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FIBER-REINFORCED CERAMIC MATERIALS FOR HIGH DYNAMICAL AND TRIBOLOGICAL LOADED PISTON RODS

MATERIAŁY CERAMICZNE ZBROJONE WŁÓKNAMI NA TŁOCZYSKA PRACUJĄCE W WARUNKACH DUŻEGO OBCIĄŻENIA DYNAMICZNEGO I TRYBOLOGICZNEGO

The profitable application of the fiber-reinforced ceramics with high loaded carbon fiber-textile reinforcement and wear resistant ceramic surface is by means of adjustable material properties or dynamic and tribological loaded component parts in the chassis range. For this, the dimensioned structure, free from leakage and tribological optimized piston rod used in the shock absorber will be acquired. The several variants of the load transmission in component parts will be investigated and the resistance values of searched fiber-reinforcement as well as the measurements taken will be determined, in regards to friction and wear of tribological systems. The aim is to reduce the weight of piston rod and to minimize the friction between the rod the rod seal.

Keywords: **ceramic matrix composites, tribological abrasion, piston rod**

INTRODUCTION

The development of component parts made of fiber--reinforced ceramic materials has already been used in the past, mainly in aeronautics and the military technology field [1, 2]. But with decreasing costs of raw materials and manufacturing process of ceramic matrix composites, the interest of the automobile industry increases. The industry is moving towards a new direction specifically with modified materials. The advantage of this application is the material properties of fiber-reinforced ceramic with sufficient designed carbon fiber textile lamination and wear-resistant, ceramic surface. In coope- ration with BMBF (Bundesministerium für Bildung und Forschung) for a research project, a free from leakage, structure dimensioned and tribological optimized piston rod for use in automobile shock absorber system will be developed. The partners of this cooperation are the ThyssenKrupp Bilstein Suspension GmbH (TKBS), a manufacturer of automobile shock absorbers, and the Institut für Leichtbau und Kunststofftechnik (ILK) of the Technische Universität Dresden. The aim of this research contributes to development of tribological systems for translatory motions during experimental studies. A suffi- cient design structure for dynamic load allows the reduc- tion of the weight of the piston rod and minimization of the friction. That is, a different variant of transmission force in a component part is studied and strength factors of selected fiber-reinforcement are determined. After testing the components, the influence strength cases will be analyzed and introduced. This paper focuses on the investigation of tribological relationship of ceramic surface with a different fiber reinforced structures. The piston rod is integrated in a corresponding shock absorber so that the measurements regarding friction force ratio and wear of the tribological systems will be carried out.

TECHNICAL BASICS OF SHOCK ABSORBERS

While a vehicle moves through unevenness on the road surface and during fast changes in acceleration or deceleration, the states of vibration steadily change. For safety and comfort bases, in the vehicle, a vibration damper will be installed. The automobile shock absorber system, in particular the vibration damper, is located between the transverse control arm or directly on the axle and the frame construction. With it, the aim is to improve driving safety and driving comfort in a contrary

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ratio [3-5]. A stronger damping prevents the amplification of the vehicle as well as the loss of road adhesion during vibrations. However, the soft damping promises higher driving comfort due to reduced acceleration or deceleration effects onto the passengers [4]. The structure of a single-valve damper is shown in Figure 1. In the operating piston beveled boreholes are located, onto which spring washers are secured with an accurately defined camber. During the movement of operating piston the oil flows through the holes and the washers are bent. Depending on different dimensions of washers, the properties of damping may vary.

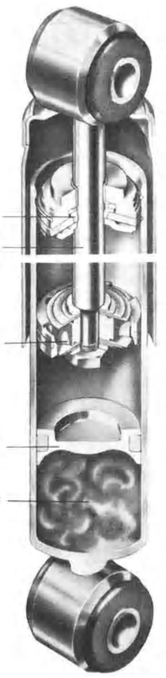

Fig. 1. Assembly of a single valve damper [5]

Rys. 1. Budowa jednozaworowego amortyzatora drgań [5]

PISTON ROD MA… CERAMICS

The ceramic r… fracture behavior a… properties, the ap… parts is limited. Th… trix can be incr… A susceptibility to cracks as well as brittle material behavior is thus smaller than … non-reinforced mo-nolithically ceramic type material. The fi… cement makes … tion of comple… possible. Besid…

nautic field, the fiber-reinforced ceramic materials are also applied in the chemical industry and in vehicle construction for breaks and clutch systems [1, 2].

To be able to infiltrate the ceramic matrix material between specific carbons roving during manufacturing process, the fiber structure should be made of short, long or continuous filament as bidirectional, unidirectional reinforcement or the fiber blanket. According to the state of the infiltration medium, vapor phase and liquid phase infiltration can be distinguished [1]. However, the ceramic, technical matrix structure composition can be reached only during chemical conversion. While manufacturing the piston rod, the polymer infiltration process is applied. At the same time, the carbon fibers with alloy of dissolved polymer in a solvent and ceramic silicon carbide powder (called Schlicker) are impregnated. The shape of a component is obtained during lamination, winding and pressing process. After the drying process the form stabilizes and the solvent volatilizes using a protective gas in pyrolyse process where the ceramic silicone carbide matrix emerges [6].

The piston rod geometry should have a cross section of 8 mm internal and 14 mm external diameter. For the mechanical and tribological analysis the piston has a length of 330 mm. Due to decrease of material density (ρ = 1.8÷2.1 g/cm^3), the weight of a steel piston rod can be reduced by 40÷50%. The tube geometry can be produced by using two different methods. One is to use a winding technology by which the fiber roving in Schlicker's bath is impregnated esp. infiltrated. At the end of the process, the fiber in the winding machine is winded with ±10° in direction axis of the tube, comparable to the manufacturing of symmetrical fiber reinforced composites. The second method is …

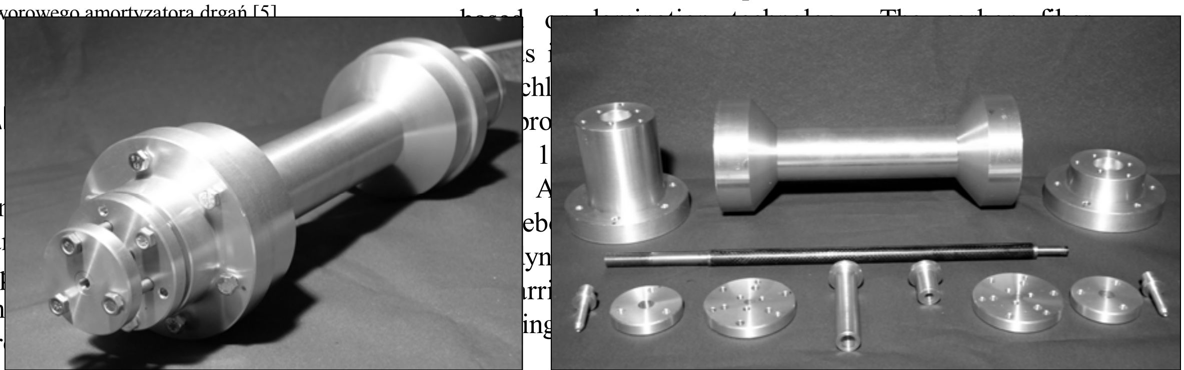

Fig. 3. Infiltration tool for resin transfer molding [7]

Rys. 3. Zestaw do infiltracji żywicą metodą RTM

The relationship between compressive stress and tension

TABLE 1. Preproduction model types [7]

TABELA 1. Typy preform [7]

denomination of	fiber type	fiber structure	weave type	matrix	remark

Rys. 2. Preformy ceramicznego tłoczyska zbrojonego włóknami [7]

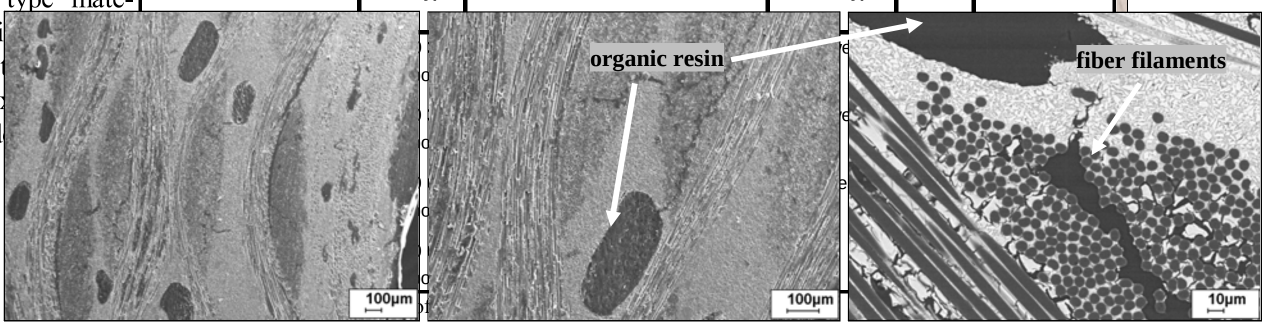

Fig. 4. SEM-pictures of a lateral cut of the fiber reinforced ceramic piston rod which is infiltrated with epoxy resin [7]

Rys. 4. Obrazy skaningowe poprzecznego przecięcia tłoczyska ceramicznego zbrojonego włóknami infiltrowanymi żywicą epoksydową [7] are adjustable on the basis of number and thickness of spring washers. According to the desired damping quality, dynamic damping forces between 3 kN (car production) and 5 kN (sport cars) appear [5], depending on the relative speed between the rod and the damping medium, whereas the compression load is adjusted less than the tensile loading. Further on, transverse forces are acting on various suspension systems, which are not considered in this research. In terms of thermal ratios, the piston rod has to be executed in temperature range from 40 to +120°C, and for short periods of time up to 160°C.

TRIBOLOGICAL TEST OF A FIBRE REINFORCED CERAMIC PISTON ROD

It is important that the ceramic matrix is leak proofed against high oil pressure. Based on the fact that a certain residual porosity is always present, the piston rod is infiltrated with organic resin. At the ILK-Dresden an infiltration tool had been developed. It works in vacuum with 6 mbar at the inner diameter of the tube and epoxy resin is pressed into the material with 20÷30 bars. It allows controlling the pressure of a resin flow over the surface by the entire thickness of tube. This infiltration medium flows and fills the pores micro cracks of SiC material.

The cross section of an unfiltered piston rod has been tested by a scanning electron microscope (SEM) showing good results. In the all areas of a rod cross section is visible that all pores and cracks are filled with resin and are closed (dark areas Fig. 4).

Another synergy effect of an infiltration with organic resin is revealed after beveling the piston rod to its final dimensions. To get a closure of resin and pores, a relatively smooth surface is developed. Such mixed surface structure made of resin and ceramic improves the sealing quality of a damper and the friction ratio of a tribological system. The hardness of a piston rod surface can be proven by a micro hardening device FISCHERSCOPE® H100C, according to DIN EN ISO 14577-1. The pointed body (indentor) a Vicker's diamond with a generating angle of 136°, is to be forced into the material being tested for certain range of measurement with defined measurement points on the surface with a load of 200 mN. The hardness values may be obtained from the relationship between the force and depth of penetration. The results are determined as a measurement line consists of 42 points. Due to grinded surface made of SiC-ceramic, carbon fiber and epoxy resin, the dispersion of hardness values takes place. The following figures (Figs. 5, 6) show the hardness lines of the measurement points. It can be seen that the surface of bidirectional fiber reinforcing rod is changed at hard and soft areas. The soft areas show the presence of resin and the hard areas show the presence of the ceramic material. The large zone of dispersion in between can be explained as the infiltrated resin of fiber bundle.

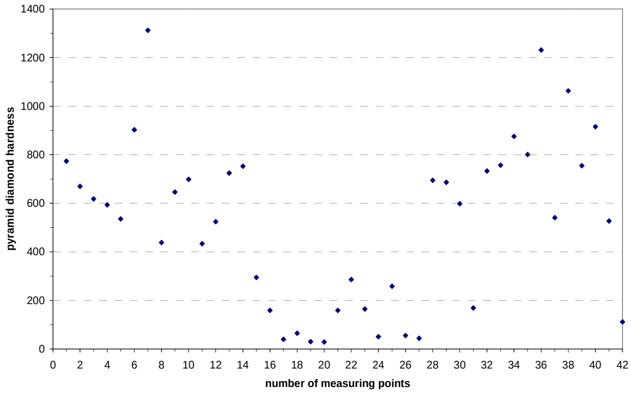

Fig. 5. Measuring line with 200 mN of preproduction model KS-14-T3-50 [7]

Rys. 5. Linia pomiarowa mikrotwardości przy obciążeniu wgłębnika 200 mN dla modelu KS-14-T3-50 [7]

A ratio of the friction from a vibration damper is determining valuation criteria. To determine the friction force, the piston rod is assembled in a test damper system, without spring washers on piston. The entire friction force consists of three individual components: the friction between the piston rod and the guiding device with the rod seal, between the operating piston and the cylinder of the shock absorber as well as the piston which separates expansion space, oil space and the cylinder of the shock absorber. Due to contact pressure, the largest frictional portion occurs between piston rod and rod seal, caused by the leak proofness of the damping system. Because of the complexity of the considered tribological system, it is not possible to directly record the unique fractions. According to experience, the friction part between piston rod and rod seal amounts to ca. 80% [statement TKBS]. Reduction of that fraction promises an intense improvement of friction behavior and increases the comfort effect in vehicles.

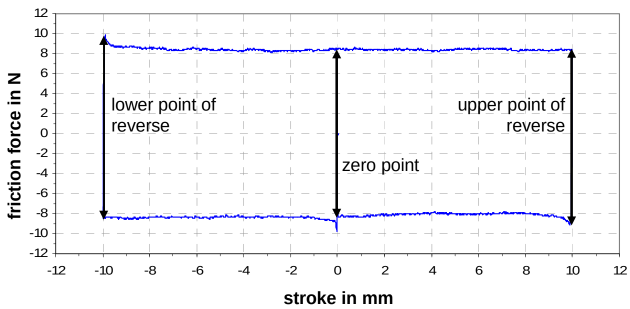

Fig. 6. Hysteresis of friction force versus stroke [7]

Rys. 6. Histereza siły tarcia względem suwu [7]

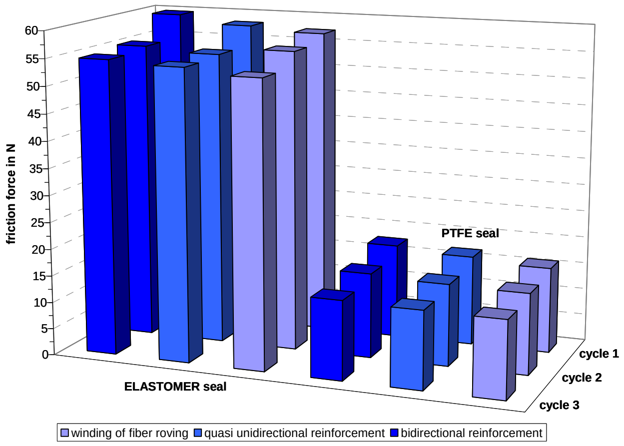

Fig. 7. comparison of the friction forces of the model types [7]

Rys. 7. Porównanie sił tarcia dla różnych modeli [7]

The analysis will be investigated using three different types of piston rods in combination with elastomer seal and PTFE seal, respectively. To be able to test the primary influence of abrasion behavior on the material pairing, three cycles on each type of piston rod are measured. Abrasion effect results from marginal abrasive wear and adjusts the surface between piston rod and rod seal. It accrues by smoothing of surface roughness as well as fractional substantial modification in border areas of surface [8]. The cycles distinguish as follows: The first cycle is recorded after five strokes were run. After further 50 strokes, the second cycle and after an additional 150 strokes the third cycle is measured. Starting from zero position, the piston rod is moved in for 10 mm, after that it is moved out for 20 mm and is moved back to zero position subsequently. For a statistical significance, this procedure is rerun five times. As shown in Figure 6, the maximum of friction forces at zero position as well as the lower and upper point of reverse are considered for evaluation. A summary of values of friction forces at zero position is indicated in Figure 7.

CONCLUSION

Generally, a reduction of friction forces between the first and the third cycle can be observed as a result of abrasion effect. The values measured for quasi-unidirectional reinforced model type and winding model type are similar and smaller than those for the bidirectional reinforced model type, which shows the largest amount of friction forces. By means of the undulation of bidirectional reinforcement, the friction force increases. Furthermore, for the surface roughness the friction and transverse force seem smaller, so that a correlation, in those two criteria, takes place. Moreover, the tests showed that, for the usage of elastomer seal,

a large dependence of friction forces on surface topography exists. Such behaviour can be explained on the basis of different properties of seal materials. During slipping the rigid PTFE sealing ring on micro grooves, the deformed elastomer seal lips subjected to contact pressure in individual slots will be pressed and thus manufactured with a higher friction force.

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Recenzent
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