Ceramics for Use in Brakes and Clutches

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A further increase in the power density of clutches and brakes is hardly possible using conventional friction materials. Although friction linings on the basis of sintered metals allow higher power densities than organic linings, they have serious disadvantages with regard to comfort, which means that they cannot be used in vehicles. The use of innovative ceramic materials here is promising, as is shown by the following article from the Institute of Machine Design and Automotive Engineering of the University of Karlsruhe.

1 Introduction

Successful development in the field of automotive drive trains requires a multitude of investigations, and in particular calls for a holistic view of the total system, including all subsystems and components. The Institute of Machine Design and Automotive Engineering at Karlsruhe University is carrying out research in the field of drive train engineering [1]. This article presents a system analysis and investigations into dry lining materials for clutches and brakes. Stricter legal requirements regarding the additives used in these materials – for example heavy metals – will promote a massive development of new lining materials in the next few years. As a result, completely new materials are gaining major significance. The potentials of engineering ceramics are investigated in the special research project "SFB 483". The methods, potentials and initial results of using engineering ceramics in clutches are introduced in the following.

2 System Analysis

Brakes and clutches are friction systems that use a speed differential and slip between the friction partners to cancel out the differences in velocity between loaded subsystems. At the same time, mechanical kinetic energy is dissipated. Additionally, clutches need to transmit and dose torque. As an important constraint, clutches and brakes are required to provide a high braking force in an applied state. The comparison between different frictional systems shows that the main structure of all systems consists of four system components, Figure 1. It must be taken into account that the frictional system continually changes due to friction and wear [2].

The main dimensional parameters of a dry clutch are essentially the torque to be transmitted, the engagement time and the thermal load factor of the friction pairing used [3]. In addition, the curve of the frictional coefficient in the active friction contact in the different boundary conditions is of great importance [4]. The friction pairing has to guarantee a sufficient size and constancy of the friction coefficient. A high frictional coefficient (μ > 0.4) is desirable, but this is not achieved by organic clutch linings. The intention is to achieve a frictional coefficient that is as constant as possible, independent of slip speed and frictional temperature. Only this frictional coefficient is able to prevent frictionally induced oscillations that become apparent in the form of clutch grab. Ideally, the frictional coefficient increases slightly with increasing slip speed and speed difference, since the system then has a damping effect, Figure 2, [5, 6]. This behaviour can be described with the aid of the gradient of the frictional coefficient μ', which should be positive.

\[ μ' = \frac{dμ}{dv} \]

A frictional coefficient that decreases too fast (with decreasing speed difference) is not permissible, since effective engagement or braking is otherwise not guaranteed. Demands for increased power density as well as greatly increased demands for more comfort in non-lubricated friction systems – especially in automotive engineering – limit the use of conventional organic friction materials. They permit only a relatively low temperature load and a low maximum contact pressure in order to achieve acceptable wear. Therefore, when it comes to developing new powertrains, the clutch and brake systems have a major influence on the installation space required. Clutches and brakes transform kinetic energy into thermal energy through friction. They can only fulfil their function if the following conditions can be achieved:
- high thermal dissipation to the environment
- high thermal capacity
- high temperature resistance.

Improving the existing systems is synonymous with an improvement in these criteria. Increased thermal dissipation is hardly possible because economically viable measures have already reached their limits. From a thermal point of view, the mounting position of clutches in vehicles is unfavourable. Improvements can only be achieved at high cost, for example by using forced air cooling instead of the convection and radiation cooling that is common today. A noticeably higher thermal capacity of the system is linked with an increase in weight. Achieving a higher thermal capacity while maintaining approximately the same weight is only possible in connection with highly temperature resistant materials. The use of highly temperature resistant materials and material combinations can lead to real progress, and this is where engineering ceramic materials become interesting.

The gradients of temperature in an axial direction cause a thermal deformation in a radial direction in ring-shaped friction partners [9], so-called dishing, screening or potting.

The consequence is edge wear. This means that the actual surface of the lining which makes contact is smaller than the geometrical surface, Figure 3. Production-related parallelity deviations of the friction partners to each other have similar consequences. This can cause additional geometric excitation of powertrain oscillations. The consequences of edge wear have a stronger effect in friction materials with a high mechanical rigidity, because they have less elastic deformation to allow them to make full contact with the surface of the mating part. Therefore, sintered metals are rarely used in a ring shape.
as friction partners but instead as several small segments. For clutches in tractors and trucks, it has long since become common to use several lining segments mounted in a rigid plate or on an elastic base plate. This ensures that the lining adapts to the surface of the brake disk [8]. These design solutions can be transferred to ceramic friction materials with high stiffness.

The system analysis sums up the following relevant design criteria for clutch systems:
- temperature-stable frictional coefficient
- positive gradient of the frictional coefficient dependent on the slip speed
- high frictional coefficient \( > 0.4 \)
- high temperature stability of the whole system
- high adaptability in the working surface pair
- optimised heat dissipation
- excellent dosage or control ability
- long service life due to low overall wear of the frictional partners
- insensitivity towards interfering influences
- low total weight
- high power density to minimise installation space
- tolerant failure behaviour
- speed strength.

3 Experimental Approaches for the Investigation of Friction Systems

The exact processes that occur in the friction layer are still the subject of basic research. In order to optimise the friction system by modifying the relevant parameters, it is useful to gain a better knowledge of the friction process. Vehicle clutches are the subject of intense research at the University of Karlsruhe. One of these projects examines the influence of temperature on friction pairings.

Ageing and deterioration of the linings are in most cases the consequence of temperature effects, especially of short-term temperature peaks (hot spots). The temperature distribution over the surface of the friction material is recorded using a high-speed thermal camera. The camera used is currently the fastest commercially available full image thermal camera. It produces a full image with a size of 256x256 pixels with exposure times as short as 2\( \mu \)s. The camera also has a high focusing quality in enlargements of moving objects. These investigations make it possible to experimentally locate the development of hot spots which until now have only been estimated with calculations based on uncertain assumptions.

In order to gain a direct view onto the friction surface, a sapphire window is set into the grey cast iron disk, Figure 4. The sapphire window maintains the frictional contact. Sapphire is most suitable for thermographic investigations. It is highly temperature stable and scratch resistant as well as being transparent for IR radiation and the visible light spectrum. Moreover, sapphire has approximately the same volume specific heat capacity as steel and a similar heat conductivity. Figure 5 shows the temperature distribution on the organic lining during the slip process at different speeds. The non-homogeneous distribution of temperature is clearly recognisable, and is determined by the system performance and the properties of the compound material.

The experimental knowledge acquired in this way is used to produce the theoretical model of the friction contact. Studies are currently being carried out to describe complex frictional systems using the Finite Element Method.

4 Potentials of the Friction Materials

4.1 Organic Linings

Current vehicle design relies extensively on organic lining materials. These are epoxy resins linked with phenol and melamine resins and butadiene rubber [7]. At higher temperature loads, the frictional coefficient drops because of the fluid decomposition products of organic, resinous adhesives. The use of phenol resins as a binder for inorganic fillers was already known in the 1940s, and had the same thermal disadvantages as we have today [10]. The filler most commonly used in the past, asbestos, has been completely replaced. The temporary operating temperatures of the single resins range at most between 120°C and 180°C [11]. However, clutch and brake linings are able to withstand much higher temperatures for a short time due to the use of inorganic extenders with a high thermal conductivity or a high thermal capacity. Therefore, vehicle clutches are able to withstand 250°C and train brakes with linings with a high degree of hardness can withstand a constant temperature of 500°C and a short-term temperature of 700°C [8], but high wear and environmental pollution caused by the thermal decomposition of the organic binders is inevitable.

The advantages of the organic linings are high shift comfort and the possibility to influence the gradient of the frictional coefficient by means of additives.

4.2 Sintered Metals

Sintered metal linings have been used in brakes and industrial clutches for some decades. Sintered metals are stiffer and harder than organic linings. Therefore, design measures are necessary in order to take account of the high stiffness of the sintered metals. Small frictional elements are individually sprung or fixed onto a resilient base plate to allow the linings to adapt to the surface of the brake disk or the clutch pressure plate, Figure 6 and 7. Sintered metal linings on the basis of copper and above all iron alloys are used for disk and drum brakes and main clutches for heavy trucks. They can withstand high temperatures of over 800°C and have a high frictional coefficient. Depending on the composition of the lining, the frictional coefficient is between 0.4 and 0.7, and falls with rising temperatures [12]. In high-performance systems, such as brakes in high-speed trains, sintered metals with a high ceramic content, so-called cermet frictional materials, are used [13].

Sintered metal / cast iron friction pairings have an unfavourable shift comfort that previously prevented them from being used in the comfort-sensitive area of motor vehicles.

4.3 Carbon Fibre Composite (CFC)

In aircraft design and motor racing, brake disks, brake linings and clutch disks made of carbon fibre composite (CFC) are used [14]. These carbon materials have also been experimentally implemented as brake disks in rail vehicles. [15]. They have an especially small density and are more temperature resistant than organic friction linings. However, their use in mass-produced vehicles is counteracted by:
- a temperature-dependent frictional coefficient that leads to poor cold braking behaviour
- high wear at low temperatures and low application pressure
- the tendency to oxidise above 600°C
- the very high material costs that result from the extremely energy-intensive production.