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Ceramics that Brake

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Due to their high heat resistance, thermal stability and hardness, ceramic materials have been used in the friction industry since its early days. Developers of these components relied on ceramics' beneficial properties to deliver increased life in the most extreme conditions. Today, an increasing number of formulations and composite materials used in brake pads and clutch linings contain ceramics, and the task of material selection and representative testing methods continues to challenge the material scientists faced with the demands of the application.

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Brake Pad Construction

Since the industry designs wear surfaces and engineers brake system dynamics for vehicles ranging from locomotives to Lamborghinis, the material science-related challenges are vast and complex. However, almost all brake pads made today include five primary components—each with a different function. In addition, the ratios of these components vary widely in the different formulations and applications. The components include:

- Abrasives—improve stopping performance, modify friction wear
- Fillers—improve the manufacturing process, reduce cost
- Reinforcing fibers—improve mechanical strength
- Lubricants—counter the wear of abrasives, modify friction coefficient
- Binders—hold the various components together

Ceramic materials can be found in all five of these basic categories, which underscores the variety of commercially available ceramics used in friction around the globe. From ceramic fiber wool to hard zirconia abrasives and potassium titanate whisker fibers, the material list is long.

A Closer Look

The abrasive component of a brake pad is most likely to contain ceramic materials, although the design may require the abrasive to range in hardness to balance the properties required. To illustrate this range, consider that the abrasive could be as hard as tungsten carbide, for race cars that need to have the "grab" while cornering and change their rotors every race. More common abrasives include zirconia, silicon carbide, alumina, silica and magnesia materials, providing many options in designing the composite material that is pressed into the wear pad.

Fillers in the brake pad manufacturing process can mean many different things in terms of material selection and function. The simplest description of a filler is a low-cost material that fills the space in the brake pad to reduce the overall cost of the pad. However, the filler label is often applied to materials that act as the abrasive, a reinforcing fiber or a friction modifier. A filler material is often specifically used to facilitate the manufacturing process. The industry has applied this term to metallics, organics and inorganics (ceramics and mineral fibers) as a virtual catch-all phrase to describe what is not being used as a binder, reinforcing fiber, abrasive, or lubricant.

As the name would suggest, reinforcing fibers are used to reinforce and strengthen the matrix. However, the selected fiber's thermal properties affect the composition, as well as the tribological behavior when the pad is in use. Therefore, sufficient attention to fiber selection and its interactions with the other components is critical. Asbestos, mineral wool fibers, ceramic fibers (including potassium titanate fibers), and fiberglass are harder and more heat resistant, while softer fibers such as aramid (Kevlar®) and other synthetics are used to balance the feel of the brakes. Metallic fibers such as chopped copper or steel wire are used when better thermal transfer properties are needed.

Lubricants are typically solid powders such as graphite that are used in brake pad formulations to balance the effects of friction, braking ability, and the wear of pad and rotor. In combination with the appropriate abrasives and friction modifiers (fillers), the lubricant provides a wear surface that acts as an intermediate layer between the mated wear surfaces, which helps reduce the loss of material on the pad and rotor. Lubricants are often used along with metal sulfides to achieve the desired effect.

Binders are the engineered "glues" that hold the powders, fibers, oils, etc., together, which is important throughout pad manufacturing. Binders also need to withstand the heat, vibration and stresses of braking. Phenolic resin is likely the most common binder, but other materials such as silicone, rubber, epoxy and other oils are used for specific applications where the trade-off in some properties allows for better performance in particular environments.

Brake Pad Classification

The many combinations of these materials allow engineers to tailor the brake to address the proper balance of noise, vibration, heat and wear on either the rotor or the pad, as well as the "feel" of the braking to the driver—for literally every vehicle on the planet. Several brake pad types or classifications are used in the industry, including:

- Asbestos—pads made with mineral fiber used for years as reinforcing filler
- Metallic—composed primarily of metal such as steel or copper fibers, iron powder
- Semi-metallic—uses similar metals combined with organic fillers and binders
- Non-asbestos organic (NAO)—employs a matrix of organic and inorganic materials
- Ceramic—composed of ceramic fibers, nonferrous filler materials, ceramic powders

Asbestos is a naturally mined fibrous material that had been widely used as reinforcing filler in brake pads for much of the 20th century. When its health risks and carcinogenic characteristics became known, most manufacturers and many countries banned the use of asbestos. While some friction materials are still made with asbestos in limited parts of the world, this class of brake pads makes up a very small part of the overall market.

Metallic brake pads are composed primarily of metals such as steel or copper fibers, iron powder and graphite, as well as inorganic fillers and friction modifiers or binders. This type of brake pad is widely used due to its cost and durability; however, excessive noise and brake rotor wear can result, especially in more severe environments (e.g., heavy trucks).

Semi-metallic pads use a similar mix of metallic fibers, including chopped steel wire or steel wool, iron powder, copper fibers, and graphite (as a lubricant). These fibers are mixed with organic binders such as phenolic resin. Fillers can include everything from rubber dust, cashew dust, mica, and vermiculite or calcium carbonate and potassium titanate, which also help modify the friction coefficient. These pads offer good heat transfer properties and are more durable than metallics, but can also increase rotor wear, produce noise and dust, and fail to perform efficiently at lower temperatures.

NAO brake formulations were designed to replace asbestos brake pads. NAOs employ the use of a matrix of organic and inorganic fillers, friction modifiers, abrasives, and binders. While not considered a fully ceramic material, it is common to have NAOs referred to as “ceramic” due to the practice of using materials like potassium titanate, ceramic fiber wool, silica, zirconia, alumina, silicon carbide, and others as fillers and abrasives. These may also contain mined mineral fibers, aramid fibers, and graphite as a lubricant. NAO pads produce less noise and typically have a better “feel” when braking, but they may create more dust and have a higher pad wear rate.

Ceramic friction materials are not new to the industry; early manufacturers used more traditional ceramic processing to fuse oxides together with silicates to create a ceramic body with a ceramic/glass matrix. Today’s “ceramic” pads are more of a composite material with predominately ceramic materials in an organic resin matrix, and they may still include small amounts of metal, such as copper fiber for heat transfer. The ceramic portion can be composed of ceramic powders and fibers for reinforcement, ceramic fillers such as potassium titanate, and ceramic abrasives such as zirconia or alumina.

Ceramic pads are quieter, produce little dust, have less rotor wear and offer superior braking performance. However, they are more expensive and are typically used only in premium vehicles or in extreme operating conditions. Ceramics can also be used in rotors as a composite in a carbon or metallic matrix, or as a surface layer to deliver optimum braking in high-performance cars.

Conclusion

A variety of brake pads is currently produced to cover the broad range of vehicles and other machines that need braking systems. When combined with the fact that most brake pad formulations can contain 10-25 individual material components that cover the five primary functions outlined above, the permutations and combinations of ceramics, metals, organic materials, and chemicals that an engineer must understand and apply is enormous.

To detail all of the possible ceramic materials and their applications in the friction industry would be a very long discussion. In many cases, the true knowledge and understanding lies within the brake pad companies that guard their secret formulations very closely.

Every new material that is introduced to a pad formulation is required to undergo strict testing in the brake pad manufacturer’s lab. Once the initial approval is obtained, a newly engineered brake pad will be subjected to extensive testing on a dynamometer, which simulates every imaginable scenario for a given vehicle and follows a strict set of parameters and performance dictated by automakers and industry specifications.

Fortunately for the safety of the general public, every pad is designed for a specific vehicle, thoroughly tested according to that vehicle’s requirements, and proven to be safe and effective before ever being approved for the automaker. Ceramics are indeed a critical part of this safety and should be appreciated the next time one has to stop suddenly while behind the wheel.

For additional information, contact TAM Ceramics at 4511 Hyde Park Blvd., Niagara Falls, NY 14305; call (716) 278-9403; or visit www.tamceramics.com.

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