The impact of surface-active inert lubricants on brake friction composites

Воздействие поверхно-активных инертных материалов на тормозные фрикционные композиты

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Abstract
This work discusses the development of an organic friction material through powder metallurgy techniques, focusing on the determination of optimal processing conditions. In the formulation of phenolic resin matrix composites, barite is utilized as a filler material, while brass chips serve as the reinforcing component. The role of surface-active inert materials in the preparation of brake composition samples has been studied and the effects of the powder formation process have been determined.
Keywords: powder metallurgy, composite materials, lubricants, pre-forming, density

Аннотация
В работе рассмотрены вопросы получения органической фрикционной композиции на основе методов порошковой металлургии и подбор оптимальных технологических режимов. В составе фенолформальдегидных матричных композитов в качестве наполнителя и армирующего элемента использованы барита и латунная стружка соответственно. Исследована роль поверхностно-активных инертных материалов при приготовлении образцов композиций, и определены эффекты процесса их формирования.
Ключевые слова: порошковая металлургия, композиционные материалы, смазочные материалы, холодное прессование, плотность.

Brake pad composites are specialized materials used in automotive and industrial braking systems to provide the necessary friction for slowing down or stopping a vehicle. While friction exists in nearly all technical systems, the nature of the required frictional forces can differ depending on the application. Among these systems, the brake is one of the equipments that require the highest frictional force. The presence of high friction force in the braking system means that a high coefficient of friction is ensured. The coefficient of friction is the ratio between the frictional force and the normal force. The friction coefficient depends not only on the properties of the contact materials, but also on the wear mechanisms. The materials used in tribo-systems must possess high wear resistance and excellent heat resistance [1].

The development of advanced friction materials is necessary to meet the evolving demands of modern braking systems, which require improved performance, durability, and environmental compliance. One of the current trends in the development of friction materials is the application of organic components [2]. Brake pad composites are typically made from a mix of materials, including reinforcements, binders, friction modifiers and space fillers [3]. One of the primary concerns in preparing friction materials is achieving consistent homogeneity and enhancing the powder forming process. This is crucial because the properties of the final composite—such as hardness, density, and porosity—are heavily influenced by the uniformity and quality of the powder formation [4].

The powder forming process, involves transforming loose powder into solid components with precise shapes and high dimensional accuracy [5]. In addition to parameters like mechanical mixing, compaction, and sintering, the lubricants used during the forming process are very important. They play a key role in enhancing the efficiency of the process and improving the quality of the final product. Both internal and external lubricants are used as lubricants in the production of friction materials. The main purpose of external lubricants is to remove parts from the press without cracks. Although a number of lubricants are effective for this purpose, in some cases, external lubrication can negatively impact the compressibility of the particles. In this regard, it is important to examine the effects of both internal and external lubricants. The use of internal lubricants or plasticizers is a common practice to enhance the flexibility, processability, and overall performance of these materials.

In addition to liquid lubricants, solid lubricants are also used in friction compositions. These solid lubricants further reduce friction between particles, ensuring a homogeneous distribution and enhancing the physical properties of the composite [5]. Certain lubricants can facilitate better sintering by reducing oxidation and aiding in the diffusion processes [6].

Thus, different surface-active inert and solid lubricants were used in sample compositions and their effects on the formation process were investigated. In this study, barite, phenolic resin, aluminum oxide, wallostonite, lead, tin, copper-graphite, molybdenum disulfide, magnesium oxide, and brass chips were used to prepare new organic friction composites. The brake constituents are prepared through a process involving mixing, pre-forming, and hot pressing. The brake samples are formed using a die at a pressure of 10 MPa. Subsequently, the pre-formed materials are hot-pressed at a temperature of 160°C under a pressure of 15, 25 and 35 MPa. The obtained test specimens were in size of 22,1×15,2×7,6 and divided into two blocks by cutting in half (Fig 1.). The cut samples were used in friction, porosity and density tests.

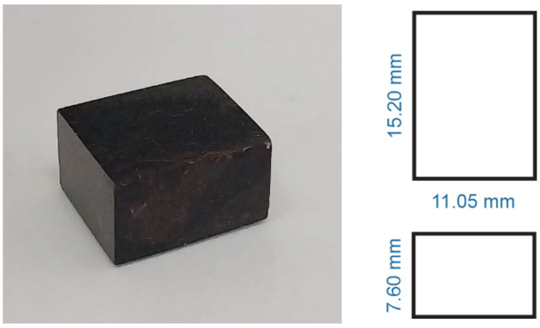

Fig. 1. Obtained test specimen and dimensions

An apparatus equipped with a drum measuring 50 mm in diameter and 90 mm in length was utilized for the dry mechanical mixing of powder components. The device was powered by an electric motor operating at a speed of 2700 revolutions per minute (rpm).

The pressing procedure was executed in accordance with a uniaxial press-die configuration (Fig. 2.).

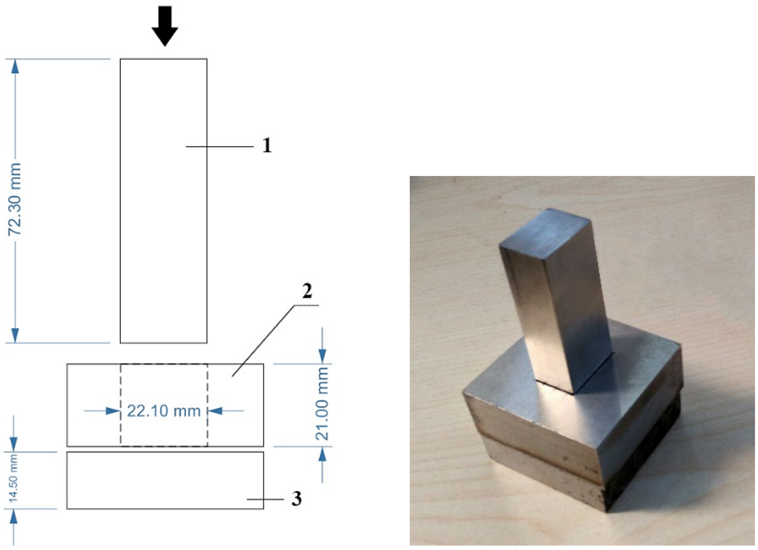

Fig. 2. Diagram of rectangular press die
1-Upper punch, 2-die cylinder, 3-bottom punch

As particle-to-particle contact increases during the compaction process, elastic deformation is replaced by plastic deformation and pore size begins to decrease. The sample's final hardness escalates concomitantly with heightened mechanical pressure. Notably, applying pressure to the matrix walls causes frictional forces to increase with pressure, resulting in uneven density distribution along the vertical axis of the pressed specimen [6].

The densities of the obtained brake samples were measured using Archimedes' principle, which involves submerging the samples in a liquid and measuring the volume of displaced liquid according to ASTM B311-08. Uneven density distribution appears in samples with a height greater than the cross-sectional diameter. Lubricants can be used to prevent this phenomenon. Thus, lubricating the matrix walls with paraffin and industrial oils or adding plasticizers to the composition can help eliminate these shortcomings [7]. When observing the microstructure of the brake friction samples given in Fig. 3, it is possible to see that the components are not homogeneous in the samples without lubricant.

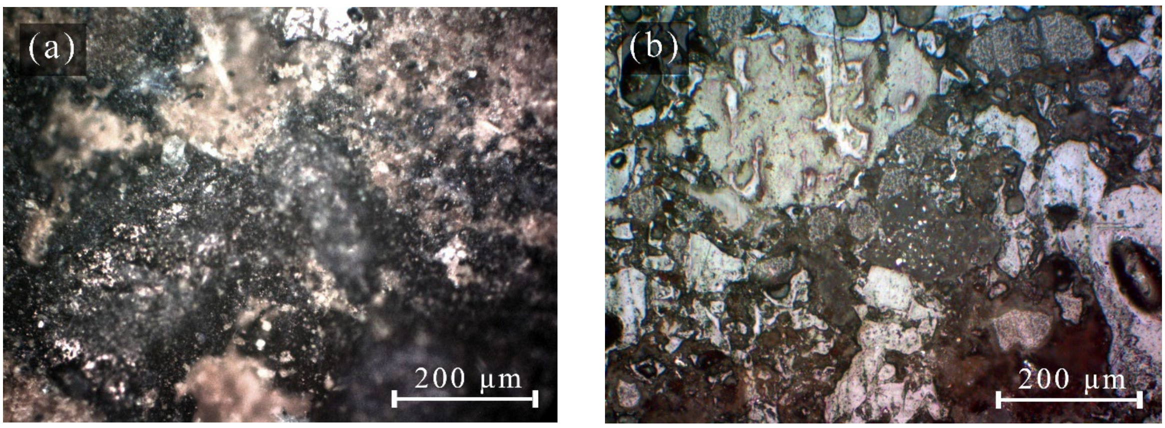

Fig. 3. Microstructural differences of brake friction composites prepared a) without and b) with the presence of lubricants

The microstructure of the samples prepared in the presence of lubricant presents phases such as matrix, reinforcement agent, binder and fibers. Optical microscopy reveals a homogeneous microstructure with fully mechanically interlocked components. This strong mechanical bonding, facilitated by the lubricants, ensures better structural formation. Porous materials often have less actual contact area between surfaces compared to dense materials. This reduced contact area can lead to lower friction coefficients under certain conditions. However higher density materials tend to have smoother surfaces, which can reduce the friction coefficient by minimizing interlocking and adhesion forces [8]. Therefore, the density should be at an optimal level. The enhanced flow and distribution of the powder-lubricant mixture result in more uniform density and improved mechanical properties. Certainly, the mechanical properties of a material significantly influence its frictional characteristics..

The figure 4 illustrates the variation in the friction coefficient of brake friction composites over time, measured in seconds. The blue line represents the friction coefficient of the composite sample prepared without the presence of lubricant, while the red line represents the sample prepared with the lubricant. As seen in the diagram below, the presence of a lubricant in brake friction composites significantly stabilizes the friction coefficient, leading to more consistent performance and potentially reducing wear. The relationship between porosity, density, and friction coefficients can vary depending on the specific materials involved, the nature of the surfaces in contact, and environmental conditions such as lubrication type and temperature.

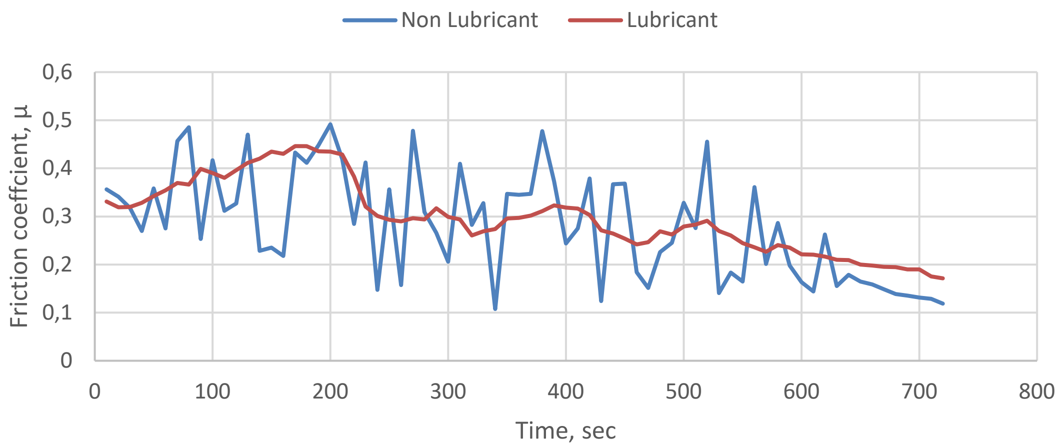

Fig. 4. Comparison of friction coefficient over time for brake friction composites

Furthermore, it was observed during the study that the lubricant applied to the mold surface exerts considerable influence on sample quality. Therefore, a comparative analysis was carried out to identify differences in plasticizers and lubricants. Glycerin, powdered boric acid, wax, and rosin were employed as plasticizers. Paraffin, glycerin and talc were used as lubricants for the walls of the press mold and the punch.

In the initial stage the powder products are filled into a mold and compacted (10 MPa), then the pre-formed powder samples are put into a muffle furnace with the mold and heated. Following the heating phase, the samples undergo a secondary pressing and are maintained under pressure for a specified duration. After this secondary pressing, the samples are allowed to cool to room temperature before examination.

The results of physical parameters measured for each of glycerin, powdered boric acid, wax, and rosin are shown in Fig. 3. Measurement of physical properties showed that glycerin and boric acid are more effective than other plasticizers.

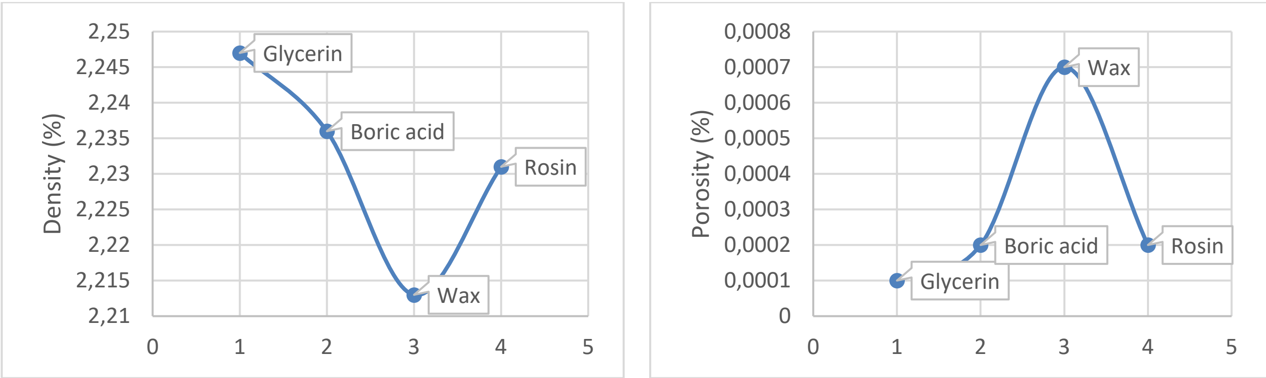

Fig. 3. Comparison of the influence of plasticizers on the physical properties of composites

The lowest values were observed in samples prepared using wax. Although both results can be considered satisfactory, the presence of glycerin during the forming process not only reduced the density distribution in all directions, but also minimized porosity. Rosin also had little effect on the formation of the structure. However, glycerin has been found to be very effective in prevention of cracks. Porosity was minimal in the samples prepared by applying glycerin. Experiments have shown that the use of 5-10 wt.% lubricant achieves satisfactory physical properties (Fig.4).

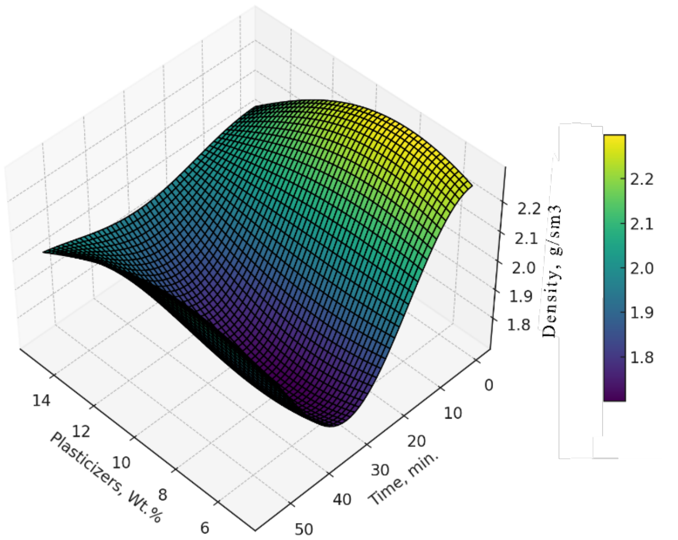

Fig. 4. Effect of internal lubricants on density over time

As indicated by the graph, glycerin is effective only within specific percentages depending on the time; deviations above or below this range result in decreased strength of the green compact. The more lubricant is added to a powder mix, the greater the compressibility will be limited and the more the flow behaviour will deteriorate [9]. Excessive use of lubricants can change the original volume size of the pressed mixture and impair its function.

In general, glycerin was more effective as an internal lubricant and paraffin as an external lubricant in terms of porosity. Both lubricants were tested for different pressures (Fig. 5.). The most optimal compaction pressure was determined to be 25 MPa. So, the density was higher under the mentioned condition. The pressure in these samples varied between 1.9-2.2 g/cm^3.

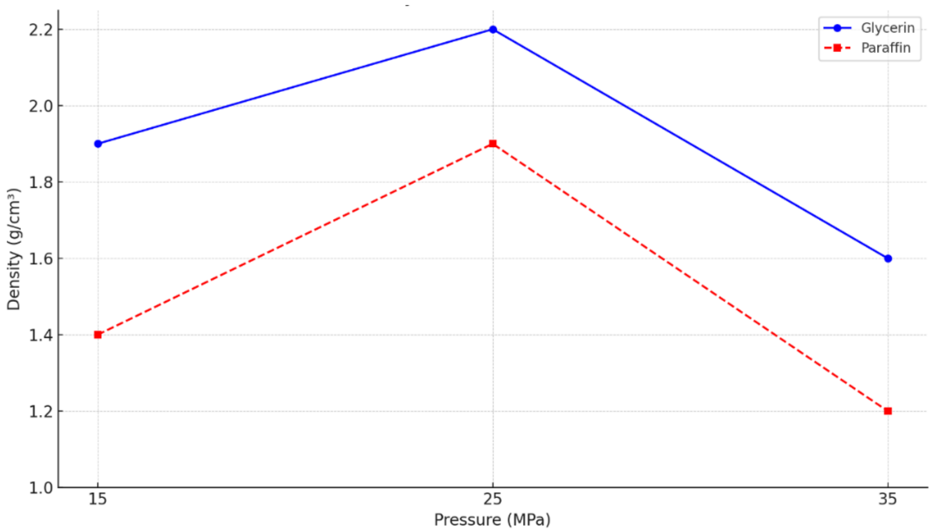

Fig. 5. Variation of density under different pressure conditions

Thus, the presence of a large amount of plasticizer leads to the fact that the metal-metal bond between particles is replaced by a metal-lubricant bond, which leads to a sharp decrease in the hardness of the material. By reducing friction, improving powder flow, enhancing compaction, managing heat dissipation, and improving surface finish, lubricants ensure that the final products meet the stringent requirements of various applications, including critical automotive components like brake composites. The results showed that application of both internal and external lubricants can significantly influence the overall success and efficiency of the manufacturing process.

Conclusion

The study utilized barite as a filler and brass chips as reinforcement within a phenolic resin matrix, with various lubricants and plasticizers incorporated to enhance the properties of the composites. The addition of lubricants facilitated better powder flow, reduced friction, and ensured more uniform compaction. Based on this research, the following conclusions can be drawn:

- Experimental findings indicate that using 5-10 wt.% lubricant achieves optimal physical properties.
- As internal lubricants glycerin and powdered boric acid were found to be more effective than wax and rosin in improving the physical properties of the composites. Glycerin, in particular, minimized porosity and reduced crack formation, enhancing the overall structural integrity.
- External lubricants such as paraffin significantly improved the uniformity of density distribution and the overall physical properties of the brake samples.

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