551164

#### Keywords:

Boron derivatives  
Ignitability  
Polyurethane  
Thermal conductivity

### ABSTRACT

Polyurethane (PU) based materials have wide application areas, especially in the thermal insulation, construction, and automotive sectors, due to their properties such as thermal and electrical insulation, lightness, and high compressive strength. In addition, studies on converting boron and its derivatives into value-added products have gained importance. In this study, the mechanical, physical, thermal, and ignitability properties of the composite materials obtained by adding boron derivatives of different weight fractions into PU were examined. Boron derivatives such as ground ulexite (U), borax pentahydrate, borax decahydrate, and ground colemanite (Col) were added to PU at 1, 3 and 5% by weight. It was shown that the density, thermal conductivity and compression modulus values increase when boron derivatives are used in PU-based composites. At the same time, the addition of ground U or Col to the PU foam reduced the water absorption value and made a positive contribution to the water absorption capacity. The PU material with 5 wt % Col added produced the greatest results, whereas 3.14% was discovered to be the lowest water absorption capability. The addition of boron derivatives increased the ignitability properties of PU foam composites. In particular, ground U or borax pentahydrate fillers showed substantial improvement in ignitability tests of PU foam composites. U (1%) demonstrated exceptional performance, reducing the PU's self-extinguishing time from 2.96 to 0 s.

### 1. Introduction

Sustainability has become increasingly important in the construction industry, especially because of its enormous ecological impact on all aspects of life and science. Reducing heat losses in buildings and thus increasing energy efficiency is crucial for sustainability [1]. One of the most important issues to consider in the design and construction of energy-efficient buildings is the selection of insulation materials [2]. These insulation materials include stone wool, glass wool, cellulose, sheep wool, polyurethane (PU) foam, expanded polystyrene, and extruded polystyrene [3]. PU foam is known for its excellent thermal insulation properties due to its low thermal conductivity (0.020-0.027 W/mK) compared to other materials, and accounts for approximately 80-90% of the insulation materials used in applications [3,4].

PU foams have been widely used in thermal insulation products such as refrigerators, freezers, and water heaters, as well as in panels designed for heat, sound and vibration insulation in buildings. They are also used in automobile and aircraft seating, interior panels for aircraft, sandwich structures in high-performance sports cars, biofilters in water treatment and waste air, microporous absorption materials, biocatalyst (enzyme) transporters in

biotechnologies and lightweight packaging materials with high surface area [5-8]. Due to their wide range of applications, research into developing PU-based foams with properties tailored for specific industries, thermal insulation and the automotive industry, has accelerated in recent years. A study investigated the effects of different sizes expanded graphite (EG) on the flame-retardant properties of rigid PU foam (RPUF) with a high density of 0.45 g/cm<sup>3</sup> [9]. They concluded that larger EG particles significantly improved the flame retardant (FR) properties of RPUF composites, while smaller EG particles resulted in poorer flame retardancy in the composites [9]. The effects of EG/bis(4-aminoanilinium) phenyl phosphonate (FR1) and pure EG FR additives on the cellular structure, thermal characteristics, flame retardancy, and compression strength of RPUF were also examined. When the ratio of EG to FR1 is 12 to 1, they obtained the best flame-retardant results [10]. Another study aimed to increase the fire resistance of rigid PU foams by adding 5, 10 and 15 wt. % nano clay and intumescent FR [11]. The experimental findings demonstrated that, despite a modest increase in thermal conductivity, the addition of nano clay or intumescent FR improved the foams' thermal conductivities, thermal stability, and fire resistance [11]. When the research was examined, it was seen that it focuses on issues such

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as thermal insulation, combustion resistance, thermal degradation, durability, sound absorption, and density. A common theme in these studies was the ignitability of PU foam materials, reflecting an ongoing effort to improve fire safety properties in various applications.

PU-based foam products are highly combustible when exposed to extreme heat or oxygen. These materials have caused worldwide concern due to their high ignitability and improving their fire safety is of extreme importance [12]. PU-based foam materials emit large amounts of smoke and toxic gases during combustion [13]. These toxic effects can be reduced by the addition of FR additives. The main FRs used depending on the structure of PU-based foam materials include inorganic FRs, intumescent systems, FRs containing phosphorus, silicon and boron. These additives play a key role in reducing thermal degradation, the release of toxic smoke and the burning tendency of PU-based foam materials, making their use essential in ensuring fire safety [14]. There are several studies discussing the use and potential industrial applications of chlorinated FRs in PU foams. Chlorinated FRs are common in PU manufacturing due to their efficiency in inhibiting flame spread, but they pose environmental concerns and health risks, leading to increased research on alternatives.

Some studies note that mineral-based additives (such as clay and metal hydroxides), while inexpensive, tend to affect the processing of foam materials due to their particle size, have the potential to cause blockages in production lines, and be chemically inert to the PU matrix [15]. As seen from studies, small particles tend to agglomerate. These large agglomerates can cause blockages as they pass through pipes and prevent the fluid from being properly delivered. This can cause production downtime. An uneven distribution of material can negatively impact the quality of the final product, which can lead to rework requirements during the production process. Large particles can block flow or make it harder for the fluid to move. Large particles also settle to the bottom more quickly or cause blockages. This can increase processing time and reduce efficiency. Large particles are generally denser, which can lead to handling and storage difficulties. Despite such production disadvantages, it is possible to overcome these problems with optimum particle size and homogenization.

Taking these problems into consideration, studies have focused on the use of boron derivatives as flame retardant. Due to the good ignitability properties of boron derivatives, they can prevent further spread of combustion by forming an impermeable glass-like coating on the material surface during thermal degradation [16]. Studies have shown that boron derivatives are effective as FRs in polymer-based systems [17]. The most commercially significant boron minerals include tincal, boracite, colemanite (Col), ulexite (U), pandermite, szaybelite, kernit, and hydroboracite, although more than 230 boron minerals

are known in nature. The primary boron minerals are Col (76%), tincal (22%), U (2%), which are converted into high-value products. Concentrated tincal, boric acid, borax decahydrate (BD), Etidote-67, borax pentahydrate (BP), anhydrous borax, zinc borate, sodium perborate, boron oxide, ground colemanite, calcined tincal, and ground U are the products that can be extracted from these ores [18]. While the boron reserve in Türkiye was around 600 million tons in 1978, according to the latest research, today Türkiye has around 3 billion tons of boron reserves. While Türkiye held a 16% share of the global boron market in the 1970s, it has recently become the world's largest borate producer, with a 47% market share [19]. Studies on the production of PU-based foam materials using boron derivatives are very limited in literature. A study explored its usability as FR by mixing N,N'-di(methyleneoxy-3-hydroxypropyl) urea and boric acid into the rigid PU-polyisocyanurate foam (PUR-PIR) [20]. As a result of the study, it was observed that with the addition of the boric acid, the brittleness of the PUR-PIR foam decreased and it showed good resistance to burning [20]. Another study incorporated boron oxide ( $B_2O_3$ ) and its derivatives as fillers at 5-20% in weight fractions, which increased the rigid PU foam materials' resistance to thermal deterioration and combustion [21]. While the inclusion of boron oxide increased the thermal conductivity of the material, which could be seen as a drawback, the study found that as the  $B_2O_3$  ratio increased, both the combustion resistance and the mass remaining after combustion significantly improved. [21]. A study examined the use of derivatives of hydroxyethyl urea that were boron-modified to create foamed PU materials, further exploring the FR properties of boron-based additives [22]. Following the study, it was observed that the boron-modified PU foams demonstrated good dimensional stability, compressive strength, and thermal insulation properties when compared to the non-modified PU foams obtained using hydroxyethyl urea derivatives [22]. The impact of untreated and silane-coated boron nitride nanofillers, as well as wrinkled and holey flash graphene, on the mechanical, physical, and thermal characteristics of flexible PU foams was examined [23]. Their findings indicated that both treated and untreated boron nitride nanoparticles were effective in significantly reducing the wet compression set of the foams, enhancing their mechanical resilience [23]. In another study, the effect of ammonium pentaborate added to PU foam material together with FRs on ignition properties was investigated. It was observed that the FR formed a thermal barrier by cross-linking with boron chemicals during combustion and increased combustion resistance [24]. In their study, Chmiel et al. synthesized oligoetherol PU foams from ethylene carbonate and boron derivative melamine diborate [25]. It was found that the products had high thermal resistance and could withstand temperatures around 175°C [25]. In another study, they included two boron-containing inorganic compounds, zinc borate and boron phosphate, into rigid PU foams

and examined the smoke suppression performance and FR effect of the system. It was revealed that both boron-containing inorganic compounds inhibited smoke/heat release [26]. TA study prepared sodium polyborate by dissolving boric acid and sodium tetraborate decahydrate in water and examined its flame retardancy properties [27]. The new material was produced by first wrapping polyvinyl alcohol on expandable graphite and then dipping it in boric acid aqueous solution. The improved flame retardancy was attributed to the suppression of the "popcorn" effect of expanded graphite by polyvinyl alcohol-boric acid [28]. Another study assessed the effects of triphenyl phosphate, aluminum trihydrate and zinc borate on thermal insulation, mechanical and FR properties of rigid PU foam composites [29].

Although many different additives and boron derivatives were investigated in rigid PU foam materials preferred as insulation materials, there is no study in which ground U, BP, BD, and ground Col are considered together and compared. In this study, the investigation of the effects of different boron derivatives such as ground U, BP, BD and ground Col with different water contents on the thermal conductivity, compressive strength, ignitability, density and water absorption capacity of the insulation material will make an original contribution to the literature.

In this study, boron derivatives were utilized as FRs in the development of a new PU-based foam material. PU-based composite material was produced by adding, 1-5 wt% of ground U, BP, BD, and ground Col as boron derivatives to enhance its thermal, mechanical, and physical properties. The thermal conductivity, compressive strength, ignitability, density, and water absorption capacity of the composites were investigated by various characterization techniques.

## 2. Materials and Methods

### 2.1. Materials

In this study, a mixture of 100 g/140 g polyol/isocyanate (Yücel Composite, Türkiye) was used to produce PU foam. Ground U (particle size, 75 $\mu$ m), BP (75 $\mu$ m), BD (63 $\mu$ m), and ground Col (45 $\mu$ m) were used as fillers

in the composites at 1, 3, and 5 wt% in composites (Eti Maden, Türkiye). Boron minerals of Na origin are called 'borax', those of Ca origin are called 'colemanite' and those of Na-Ca origin are called 'U'. As the amount of water in borax decreases, it transforms from decahydrate to pentahydrate.

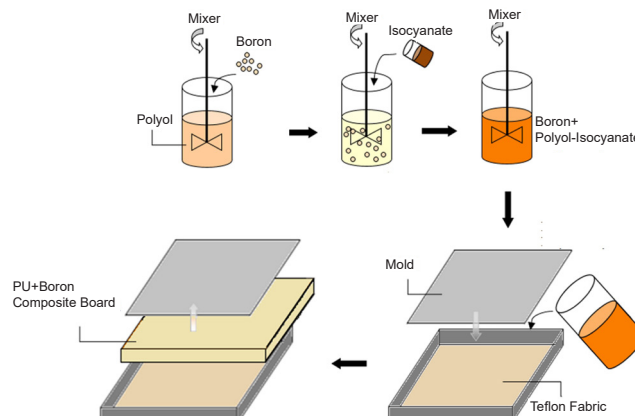
### 2.2. Preparation of Composite Foams Consisting of Polyurethane and Boron Derivatives

Polyol and boron derivatives were mixed using a mechanical mixer at 800 rpm for 30 min. Isocyanate was then added to the homogeneous mixture and stirred for an additional 10 s before being poured into a 300 mm x 300 mm x 30 mm mold. The compositions of the test samples are given in Table 1.

**Table 1.** Mixing ratios for PU and boron derivatives

Sample	PU%	BD%	BP%	U%	Col%
PU	100	-	-	-	-
PU+BD1	99	1	-	-	-
PU+BD3	97	3	-	-	-
PU+BD5	95	5	-	-	-
PU+BP1	99	-	1	-	-
PU+BP3	97	-	3	-	-
PU+BP5	95	-	5	-	-
PU+U1	99	-	-	1	-
PU+U3	97	-	-	3	-
PU+U5	95	-	-	5	-
PU+Col1	99	-	-	-	1
PU+Col3	97	-	-	-	3
PU+Col5	95	-	-	-	5

Teflon cloth was used to coat the mold prior to the molding process to keep the material from sticking. The mold's cover was sealed and tightened after the material was poured into it. Following a curing period of 24 h at room temperature (22 $\pm$ 3 $^{\circ}$ C), the mold was opened, and the PU composite foam material with the desired mixture properties was removed from the mold as seen in Figure 1.



**Figure 1.** Production process of the composite board

## 2.3. Characterization

### 2.3.1. Density measurement

Using a densimeter (Mirage, Densimeter MD-200S, Japan) the specimens' densities were measured in accordance with ASTM D792.

### 2.3.2. SEM analysis

Scanning electron microscopy (SEM, Thermo Scientific, Apreo S, USA) was used to visualize the morphology of the neat PU and boron derivatives composites. Using a coating device (Leica, EM ACE600, Germany), samples were coated with Au/Pd prior to analysis.

### 2.3.3. Thermal conductivity

A heat flow meter (TA Instruments, FOX 314 Heat Flow Meter, USA) was used to measure, the thermal conductivity value of 300 mm x 300 mm x 10 mm PU samples and its composites in accordance with ISO 12667 standards.

### 2.3.4. Ignitability tests

The ignitability of test specimens was investigated in accordance with ISO 11925-2 standard. The midpoint of the specimens' lower edge was exposed to flame for 15 s during the ignitability test. Next, the amount of time it took for the flame to extend 150 mm above the application point was noted, and the amount of particles that caught fire during the 20 s was calculated in Figure 2.



Figure 2. Ignitability test

### 2.3.5. Compression test

Compression tests were carried out using an autograph (Shimadzu, Autograph AG-IS Series, Japan) universal testing apparatus in compliance with ISO 29469 standards. On the specimens with dimensions of 50 mm x 50 mm x 20 mm, a load was applied at a rate of 2 mm/min during the test. The elasticity modulus was calculated using the linear regression method.

### 2.3.6. Water absorption capacity measurement

Short-term water absorption capacity tests of the prepared composite samples were carried out according to ISO 29767. The samples were subjected to short-term water absorption tests at  $23 \pm 5^\circ\text{C}$  ambient temperature and  $50 \pm 5\%$  relative humidity conditions. Tests were conducted for 24 h under the specified conditions. Water absorption was calculated using Equ 1 [30] where  $w_0$  refers to dry sample weight before immersion and  $w_1$  stands for the weight of sample after immersion in water.

$$\text{Water absorption \% (WA)} = \frac{w_1 - w_0}{w_0} \times 100 \quad (1)$$

## 3. Results and Discussion

### 3.1. Density

Table 2 illustrates that the density values for the composites were greater than those of the pure PU. As expected, the density of the composites increased as the filler's weight percentage increased. It has been known that the density of PUs depends largely upon the density of the fillers [31]. Since the densities of U ( $2.13 \text{ g/cm}^3$ ), Col ( $2.42 \text{ g/cm}^3$ ), BD ( $1.73 \text{ g/cm}^3$ ), and BP ( $1.815 \text{ g/cm}^3$ ) are higher than that of PU, PU composite materials showed increased density values [32-34]. The highest density was found for PU composite material containing 5 wt% ground U and 5 wt% ground Col.

Table 2. Density values and ignitability test results of PU and its composites

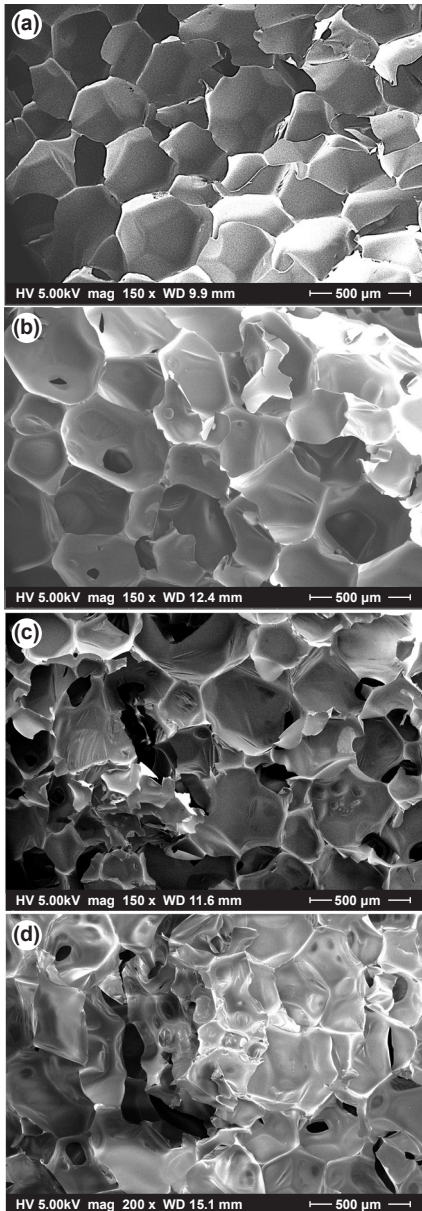
Sample	Density ( $\text{g/cm}^3$ )	Ignitability Test
PU	$0.052 \pm 0.00570$	could not pass
PU+BD1	$0.054 \pm 0.00245$	could not pass
PU+BD3	$0.057 \pm 0.00326$	pass
PU+BD5	$0.061 \pm 0.00245$	pass
PU+BP1	$0.055 \pm 0.00400$	pass
PU+BP3	$0.058 \pm 0.00735$	pass
PU+BP5	$0.061 \pm 0.00980$	pass
PU+U1	$0.053 \pm 0.00326$	pass
PU+U3	$0.056 \pm 0.00980$	pass
PU+U5	$0.062 \pm 0.00816$	pass
PU+Col1	$0.055 \pm 0.00490$	pass
PU+Col3	$0.059 \pm 0.00245$	pass
PU+Col5	$0.062 \pm 0.00490$	could not pass

### 3.2. Morphology

Figure 3 shows the effects of different amounts of U contents, which give the worst results in terms of thermal conductivity values, on the morphological structure of PU foam. Most of the cell types of pure PU were hexagonal, the cell morphology was relatively complete, and the cell size distribution was relatively uniform. It was seen that the foam is a closed-cell



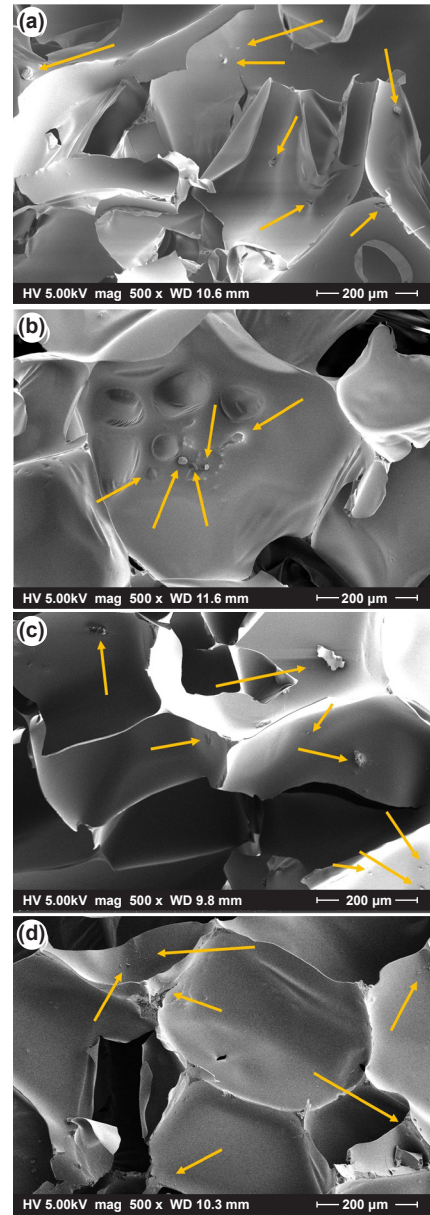
type. Here, the smooth texture of the foam material was disrupted when U is added. It was thought that increasing U amounts (especially 5%) caused the cells to shrink, due to the fact that the added U prevented the foam from expanding during curing and the increase in viscosity of the material [26]. However, the additives encourage more cell formation [35]. According to SEM images, adding 5% U in particular caused the cell walls to distort and reduced the homogeneity of the cell structure, which increased thermal conductivity and decreases compressive strength.



**Figure 3.** SEM images of a) neat PU, b) PU+U1, c) PU+U3, d) PU+U5

The SEM images of the morphology of the PU network after boron loading did not show much difference due to the low-weight fractions of the minerals and possible inhomogeneous distribution. Therefore, for visibility, SEM images of PU foams containing 5% boron derivative are given in Figure 4. No signs of aggregation were observed in the added boron particles. Relatively large particle sizes were found in

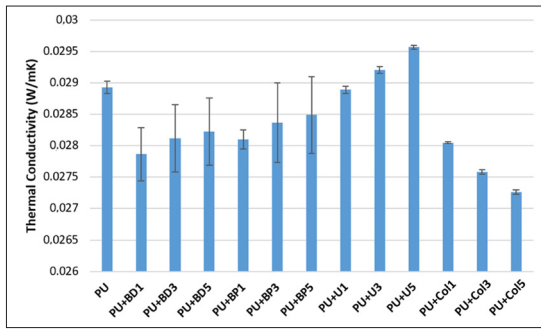
the images with the same magnification value ( $\times 500$ ) (Figure 4b, c). On the other hand, it was seen that the additive sizes in the images were smaller than the maximum grain sizes specified by the manufacturer.



**Figure 4.** SEM images of a) PU+BD5, b) PU+BP5, c) PU+U5, d) PU+Col5

### 3.3. Thermal Conductivity

Figure 5 displays the thermal conductivity values of PU and its composites. Each sample was measured three times, and the average of the results was used. The results showed that PU had a thermal conductivity of 0.0289 W/mK. It was observed that the addition of boron derivatives to the material reduced the thermal conductivity. Typically, PU foam materials have thermal conductivity values between 0.02 and 0.03 W/mK [36]. Thermal conductivity values of U, Col, BP, and BD are given as 0.482 W/mK, 0.526 W/mK, 0.647 W/mK, and 0.740 W/mK, respectively [33,34,37].

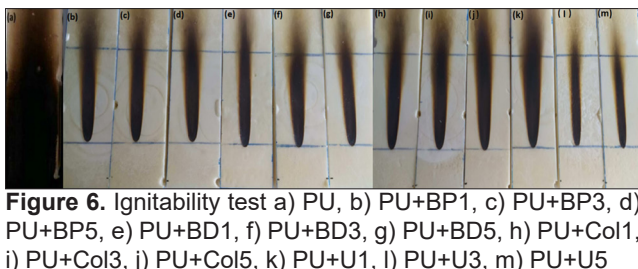


**Figure 5.** Thermal conductivity values of PU and its composites

It was observed that the addition of BD, BP, and Col contributes to the thermal insulation property of the material by decreasing the thermal conductivity value of the PU. The addition of BD and BP boron derivatives at low rates significantly reduced the thermal conductivity and made a greater contribution to the material. On the other hand, as the amount of Col increased in the composite foam, a significant decrease was observed in the thermal conductivity of the material. Interestingly, the only observed negative effect was associated with the composite foam containing ground U, which demonstrated reduced insulation properties compared to pure PU. The interface between polymer and filler plays an important role in determining the thermal conductivity of a composite material. Dislocations, point defects, and interface incompatibility with polymers and crystalline fillers such as boron derivatives cause a decrease in thermal conductivity [38]. In addition, the large particle size of ground U may have facilitated the filling of air gaps within the PU foam, further increasing thermal conductivity.

### 3.4. Ignitability

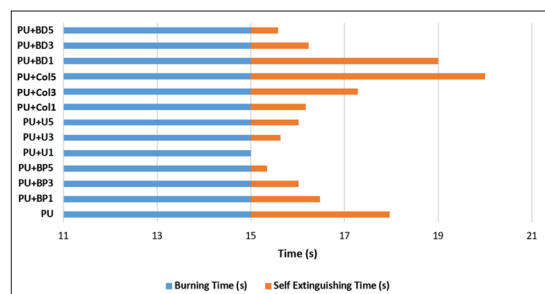
The ignitability test results are given in Table 2 and Figure 6. Figure 6a illustrates that the PU sample failed the test due to rapid flame spread and quick time to reach the 150 mm line. However, when boron derivatives were added to the PU, materials showed improved ignitability results as is seen in Figure 6. Notably, the slowest flame propagation was observed with a 5 wt% loading of U, as seen in Figure 6b.



**Figure 6.** Ignitability test a) PU, b) PU+BP1, c) PU+BP3, d) PU+BP5, e) PU+BD1, f) PU+BD3, g) PU+BD5, h) PU+Col1, i) PU+Col3, j) PU+Col5, k) PU+U1, l) PU+U3, m) PU+U5

Figure 7 shows the self-extinguishing times of the foam materials after being exposed to flames for 15 s. The pure PU foam material extinguished itself in about 3 s. The foam material with the addition of 1% U was extinguished immediately upon removal of the flame. Although some increases in extinguishing time

were observed with higher amounts of U, it still yielded better results compared to pure PU. The addition of BP significantly reduced the self-extinguishing time, with shorter extinguishing times noted across all weight fractions compared to pure PU foam. Considering the Col-filled PU composites, it affected the self-extinguishing results worse than the other fillers. It was observed that foam materials with 5% Col and 1% BD were added quenched longer than pure PU foam material. Boron compounds were reported to improve the FR properties of polymeric composites [39]. It was concluded that due to the flame-retardant properties of boron compounds, BD and boric acid fillers, reduced the ignitability of the composites obtained [40]. It has also reached the category of self-extinguishing materials at higher boric acid filler composites [40]. It was concluded in a study that boron-filled PU composites had reduced ignitability compared to PUs [41]. Current results revealed that the ignitability of the PU foam material increased with the addition of U and BP. On the other hand, Col and BD were found to be effective on ignitability at certain rates. Higher thermal conductivity allows heat to spread rapidly throughout the material, reducing the likelihood of heat accumulation at specific points. This can mean that heat from any ignition source is rapidly dissipated within the material, preventing the material from reaching the critical temperature required to sustain combustion. As a result, the material can self-extinguish more effectively when the heat source is removed. This is clearly seen in the example of U. In the self-extinguishing test, PU materials modified with BD performed worse than those modified with BP. However, as the amount of water in the additive increases, it is expected that the material will burn more difficultly and extinguish faster, but this is only up to a certain point. When there is more than a certain amount of water in the material and this water evaporates when the material is heated, the vapor comes out of the material in the vapor phase. Meanwhile, the increasing vapor pressure in the material causes the material to physically crack or deform [42]. The structure with surface fractures will be more exposed to flames, which reduces its resistance to burning.

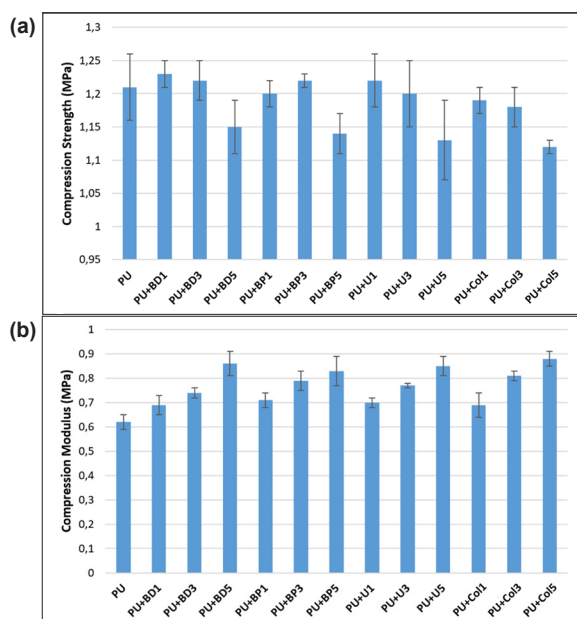


**Figure 7.** Self-extinguishing times of PU and its composites

### 3.5. Compression Tests

The compression strength and modulus of the PU composites were measured to gain additional insight into their mechanical properties. Each sample was

measured three times, and the average of the results was recorded. The compression properties of materials are given in Figure 8.



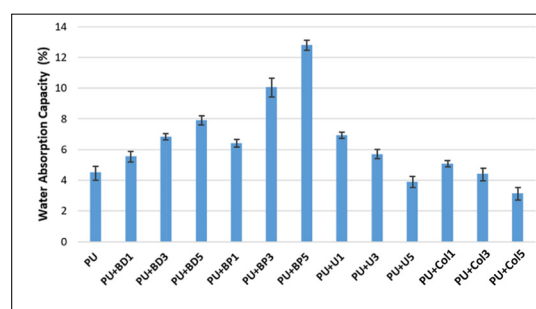
**Figure 8.** Compression strength (a) and compression modulus (b) of PU and its composites

When the compressive strengths are examined, it is seen that there is no significant change in strength with the addition of 1% and 3% of BD, BP, U, and Col fillers. However, when fillers are added at 5% their compressive strength decreases. Bishay et al. concluded that at higher filler contents, the compressive strength of the composites may decrease due to the inhibition of interaction between fillers and polymer matrix [43]. Similarly, it can be said that the decrease in compressive strength is due to the inhibition of the movement of the polymer chains due to the inhomogeneous distribution of boron fillers and may also be due to the deformation of the cell walls, especially at high additive levels such as 5%. The knowledge that the improvement of the mechanical properties of the composite material depends largely on the homogeneous distribution of the fillers is also supported by the literature [39]. Simultaneously, the formulae of BP and BD compounds (BP:  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$ , BD:  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ ) contain water molecules. This can result in micro-voids at the interface between the polymer and fillers, which lower the mechanical properties of the material [44]. The decrease in compressive strength indicates the poor distribution of boron derivative fillers in the PU, the presence of defects such as voids, and interfacial incompatibility [45].

It is well known that cellular structure and density typically affect a material's mechanical properties [46]. When the compressive modulus values are examined, it is seen that the modulus increase with the increase in the ratio of fillers. This is because fillers give the composite its strength and modulus, whereas polymers are far weaker than fillers [47].

### 3.6. Water Absorption Capacity

The water absorption values of PU composite materials are shown in Figure 9.



**Figure 9.** The water absorption capacity of PU and its composites

The water absorption capacity of the PU was found to be 4.51%. Among all the composite foam materials examined, the highest water absorption capacity was obtained in the 5 wt % BP filled PU composite with a value of 12.81%. Conversely, the lowest water absorption capacity was recorded for the 5% Col-filled PU composite, at 3.14%. As the weight fraction of BP and BD increased, the water absorption capacity of the PU also increased. It is seen that boron derivatives containing borax contribute negatively to the water absorption property of the material. It is seen that the addition of U and Col at high fractions (5%) reduces the water absorption capacity of the material. The water absorption capacities increased slightly with the addition of boron derivatives at low fractions (1-3%). Specifically, the water absorption capacity decreased to 3.91% with the addition of 5% U to the PU, while it decreased to 3.14% when 5% Col was added to the PU. The difference in water absorption capacity is related to the chemical structures and crystal water content of these substances. BP and BD contain crystal structures that contain a certain amount of water molecules. The water-binding capacity of BP and BD forms is due to the ability of crystal structures to physically hold water. Water is found as a part of this crystal structure and therefore has a high water absorption capacity. U and Col, on the other hand, are structures that contain less water and have a lower capacity to hold water. In addition, the fact that the voids in the crystal structures of these compounds are in a structure that makes it difficult for water molecules to be held may also affect this situation.

### 4. Conclusions

In this study, effects of addition of boron derivatives on ignitability, thermal, mechanical and water absorption properties of PU composites were investigated. It was concluded that the density of the composites increased via the incorporation of boron derivatives into PU. According to the ignitability test, the U and BP fillers improved the ignitability properties PU foam material as it shortened the self-extinguishing time. Especially U (1%) provided outstanding performance and



decreased the self-extinguishing time of PU from 2.96 to 0 s. The addition of BD and BP boron derivatives at low fractions made a great contribution to the material by significantly reducing the thermal conductivity value of the PU foam material. With the addition of ground Col, the lowest thermal conductivity values were obtained, and the PU thermal conductivity value, which was 0.028 W/mK, decreased to 0.0272 W/mK. It was seen that the compressive modulus values increase with the addition of boron-derived fillers, but there was no significant change in compressive strength values when 1wt % and 3wt % BD, BP, U and Col are added. When the water absorption capacities were examined for all composite foam materials, it was observed that the addition of 5wt % U or 5wt % Col contributed positively to the PU foam material, but the addition of borax-containing boron derivatives (BP and BD) negatively contributed to the water absorption of the material. The best result was obtained with 5wt % Col was added to the PU material, and the lowest water absorption capacity was found to be 3.14%. This study has shown that material properties can be improved by adding different boron derivatives for different utilization purposes of PU foam materials. PU foams with lower thermal conductivity and better flammability properties have great potential for use in exterior construction applications and various industries where flammability is a major concern.

## 5. Acknowledgements

The authors are grateful for the funding from Ege University, Office of Scientific Research Projects (Project no: 21768). We would like to thank Prof. Dr. Mehmet Sarıkanat for his support. We would like to thank Eti Maden for their support in the supply of boron derivatives.

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