



Technical overview of the main types, designs, and materials of brake pads for mobile agricultural machinery

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Abstract. Brake pads are a critical element of any machine, as they directly affect the safety of its use. Accordingly, the quality of brake pads, their resistance, and durability are key aspects that must be considered when developing braking systems for mobile agricultural machinery. The purpose of this study was to review scientific sources related to the study of the tribological properties of brake pads, their operating modes, and friction materials included in brake linings. The main parameters affecting the efficiency of brake pads were analysed and the main criteria for selecting materials for brake pads of mobile agricultural machinery were defined, namely, wear resistance, temperature resistance, and corrosion resistance. Accordingly, the materials used in the production of brake pads for such equipment must be capable of operating under any conditions, have high thermal conductivity, help reduce the wear rate, have a stable friction coefficient, and be environmentally friendly. The study focused on an overview of the types and design of brake pads, their systematisation by various features (by purpose; by design features; by friction material composition; by the presence of wear sensors) and composition (semi-metallic, non-asbestos organic, and ceramic). The study described modern components of friction materials for brake linings and found that they are usually composites formed by hot pressing coarse powders, which include many different components: a binder (thermosetting phenolic resins, often with rubber added), structural materials (metal, carbon, glass, and/or Kevlar fibres), fillers (mica and vermiculite), and friction additives (graphite and various metal sulphides). The study also assessed the main characteristics of friction material components used in the manufacture of brake linings. The findings of this study can provide researchers and scientists with useful information on the types and design of brake pads and the main materials used in the manufacture of brake linings and be useful for further practical development of braking mechanisms

Keywords: brake system; composite materials; friction; tribological properties; friction materials

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Introduction

The braking system is a critical mechanism that ensures the safety of people and goods. It works through friction between the disc and the pad, which slows the vehicle down. The brake pads grip the disc, reducing its rotation and decelerating the vehicle. The behaviour of the friction elements is determined by the active surfaces of the pad and disc and the third bodies between them. This complex tribosystem has not yet been fully explored and studied. The correct type and material for brake pads therefore directly affects braking performance and reduces maintenance costs. It is also important to consider the environmental friendliness of materials and use modern solutions to improve the safety and environmental friendliness of mobile agricultural machinery.

Brake pads, their operating modes, and the materials they are made of continue to attract considerable research attention due to their environmental impact and performance. O.I. Nazarov *et al.* (2023) investigated the frictional properties of brake materials under different braking conditions, focusing on how these conditions affect the performance of brake pads. M.G. Faga *et al.* (2019) found that the service life of braking mechanisms directly depends on braking conditions and is the inverse of the wear of friction surfaces. L. Wei *et al.* (2019) confirmed that the materials used to make pads are a key factor in wear.

D. Carlevaris *et al.* (2023) proposed the use of rice husk as a component of friction materials, while S. Venkatesh & K. Murugapoopathiraja (2019) and W. Li *et al.* (2021) investigated the potential of rice husk ash and barite-calcite as inert filler. Their findings showed that the use of these natural ingredients not only does not impair the performance of brake pads but contributes to improved wear resistance and reduced friction material emissions.

Composite materials, as noted by F. Khan *et al.* (2024), play a key role in improving the durability of brake linings due to their ability to withstand high loads and ensure stable performance even under extreme conditions. The use of such materials reduces the risk of damage and wear

to brake components, making the system more reliable and durable. This is especially important for heavy vehicles and vehicles operated at high speeds and requiring frequent braking. The high strength of the composites also reduces the need for frequent brake pad replacements, which helps to reduce maintenance costs and improve overall vehicle efficiency.

On the other hand, S. Mulani *et al.* (2022) emphasised that the use of composite materials can considerably reduce the weight of a car, which improves its handling and dynamic characteristics. Reducing vehicle weight helps to save fuel, which is an essential factor in reducing carbon dioxide emissions and increasing the environmental sustainability of road transport. The lighter brake pads also reduce the load on the suspension and braking system, which improves the overall stability of the vehicle on the road and provides a more comfortable driving experience.

S. Manoharan *et al.* (2019) further showed that the morphology of potassium titanate used in composite materials considerably affects the performance of braking systems. This component contributes to the formation of contact plateaus and transfer films on rubbing surfaces, which results in high frictional stability and wear resistance. According to the findings, potassium titanate in the form of chips demonstrates improved characteristics compared to other materials, which allows increasing the reliability of brake systems, reducing wear, and ensuring stable friction properties even under high loads. Thus, the introduction of new materials and technologies in the production of brake systems opens new opportunities to improve the efficiency and environmental safety of vehicles.

P. Ghosh *et al.* (2020) investigated the effect of the concentration of fibre components (aramid/lapinus) on friction composites. Their findings confirmed that changing the composition of the composite affects properties such as the coefficient of friction and thermal conductivity. S. Jeganmohan *et al.* (2020) studied the thermal properties of materials, including thermal

decomposition, while V.V. Kumar & S.S. Kumar (2019) found that composites with lower fibre content have a lower wear rate, but higher fibre content increases thermal conductivity.

Therewith, the available information is usually scattered, and methodological issues are still understudied, namely definitions, systematisation, and classification of types, designs, and materials of brake pads. The purpose of this study was to review, systematise, and classify the types and design of brake pads and analyse modern materials used in the manufacture of brake linings.

The study employed systematic and qualitative approaches, which involve the use of analysis and synthesis, formalisation, tabular and graphical interpretation of the results and contribute to the integrity of the study, with the identification of various characteristic features.

Material Requirements for Disc Brake Pads

During braking, the force acting on the pad attracts it to the disc, forming a so-called tribological contact between them (Aulin *et al.*, 2024). Tribological contact is the interaction between surfaces that are in relative motion to each other. The term combines the aspects of friction, wear, and lubrication studied in tribology, which are characterised by certain tribological properties that determine the behaviour of materials or joints in friction. The main tribological properties are presented in Table 1. These qualities are key when selecting materials for mechanisms and joints subject to friction to ensure their durability and efficiency. And, as shown in Figure 1, as a result of friction in the braking system of mobile agricultural machinery, kinetic energy is dissipated and converted into heat.

Table 1. Basic tribological properties and their characteristics

Properties	Characteristics
coefficient of friction	determines the sliding resistance between two surfaces
wear resistance	determines the ability of the material to resist mechanical wear
anti-friction property	determines the possibility of reducing friction between moving parts
score resistance	determines the ability of surfaces to resist scoring on contact
lubricating property	indicates the ability of a material or lubricant to reduce friction and wear
temperature resistance	determines the ability to maintain tribological properties at hot or cold temperatures
corrosion resistance	ability to resist corrosion in friction conditions

Source: compiled by the author of this study based on W. Li *et al.* (2022)

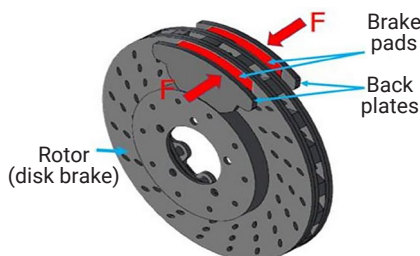


Figure 1. Friction force between brake pads and brake disc surface

Note: F – friction force

Source: A.P. Irawan *et al.* (2022)

The power dissipation equation proposed by R. Dante (2015) is a basic expression for any type of brake, as it introduces the concept of an external force, which is a source of counteracting the motion, into the underlying concept:

$$\frac{\delta W_d}{dt} = w(\bar{X})F_N, \quad (1)$$

where W_d is the dissipated work; t is time; $w(\bar{X})$ is the proportionality coefficient; \bar{X} is a set of variables affecting the proportionality coefficient; v is velocity; F_N is the friction force created between two opposing surfaces.

The heat energy generated by power dissipation is transferred to the components in contact. Excessive thermal load can cause vibration (disc thickness changes), surface cracking, and severe wear of the contact surfaces (Fig. 2).

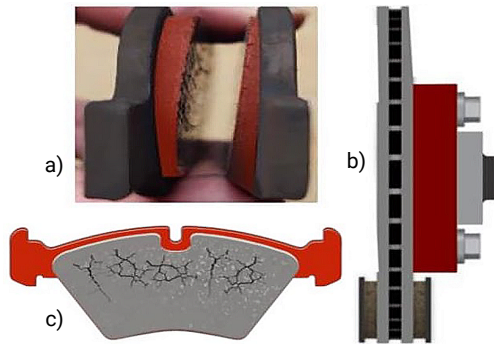


Figure 2. Brake pad failure caused by excessive heat load

Note: a – wear, b – change in disc thickness, c – surface cracking

Source: A.P. Irawan *et al.* (2022)

This reduces the thickness of the friction material of the pad. Reaching the limit value, the pad must be replaced. The friction material is the very obstacle that, when the brakes are applied, allows the vehicle to decelerate and stop in time. To avoid such defects, the material used in the production of brake pads must meet the following criteria:

- ┆ be operable in various operating situations (e.g., high temperature, pressure, velocity);
- ┆ have high thermal conductivity;
- ┆ help reduce the rate of wear;
- ┆ have a stable coefficient of friction;
- ┆ be environmentally sustainable.

Therefore, for the braking mechanism to function efficiently and for the pads themselves to be durable, the quality of their manufacture becomes a vital aspect to consider when selecting the right combination of materials.

Main Types and Designs of Disc Brake Pads

When considering the classification of brake pads, it can be noted that they are divided into several main types, depending on the design features and material of manufacture:

For its intended purpose:

- ┆ for ordinary road vehicles – designed for moderate use in urban and intercity conditions;
- ┆ for high-speed vehicles – designed for higher velocities and frequent braking;
- ┆ for trucks and buses – designed for heavy loads and intensive use;
- ┆ for racing cars – optimised for maximum performance under extreme braking conditions.

For design features:

- ┆ single-layer – consisting of a single layer of friction material;
- ┆ multilayer – have several layers of friction material to increase strength and efficiency;
- ┆ with additional layers – have additional layers of friction material to reduce vibrations and noise.

According to the composition of the friction material:

- ┆ semi-metallic;
- ┆ NAO – non-asbestos organic;
- ┆ ceramic.

The composition and main characteristics of brake pads by type are presented in Table 2.

Table 2. Composition and main characteristics of brake pads by type

Name	Composition	Advantages	Disadvantages
Semi-metallic	The composite of this friction material consists of 30–70% metal (copper or steel) and graphite. This composite is complemented by other inorganic materials and binders	<ul style="list-style-type: none"> ┆ high thermal conductivity, which allows for efficient heat dissipation during braking; ┆ long service life; ┆ wide temperature range; ┆ good performance at hot temperatures. 	<ul style="list-style-type: none"> ┆ noisier; ┆ higher levels of brake disc wear; ┆ less environmentally friendly and generate more black dust.

Table 2. Continued

Name	Composition	Advantages	Disadvantages
NAO (non-asbestos organic)	The friction linings are made from a mixture of organic fibres such as glass fibre, Kevlar, aramid, carbon fibre, and high-temperature resins. The metal content in their composition does not exceed 20%.	<ul style="list-style-type: none"> ┆ less noise and softer braking; ┆ less wear on the brake discs; ┆ more environmentally friendly as they do not contain asbestos. 	<ul style="list-style-type: none"> ┆ shorter service life than metal pads; ┆ less effective at hot temperatures; ┆ used for small passenger cars
Ceramic	The friction layer of this type consists of ceramic fibres bonded with special resins, sometimes with a small amount of non-ferrous metals	<ul style="list-style-type: none"> ┆ long service life; ┆ stable performance even at hot temperatures; ┆ reduce the amount of brake dust. 	<ul style="list-style-type: none"> ┆ more expensive to produce and usually have a higher price; ┆ low initial coefficient of friction.

Source: compiled by the author of this study based on V.I. Mohyla & M.H. Aldokimov (2018), A. Sinha *et al.* (2020)

In terms of the availability of wear sensors:

┆ without wear sensors and without mechanical wear detectors;

┆ with mechanical wear detectors;

┆ with wear sensors: with pre-installed sensors, with seats for mounting existing sensors, with integrated sensors.

Each type of brake pad has its advantages and disadvantages, and the choice depends on the concrete operating conditions and performance requirements. A closer look at the construction of brake pads reveals that they usually comprise several layers (Fig. 3).

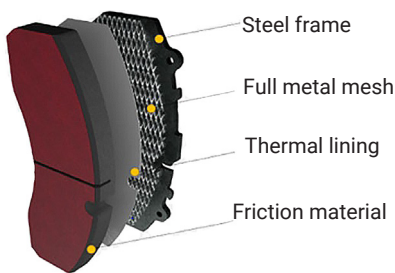


Figure 3. Brake pad layers

Source: developed by the author of this study

Adhesive – designed to hold the friction material to the other layers of the brake pad. This is ensured by a sub-layer placed between the friction material and the back plate. The main

function of the sub-layer is to reduce vibrations caused by the contact of friction materials with the disc. Rear plate – designed to maintain the necessary rigidity in the brake pad to allow it to continue to move along the calliper guide. Some brake pads use special interference pads to minimise the amount of unnecessary noise during braking. Friction material is the main layer on the brake pads that comes into direct contact with the brake disc during braking. Friction material comprises various components, each of which is designed for specific applications (Arman *et al.*, 2018; Ige *et al.*, 2019; Kumar & Selvaraj, 2019). The combination of these components can vary depending on the performance requirements and the purpose of the material (Rogovskii, 2021). Such materials are widely used in various industries, and therefore their composition is adapted to concrete operating conditions. This approach allows achieving optimum performance that ensures the reliability and durability of products in various environments.

Main Components of Brake Lining Friction Materials

Brake lining materials are usually composites created by hot pressing coarse powders, which also contain many (usually 10-20) different components. The components of friction materials are as follows: Binders– designed to create a thermally

stable matrix (holding all other components together). Typically, they consist of thermosetting phenolic resins, often with the addition of rubber to improve the damping friction properties; Structural materials – provide mechanical strength of the pad. For these purposes, metal, mineral, and ceramic fibres, glass, and/or Kevlar fibres, and rarely various carbon fibres are used; Fillers – designed to reduce the cost and improve the processability of the lining. Various minerals such as mica and vermiculite are often used as fillers; Friction additives – help to ensure stable friction

properties of the pad and control the wear rate of the friction pair (disc and pad). They contain solid lubricants (graphite and various metal sulphides) that help to stabilise the coefficient of friction, especially at hot temperatures. Abrasive particles – designed to create a more reliable friction surface by removing iron oxides and other unwanted surface films from the brake disc. The latter are usually made of aluminium oxide and silicon, which increase both the coefficient of friction and disc wear. The main components of the brake lining friction materials are described in Table 3.

Table 3. Composition and characteristics of the main components of brake lining friction materials

Components	Materials	Characteristics
Metal particles	Steel	<ul style="list-style-type: none"> ↓ used to increase strength and thermal conductivity, ↓ promotes rapid dissipation of heat generated during braking.
	Copper	<ul style="list-style-type: none"> ↓ increases thermal conductivity and wear resistance, ↓ improves braking performance at hot temperatures, ↓ its use is decreasing due to environmental restrictions.
	Brass and aluminium	<ul style="list-style-type: none"> ↓ used to reduce pad weight and increase corrosion resistance, ↓ improve heat transfer and resistance to deformation during heating.
Organic materials	Cellulose	<ul style="list-style-type: none"> ↓ provides good adhesion and reduces the weight of the material.
	Natural rubber and rubber compounds	<ul style="list-style-type: none"> ↓ added to improve flexibility and reduce braking noise, ↓ contribute to increased wear resistance and durability at cold temperatures.
	Kevlar and other synthetic fibres	<ul style="list-style-type: none"> ↓ used to increase strength and heat resistance, ↓ provide high resistance to abrasive wear.
Ceramic particles	Silicon carbide	<ul style="list-style-type: none"> ↓ increases the wear resistance and heat resistance of the material, ↓ known for its ability to operate at hot temperatures without losing efficiency.
	Aluminium oxide	<ul style="list-style-type: none"> ↓ increases wear resistance and helps dissipate heat, ↓ helps to reduce braking noise.
Resins	Phenolic resins	<ul style="list-style-type: none"> ↓ used as a binder to hold all the components together, ↓ high heat resistance and strength.
	Epoxy resins	<ul style="list-style-type: none"> ↓ used to provide additional strength and chemical resistance, ↓ improve the adhesion between different components of the material.
Fillers and modifiers	Graphite	<ul style="list-style-type: none"> ↓ reduces friction and wear, ↓ helps to avoid squeaks and noises when braking.
	Copper powder	<ul style="list-style-type: none"> ↓ increases thermal conductivity and wear resistance, ↓ improves overall friction characteristics.
	Metal sulphides	<ul style="list-style-type: none"> ↓ used to reduce friction and increase wear resistance, ↓ reduce the possibility of jamming the pads.
Anti-friction additives	Anti-friction additives	<ul style="list-style-type: none"> ↓ reduce wear and friction between the brake disc and brake pad, ↓ improve the overall efficiency and durability of the braking system.

Source: compiled by the author of this study based on D. Chan & G.W. Stachowiak (2004), R. Dante (2015), G. Gautier di Confiengo & M.G. Faga (2022)

The main purpose of using composite materials in brake linings is to achieve the optimum combination of strength, wear resistance, thermal

conductivity, noise absorption, and other characteristics that are important for effective braking. Their advantages and disadvantages are presented in Table 4.

Table 4. Advantages and disadvantages of using composite materials in brake linings

Advantages	Disadvantages
Stable performance regardless of operating conditions	Higher cost
Less aggressive on brake discs, reducing wear	Greater sensitivity to operating conditions
Higher environmental friendliness compared to asbestos pads, which reduces the impact on the environment and human health	Need for special storage conditions
More effective braking compared to conventional materials	

Source: compiled by the author of this study based on R. Dante (2015)

Notably, current research on the components of friction materials for brake linings is largely concerned with two areas: 1) ceramic-based materials, which use high-purity inorganic compounds and ultrafine synthetic substances as raw materials, which have a high melting point and can maintain good chemical stability at hot temperatures (Li *et al.*, 2021), which allows for stable friction coefficient, good heat resistance, long service life, comfortable braking, no braking noise, etc. Such pads have an exact chemical composition, precision production technology, and excellent structure; 2) ceramic-based materials that use natural fibres that are not harmful to human health. Biomass from agricultural activities is a trendy material to produce brake pads because it is commercially acceptable and environmentally friendly. Banana peels, palm waste, aramid fibres, flax fibres (Arman *et al.*, 2018), cashew shells, coconut shells (Irawan *et al.*, 2022), rice straw, and rice husks (Carlevaris *et al.*, 2023) all contain agricultural waste that can be used as reinforcing material in polymer composites. Natural fibres have many advantages over synthetic fibres due to their low density, abundance, low cost, recyclability, biodegradability, renewability, and relatively high strength and rigidity.

Earlier studies, presented by A.A. Kashkanov *et al.* (2010), mainly focused on the interaction of the brake disc and pad, with special attention to the formation of a tribofilm on the disc

surface. This study has identified critical aspects of the braking process but has hardly addressed the characteristics of the brake pad surface itself. Other researchers noted this shortcoming, specifically, M. Eriksson & S. Jacobson (2000). They stressed that the surface of the pad is still relatively unexplored, noting the need for a deeper investigation of this element of the tribosystem.

Subsequent research, such as the study by P. Balaji *et al.* (2024), aims to expand the knowledge of the brake disc and pad tribosystem, including a detailed analysis of the pad surface. V. Jankauskas & D. Kairiūnas (2021) also confirmed the significance of this aspect, focusing on the characteristics of the pad surface and its materials. M. Kchaou *et al.* (2013) indicated that pad surface properties play a crucial role in ensuring stable braking. Additionally, the materials used to make the pad substantially affect its performance, as discussed in T. Singh *et al.* (2016).

U.V. Saindane *et al.* (2020) discussed the prospects for the use of new friction materials for brake pads, focusing on improving their wear resistance, stability of friction characteristics, and environmental safety. Scientists propose the use of alternative materials that can replace conventional metal or asbestos components, which are still widely used but have a series of disadvantages, including negative impacts on health and the environment. According to their research, new composite materials, which can include organic

and inorganic components, such as fibres, nanoparticles, ceramics, help to improve braking efficiency and reduce wear, as well as reduce emissions of harmful particles during operation.

In terms of environmental impact, A.P. Irawan *et al.* (2022) raised the issue of the environmental impacts of brake pad wear. N.M. Kharytonova & V.O. Khrutba (2021) developed a classification of micro-pollutants contained in waters near motorways, where a considerable proportion of pollution comprises polymeric components from brake pads. This highlights the significance of investigating the environmental impact of brake materials.

Special attention is paid to improving brake pad materials. D. Aleksendrić & P. Carlone (2015) propose innovative solutions for the design and manufacture of composite materials that can improve the efficiency and reliability of braking systems. According to K.L. Sundarkrishnaa (2015), composite materials not only improve the performance of brake pads, but also reduce brake dust and noise during braking, which is a compelling argument in favour of their use.

Another area of research is the impact of nanomaterials. K.H. Cho *et al.* (2008) investigated how nanoparticles of various materials can improve the performance of brake pads. The researchers highlighted the potential of nanoparticles in composite materials to improve their friction properties. M. Baklouti *et al.* (2015) analysed the effect of various ingredients in friction material compositions, which also contributed to the efficiency of the braking process.

Thus, research in this area is expanding the understanding of the mechanisms of interaction between brake discs and pads, specifically their surface characteristics and the impact of the latest materials, which opens opportunities for improving the design and efficiency of braking systems.

Using agricultural waste in brake linings can reduce environmental pollution and health risks. However, the use of agricultural waste or natural fibre in the manufacture of brake linings considerably affects the wear rate, friction coefficient, and durability.

Conclusions

A critical review of scientific sources related to the study of the tribological properties of brake pads, their operating modes, friction materials that make up brake linings and emissions of harmful particles into the environment during braking showed certain methodological gaps in this area of research, namely, a lack of definitions, systematisation of information, and a lack of classification of types, designs of pads and materials for the manufacture of brake linings.

To overcome the identified shortcomings, the study systematised and classified the types and design of brake pads and analysed the key characteristics of the main materials used in the manufacture of brake linings for mobile agricultural machinery. It was found that the main criteria for selecting materials for brake pads are wear resistance, temperature resistance, and corrosion resistance. Accordingly, the materials used to produce brake pads must be able to perform under different conditions, have high thermal conductivity, help reduce the wear rate, have a stable coefficient of friction, and be environmentally friendly.

In this study, all brake pads were divided into four types depending on the requirements of particular brakes and vehicles: by purpose; by design features; by friction material composition; and by wear sensors. Each type of brake pad has its advantages and disadvantages, and the choice depends on the concrete operating conditions and performance requirements. By composition, brake pads are classified into semi-metallic, non-asbestos organic, and ceramic

As for modern components of friction materials for brake linings, they were divided into six main groups: metal particles (steel, copper, brass); organic materials (cellulose, natural rubber, rubber compounds, Kevlar, and other synthetic fibres); ceramic particles (silicon carbide, aluminium oxide); resins (phenolic and epoxy); and fillers.

Further research will be related to the development, testing, and application of new components of brake lining friction materials and, accordingly, the expansion of the classification

of types of brake pads and brake lining friction materials.

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Conflict of Interest

None.

References

- [1] Aleksendrić, D., & Carlone, P. (2015). Soft computing in the design and manufacturing of composite materials. In *Applications to brake friction and thermoset matrix composites* (pp. 1-5). Amsterdam: Woodhead Publishing. [doi: 10.1533/9781782421801.1](https://doi.org/10.1533/9781782421801.1).
- [2] Arman, M., Singhal, S., Chopra, P., & Sarkar, M. (2018). A review on material and wear analysis of automotive Break Pad. *Materials Today Proceedings*, 5(14-2), 28305-28312. [doi: 10.1016/j.matpr.2018.10.114](https://doi.org/10.1016/j.matpr.2018.10.114).
- [3] Aulin, V., Rogovskii, I., Lyashuk, O., Tykhyi, A., Kuzyk, A., Dvornyk, A., Derkach, O., Lysenko, S., Banniy, O., & Hrynkiv, A. (2024). Revealing patterns of change in the tribological efficiency of composite materials for machine parts based on phenylone and polyamide reinforced with arimide-T and fullerene. *Eastern-European Journal of Enterprise Technologies*, 3(12(129)), 6-19. [doi: 10.15587/1729-4061.2024.304719](https://doi.org/10.15587/1729-4061.2024.304719).
- [4] Baklouti, M., Cristol, A.L., Desplanques, Y., & Elleuch, R. (2015). Impact of the glass fibers addition on tribological behavior and braking performances of organic matrix composites for brake lining. *Wear*, 330-331, 507-514. [doi: 10.1016/j.wear.2014.12.015](https://doi.org/10.1016/j.wear.2014.12.015).
- [5] Balaji, P., Surya Rajan, B., Sathickbasha, K., Baskara Sethupathi, P., & Magadevan, D. (2024). The significance of low and high temperature solid lubricants for brake friction applications and their tribological investigation. *Tribology International*, 191, article number 109109. [doi: 10.1016/j.triboint.2023.109109](https://doi.org/10.1016/j.triboint.2023.109109).
- [6] Carlevaris, D., Leonardi, M., Straffelini, G., & Gialanella, S. (2023). Design of a friction material for brake pads based on rice husk and its derivatives. *Wear*, 526-527, article number 204893. [doi: 10.1016/j.wear.2023.204893](https://doi.org/10.1016/j.wear.2023.204893).
- [7] Chan, D., & Stachowiak, G.W. (2004). Review of automotive brake friction materials. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, 218, 953-966. [doi: 10.1243/0954407041856773](https://doi.org/10.1243/0954407041856773).
- [8] Cho, K.H., Cho, M.H., Kim, S.J., & Jang, H. (2008). Tribological properties of potassium titanate in the brake friction material; morphological effects. *Tribology Letters*, 32, 59-66. [doi: 10.1007/s11249-008-9362-x](https://doi.org/10.1007/s11249-008-9362-x).
- [9] Dante, R. (2015). *Handbook of friction materials and their applications*. Sawston: Woodhead Publishing.
- [10] Eriksson, M., & Jacobson, S. (2000). Tribological surfaces of organic brake pads. *Tribology International*, 33(12), 817-827. [doi: 10.1016/S0301-679X\(00\)00127-4](https://doi.org/10.1016/S0301-679X(00)00127-4).
- [11] Faga, M.G., Casamassa, E., Iodice, V., Sin, A., & Gautier, G. (2019). Morphological and structural features affecting the friction properties of carbon materials for brake pads. *Tribology International*, 140, article number 105889. [doi: 10.1016/j.triboint.2019.105889](https://doi.org/10.1016/j.triboint.2019.105889).
- [12] Gautier di Confiengo, G., & Faga, M.G. (2022). Ecological transition in the field of brake pad manufacturing: an overview of the potential green constituents. *Sustainability*, 14(5), article number 2508. [doi: 10.3390/su14052508](https://doi.org/10.3390/su14052508).

- [13] Ghosh, P., Banerjee, S.S., & Khastgir, D. (2020). Performance assessment of hybrid fibrous fillers on the tribological and thermo-mechanical behaviors of elastomer modified phenolic resin friction composite. *SN Applied Sciences*, 2(5), article number 788. doi: [10.1007/s42452-020-2424-x](https://doi.org/10.1007/s42452-020-2424-x).
- [14] Ige, O.E., Freddie, I.L., & Adewumi, G. (2019). [Biomass-based composites for brake pads: A review](#). *International Journal of Mechanical Engineering and Technology*, 10(3), 920-943.
- [15] Irawan, A.P., Fitriyana, D.F., Tezara, C., Siregar, J.P., Laksmidewi, D., Baskara, G.D., Abdullah, M.Z., Junid, R., Hadi, A.E., & Hamdan, M.H.M. (2022). Overview of the important factors influencing the performance of eco-friendly brake pads. *Polymers*, 14, article number 1180. doi: [10.3390/polym14061180](https://doi.org/10.3390/polym14061180).
- [16] Jankauskas, V., & Kairiūnas, D. (2021). Investigation of tribological characteristics of brake pairs elements of mobile machine. *Problems of Tribology*, 26(3/101), 26-30. doi: [10.31891/2079-1372-2021-101-3-26-30](https://doi.org/10.31891/2079-1372-2021-101-3-26-30).
- [17] Jeganmohan, S., Sugozu, B., Kumar, M., & Selvam, D.R. (2020). Experimental investigation on the friction and wear characteristics of palm seed powder reinforced brake pad friction composites. *Journal of the Institution of Engineers (India) Series D*, 101, 61-69. doi: [10.1007/s40033-020-00210-9](https://doi.org/10.1007/s40033-020-00210-9).
- [18] Kashkanov, A.A., Rebedajlo, V.M., & Kashkanov, V.A. (2010). [Estimation of operational braking properties of cars in the conditions of inaccuracy of the initial data](#). Vinnitsia: VNTU.
- [19] Kchaou, M., Sellami, A., Elleuch, R., & Singh, H. (2013). Friction characteristics of a brake friction material under different braking conditions. *Materials & Design*, 52, 533-540. doi: [10.1016/j.matdes.2013.05.015](https://doi.org/10.1016/j.matdes.2013.05.015).
- [20] Khan, F., Hossain, N., Mim, J.J., Rahman, S.M., Iqbal, J., Billah, M., Chowdhury, M.A. (2024). Advances of composite materials in automobile applications – a review. *Journal of Engineering Research*. doi: [10.1016/j.jer.2024.02.017](https://doi.org/10.1016/j.jer.2024.02.017).
- [21] Kharytonova, N.M., & Khrutba, V.O. (2021). Classification of sources of micropollutants as components of pollution of surface road runoff. *Roads and Bridges*, 23, 251-258. doi: [10.36100/dorogimosti2021.23.251](https://doi.org/10.36100/dorogimosti2021.23.251).
- [22] Kumar, V.V., & Kumaran, S.S. (2019). Friction material composite: Types of brake friction material formulations and effects of various ingredients on brake performance – a review. *Materials Research Express*, 6(8), article number 082005. doi: [10.1088/2053-1591/ab2404](https://doi.org/10.1088/2053-1591/ab2404).
- [23] Kumar, V.V., & Selvaraj, S.K. (2019). Friction material composite: types of brake friction material formulations and effects of various ingredients on brake performance – a review. *Materials Research Express*, 6, article number 2404. doi: [10.1088/2053-1591/ab2404](https://doi.org/10.1088/2053-1591/ab2404).
- [24] Li, W., Yang, X., Wang, S., Xiao, J., & Hou, Q. (2021). Research and prospect of ceramics for automotive disc-brakes. *Ceramics International*, 47(8), 10442-10463. doi: [10.1016/j.ceramint.2020.12.206](https://doi.org/10.1016/j.ceramint.2020.12.206).
- [25] Li, B., Li, P., Zhou, R., Feng, X-Q., & Zhou, K. (2022). Contact mechanics in tribological and contact damage-related problems: A review. *Tribology International*, 171, article number 107534. doi: [10.1016/j.triboint.2022.107534](https://doi.org/10.1016/j.triboint.2022.107534).
- [26] Manoharan, S., Vijay, R., Singaravelu, L.D., & Kchaou, M. (2019). Experimental investigation on the tribo-thermal properties of brake friction materials containing various forms of graphite: A comparative study. *Arabian Journal for Science and Engineering*, 44, 1459-1473. doi: [10.1007/s13369-018-3590-7](https://doi.org/10.1007/s13369-018-3590-7).
- [27] Mohyla, V.I., & Aldokimov, M.H. (2018). [Brake pad and ways to improve it](#). *Scientific Journals of Volodymyr Dahl East Ukrainian National University*, 2(243), 160-162.

- [28] Mulani, S.M., Kumar, A., Shaikh, A.H.N.E.A., Saurabh, A., Singh, P.K., & Verma, P.C. (2022). A review on recent development and challenges in automotive brake pad-disc system. *Materials Today Proceedings*, 56(1), 447-454. doi: [10.1016/j.matpr.2022.01.410](https://doi.org/10.1016/j.matpr.2022.01.410).
- [29] Nazarov, O.I., Kryvoshapov, S.I., Serhiienko, M.Ye., Pavlova, N.M., Ivanchenko, Ye.I., & Kulaj, V.P. (2023). Modeling the resource of brake mechanisms of passenger cars based on the relative wear of their friction surfaces. *Bulletin of the National Technical University "KhPI". Series: Automobile and Tractor Construction*, 2, 36-42. doi: [10.20998/2078-6840.2023.2.04](https://doi.org/10.20998/2078-6840.2023.2.04).
- [30] Rogovskii, I.L. (2021). Resource of removal expenses for strong agricultural period of volume of operations. *Machinery and Energetics*, 12(2), 123-131. doi: [10.31548/machenergy2021.02.123](https://doi.org/10.31548/machenergy2021.02.123).
- [31] Saindane, U.V., Soni, S., & Menghani, J.V. (2020). Recent research status on synthesis and characterization of natural fibers reinforced polymer composites and modern friction materials – an overview. *Material Today Proceeding*, 26, 1616-1620. doi: [10.1016/j.matpr.2020.02.334](https://doi.org/10.1016/j.matpr.2020.02.334).
- [32] Singh, T., Patnaik, A., & Chauhan, R. (2016). Optimization of tribological properties of cement kiln dust-filled brake pad using grey relation analysis. *Materials and Design*, 89, 1335-1342. doi: [10.1016/j.matdes.2015.10.045](https://doi.org/10.1016/j.matdes.2015.10.045).
- [33] Sinha, A., Ischia, G., Menapace, C., & Gialanella, S. (2020). Experimental characterization protocols for wear products from disc brake materials. *Atmosphere*, 11, article number 1102. doi: [10.3390/atmos11101102](https://doi.org/10.3390/atmos11101102).
- [34] Sundarkrishnaa, K.L. (2015). *Friction material composites: Materials perspective*. Berlin/Heidelberg: Springer International Publishing. doi: [10.1007/978-3-319-14069-8](https://doi.org/10.1007/978-3-319-14069-8).
- [35] Venkatesh, S., & Murugapoopathiraja, K. (2019). Scoping review of brake friction material for automotive. *Material Today Proceeding*, 16(2), 927-933. doi: [10.1016/j.matpr.2019.05.178](https://doi.org/10.1016/j.matpr.2019.05.178).
- [36] Wei, L., Choy, Y.S., & Cheung, C.S. (2019). A study of brake contact pairs under different friction conditions with respect to characteristics of brake pad surfaces. *Tribology International*, 138, 99-110. doi: [10.1016/j.triboint.2019.05.016](https://doi.org/10.1016/j.triboint.2019.05.016).

Технічний огляд основних типів, конструкцій та матеріалів гальмівних колодок мобільної сільськогосподарської техніки

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Анотація. Гальмівні колодки є критично важливим елементом будь-якої техніки, оскільки вони безпосередньо впливають на безпеку її використання. Відповідно якість гальмівних колодок, їх стійкість та довговічність є ключовими аспектами які обов'язково потрібно враховувати при розробці гальмівних систем мобільної сільськогосподарської техніки. Метою роботи було здійснити огляд наукових джерел пов'язаних з дослідженнями трибологічних властивостей гальмівних колодок, режимів їх функціонування та фрикційних матеріалів, які входять до складу гальмівних накладок. Проаналізовано основні параметри, що впливають на ефективність гальмівних колодок та визначено головні критерії щодо вибору матеріалів для гальмівних колодок мобільної сільськогосподарської техніки, а саме: зносостійкість, температурна стійкість та корозійна стійкість. Відповідно матеріали що застосовуються при виробництві гальмівних колодок для такої техніки мають бути працездатним за будь яких умов, мати високу теплопровідність, сприяти зниженню швидкості зносу, мати стабільний коефіцієнт тертя та бути екологічно стійким. Основну увагу в дослідженні приділено огляду типів та конструкції гальмівних колодок, їх систематизації за різними ознаками (за призначенням; за конструктивними особливостями; за складом фрикційного матеріалу; за наявністю датчиків зносу) та складом (напівметалеві, органічно-безасбестові та керамічні). Проведено опис сучасних компонентів фрикційних матеріалів гальмівних накладок у якому визначено, що вони зазвичай являють собою композитиви утворені шляхом гарячого пресування грубих порошків, що включають багато різних компонентів: сполучну речовину (термореактивні фенольні смоли, часто з додаванням каучуку), конструкційні матеріали (металеві, вуглецеві, скляні та/або кевларові волокна), наповнювачі (слюда та вермікуліт), фрикційні добавки (графіт та різні сульфідні металів). Також в роботі дано оцінку основним характеристикам компонентів фрикційних матеріалів, що застосовуються при виготовленні гальмівних накладок. Результати цього дослідження можуть надати дослідникам і вченим корисну інформацію щодо типів та конструкції гальмівних колодок та основних матеріалів, що застосовуються при виготовленні гальмівних накладок і бути корисними для подальших практичних розробок гальмівних механізмів

Ключові слова: гальмівна система; композитні матеріали; тертя; трибологічні властивості; фрикційні матеріали