Friction and Wear Behavior of Fiber Reinforced Polymer-Matrix Composites Containing Ulexite and Pinus Brutia Cone Dust

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Abstract
In this study, the usability of ulexite and pinus brutia cone dust (PBCD) in friction composites were investigated experimentally. Polymer-matrix composite (PMC) samples were manufactured by powder metallurgy method. Produced samples with the same contents were compared with those of heat-treated. A special design friction tester was used to determine friction properties such as wear rate and friction coefficient. The results showed that ulexite and PBCD can be used as filler material in friction composites. The results also indicated that heat treatment improved the properties of the samples.

Key Words: brake friction composite, wear, ulexite, pinus brutia cone dust, tribology

1. INTRODUCTION
Brake linings are important element of brake systems. Brake linings are composite materials formed by the combination of many materials. Brake linings are also referred to as brake composites or friction composites. Phenolic resin is generally used as a binder in polymer matrix friction composites. A variety of fibers can be used as reinforcing elements. There are several studies occurred by using different fibers in the literature [1–13]. Various additional materials are required for friction composites to exhibit high friction performance. These materials are called friction modifiers and are classified as abrasive and non-abrasive. Non-abrasive materials contain metallic chips and solid lubricants. According to the studies, if a material improves the friction properties of the composite, it can be used as friction modifier. In the literature, there are studies that have been done by adding many different materials to friction composites [14–17]. Fewer studies have been carried out related to boron minerals in friction composites [18–22]. It is also difficult to find study related to friction composites with pine cone dust. In earlier study [23] while investigated usage of ulexite in the friction composites, it was concluded that ulexite improved the wear and friction performance of composites. The studies related to pine cone dust in friction composites also indicated that pine cone dust was an ideal material as friction modifier for friction composites.

2. MATERIAL AND METHODS
The composite samples were manufactured by adding phenolic resin as binder, steel wool as fiber, Al₂O₃ as abrasive, graphite as solid lubricant, brass powder and copper powder as metallic chips and barite as space filler. Raw materials used in this study are listed in Table 1. The letters U and P represent ulexite and PBCD, and the number represents the amount percentage in the composite. The heat-treated samples are coded with letter H. In five composites containing seven components with a fixed amount (76%), the amount of ulexite was balanced with PBCD.

In this study, the friction composites with different combinations of both ulexite and PBCD were designed and produced by powder metallurgy including powder weighing, mixing, pre-forming and hot pressing, respectively. The samples produced were compared with those whose contents were the same but applied to heat treatment. Wear and friction properties were determined using a special design friction tester.

A conventional dry mixing method was employed to produce friction composites. The general stages of production are shown in Fig. 1.

Firstly, the powder materials were passed through the sieves to be of the same size and weighed by precision scales and mixed at 150 rpm using a mixer for 10 min. The mixture...
was subjected to a pressure of 8 MPa for 2 minutes at room temperature in the pre-forming process. The ultimate sample was obtained by applying a pressure of 14 MPa at 180 °C for 10 minutes in the hotpressing process. H-coded samples (UPH₄, UPH₈, UPH₁₂, UPH₁₆, UPH₂₀) were sintered at 180 °C for 4 hours in a heat-treatment oven. The devices used for sample production are shown in Fig. 2.

The friction composites were subjected to various physical tests. Hardness of the specimens was measured by using Brinell hardness tester (average of five values on various spots of the friction surface). Density of the samples was calculated based on Archimedes principle. To evaluate friction and wear properties of friction composites, tests were performed on a special design brake tester according to TSE 555 [24]. The schematic view of the brake tester is shown in Fig. 3.

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### 3. RESULTS AND DISCUSSION

It is desirable that the wear rate is low and the friction coefficient is high in friction composites used for brake. Also, the friction stability of the composites must be high for effective braking performance. The friction coefficient of the samples was recorded during the brake test to determine the properties of the samples such as friction and wear. Friction tests were carried out under temperature group A (temperature to 350°C and 1050 kPa pressure) as specified in TS 9076 [25]. For the test conditions, the speed was determined as 6 m/s, and the friction duration was 10 minutes. The surface temperature of the samples was measured using a non-contacting infrared thermometer. Before and after testing, samples weighed using a scale with 10⁻⁴ g precision and thus wear losses were determined. The wear rate of the friction samples was obtained by measuring the thickness change during the test procedure. All tests were repeated five times and average values are presented.

### Table 1. Raw materials used in this study (wt.%)

| Ingredient          | Samples |
|---------------------|---------|
|                     | UP₄     | UP₈     | UP₁₂    | UP₁₆    | UP₂₀    |
| **Binder**          | Phenolic resin | 22 | 22 | 22 | 22 | 22 |
| **Fiber**           | Steel wool | 15 | 15 | 15 | 15 | 15 |
| **Friction modifiers** |         |       |       |       |       |
| **Abrasive**        | Al₂O₃   | 3 | 3 | 3 | 3 | 3 |
| **Non-abrasive**    |         |       |       |       |       |
| **Metallic chips**  | Brass powder | 5 | 5 | 5 | 5 | 5 |
|                     | Copper powder | 8 | 8 | 8 | 8 | 8 |
| **Solid lubricant** | Graphite | 3 | 3 | 3 | 3 | 3 |
| **Space filler**    | Barite | 20 | 20 | 20 | 20 | 20 |
|                     | Ulexite | 4 | 8 | 12 | 16 | 20 |
|                     | PBCD | 20 | 16 | 12 | 8 | 4 |

The tester device is fully computer controllable and comprises data acquisition software. As a counterpart, we used the disk made of grey cast iron with a 280 mm diameter and a hardness of 116 HB. The test samples are with usual dimensions of 25.4 mm in diameter and 6 mm in thickness. Before the friction test, the samples were burnished to obtain at least %95 contact of pre-test status. Friction tests were carried out under temperature group A (temperature to 350°C and 1050 kPa pressure) as specified in TS 9076 [25]. For the test conditions, the speed was determined as 6 m/s, and the friction duration was 10 minutes. The surface temperature of the samples was measured using a non-contacting infrared thermometer. Before and after testing, samples weighed using a scale with 10⁻⁴ g precision and thus wear losses were determined. The wear rate of the friction samples was obtained by measuring the thickness change during the test procedure. All tests were repeated five times and average values are presented.

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Fig. 7. The thermal decomposition of the ingredient brings about overabundant fade and wear. Fade phenomena occurred stopping power is not sufficient, which is based on mechanical fade, brake fluid boiling and thermal decomposition of friction materials [26].

Fig. 4. Variation of friction coefficient of samples coded UP depending on friction duration

Fig. 5. Variation of friction coefficient of heat-treated samples depending on friction duration

Fig. 6. Variation of surface temperature of samples coded UP depending on friction duration

Friction stability is an important parameter for friction composites. Because drivers expect the same friction force to perform the same performance under unexpected braking conditions. The materials forming the brake friction composites affect the friction stability. Therefore, proprietary friction additives are used in commercial products [28]. The percent friction stability of the samples is shown in Fig. 8.

Fig. 7. Variation of surface temperature of heat-treated samples depending on friction duration

Fig. 8. The friction stability of the samples

The friction characteristics of the samples are shown in Fig. 9. When the friction characteristics of the samples are examined, the average friction coefficient value of the sample with UPH4 code containing 20% PBCD and 4% ulexite is higher than the others. In addition, heat treatment application increased friction coefficient of samples. When the specific wear rate values are considered, it is concluded that there is not a trend that is proportional to the amount of PBCD and ulexite.

Fig. 9. The frictional properties of the samples
Life of the friction composite depends on wear resistance, the ingredients and manufacturing parameters. The properties of the samples such as wear rate, hardness, density and average friction coefficient are given in Table 2.

| Sample Code | Density (g/cm³) | Brinell hardness (HB) | Wear rate x 10^(-6) (g/mm²) | Average friction coefficient |
|-------------|----------------|-----------------------|-------------------------------|-----------------------------|
| UP₈         | 2.63           | 32.3                  | 0.333                         | 0.356                       |
| UP₉         | 2.20           | 29.1                  | 0.310                         | 0.422                       |
| UP₁₀        | 2.203          | 31.8                  | 0.277                         | 0.415                       |
| UP₁₁        | 2.523          | 34.3                  | 0.320                         | 0.400                       |
| UP₁₂        | 2.131          | 27.5                  | 0.374                         | 0.436                       |
| UPH₁        | 2.255          | 33.3                  | 0.350                         | 0.503                       |
| UPH₂        | 2.197          | 30.1                  | 0.383                         | 0.461                       |
| UPH₃        | 2.242          | 30.9                  | 0.378                         | 0.443                       |
| UPH₄        | 2.122          | 29.6                  | 0.297                         | 0.471                       |
| UPH₅        | 2.099          | 28.3                  | 0.262                         | 0.466                       |

Samples of UPH₁ and UPH₅ show good friction properties. Especially, UPH₁ shows the maximum friction coefficient among the formulations. As shown in Table 2, applying heat-treatment improved both physical properties and friction properties of samples.

4. CONCLUSION

In this study, friction composites containing ulexite and PBCD were designed and produced. Physical properties and friction properties of the samples were examined. According to the test results, all samples are compatible with the literature, applicable in industry and comply with TS 555 standard. There is no direct correlation between the physical properties and friction characteristics of the brake friction composites. Ulexite and PBCD can be used as friction modifier and filler material in brake friction composites. Heat treatment has significantly improved both the physical and friction properties of the composites.

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