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The use of ceramic materials for fluid power components

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1. Introduction

The scientific paper "The use of ceramic materials for fluid power components" has the aim to show which developments in the field of ceramics and its application could be of interest for the fluid power industry and which investigations and new information exist for the materials which, if applied, lead to product improvements. The presentation deals with materials, which may not be called new in the community of material researchers; nano particles and nano tubes and materials using nano components are not subject of this article

Material research and –development is of interest for the people who produce products only, if they see a chance to make use of the novelties for their products. The transfer from research to production normally is a time consuming, costly process, which requires a high personal involvement.

2. Parts made of solid ceramics

The situation of research and application of ceramic materials and their use in solid parts is as follows:

Research in ceramic materials and also the development of manufacturing process has generally a high level in Germany and especially in a number of research institutions as for instance the Technical University Hamburg-Harburg (TUHH).

- The application of ceramics for mechanical engineering applications and especially for high loaded parts in mechanical systems is very low.
- A strategy for the development and design of ceramic parts which is tailored to the specific characteristics of ceramic materials is not available for general use, not sufficiently supported is especially:
  - the evaluation of the survival probability of dynamically loaded parts with complex shape and loading;
  - the shape optimization to minimize tensional stresses;
  - the adequate design of combinations of ceramic parts with metal parts.

The situation for the application of ceramics for products in the fields of mechanical engineering is as follows.

- There is a small number of companies which are able to produce ceramic parts for mechanical engineering applications and these companies seem to have low interest to invest in product development together with their customers.
- The communication between people in product development which have typically low knowledge about ceramics and producers of ceramic parts which normally have low knowledge about mechanical engineering is difficult.
- The producers of ceramics normally ask early for high quantities. They have low interest in producing prototypes and test samples.
- Finishing of ceramic parts is very costly due to the necessity of time and money consuming grinding process using diamond tools because of the high shrinking rate of conventional ceramic materials.

Table 1 gives information about ceramic materials, which were subject of the research and development activities described in this paper.

Table 1

Material data of ceramic materials used in the research project

Material	SiSiC	SSN	ZrO_2-TZP	Al_2O_3 99,7%	RBAO	s-3A
Elasticity modulus, GPa	380	300	210	330	380	330
Poisson ratio	0.2	0.2	0.20	0.2	0.2	0.25
Density, g/cm³	3.1	3.2	6.0	3.9	4.2	4.9
Weibull modulus, MPa	>10	>20	>10	>6	9	-
Bending strength, MPa	360	650	800	350	550-800	550
Thermal expansion coefficient, 10^3 N/mm²	4.0 e-6	3.5 e-6	11.0 e-6	7.8 e-6	7 e-6	7 e-6
Hardness, HV	20	15	12	20	20	12.6

The targets of research- and development projects about which information is given in this session are:

- generation of a methodology and operating advice in product development how to handle ceramic materials
- demonstration of the capability of ceramics for the applications, in which the parts are heavily loaded.
- qualification of ceramic materials for special applications, especially for applications in fluid power.
- evaluation of the potential to reduce manufacturing costs by the use of new materials (like RBAO) and of new processes, for instance laser sintering.
- investigation of the potential to improve product performance through the use of ceramics as a material for parts of the product.

Urban [1], member of the company Walter Voss Fluidtechnik GmbH, Sprockhövel, reports about the development of a high pressure-proportional-poppet-seat-valve with a ceramic spool/poppet. The valve of nominal size 6 controls a flow of 20 l/min at pressures of 320 bar and the requirement is 2 Mio circles under the condition of pure water as a medium. The development was a part of research project which was a cooperation between a number of companies of the fluid power industry with a number of institutes of the Technical University of Hamburg-Harburg financed by the ministry of education and research and the Forschungsfonds Fluidtechnik of VDMA. Fig. 1 shows the valve with solenoids and amplifying lever, bushing with O-rings, seat in the bushing and piston with sealing poppet (named valve poppet in the following text) and centering spring.

The project target of was to demonstrate that solid ceramic parts from conventional and from new ceramic materials fulfil the requirements of the valve and lead to an improvement of the products performance especially in water hydraulic high pressure applications. Specimen made from conventional ceramic materials using the approved processes were tested to gain experience with ceramic parts in the application and to collect reference data before parts from newly developed materials RBAO and s-3A were made and tested.

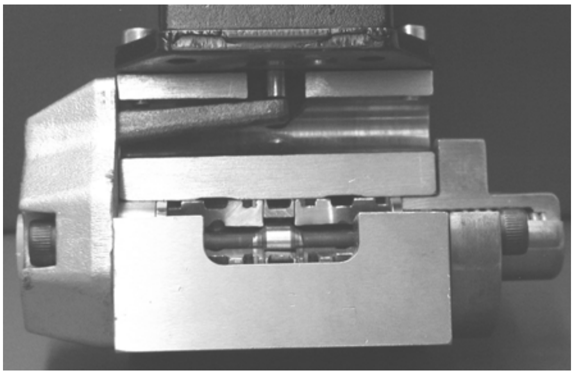

Fig. 1 Cross section of the poppet seat valve of company Walter Voss [1]

The authors Bartelt, Scheunemann und Feldmann [2] of the Institute of Mechanical Engineering design report about the methods for the qualification of ceramics as a material for fluid power components. The assessment of strength, lifetime and reliability of high stressed ceramic components cannot be based on the methods typically used for metals. Reasons are brittleness and crack growth behaviour which are characteristic for ceramic materials. In contrast to ductile materials stress concentrations in ceramics caused by microstructural defects (cracks, pores) cannot be relieved by plastic deformation. This leads to a scattering of the inert component strength depending on the size, shape and location of the cracks. Furthermore crack propagation under tensile stress appears, which leads to a time dependency of the component strength. Thus, instead of typical deterministic methods which are used for the design of metal components, statistical approaches have to be chosen for ceramics, which give information about the reliability response failure probability of the component. For the prediction of the component strength and lifetime, material data is to be determined in tests with conditions close to the later application; this is achieved by a good conformity to the application regarding material, manufacturing process, surface topology, medium (e.g. hydraulic fluid) and stress distribution.

To design the experimental procedure and experimental contents it is necessary to get to know the stresses as a function of time of highly charged components. These are components of fluid-power engines and they are to be investigated under typical operation conditions as they are used as a basis for the testing conditions. Thereby the exact values are of less importance compared with qualitative characteristics, e. g. the ratio of multiaxiality or spatial distribution and orientation of principle stresses. Parts of interest are: piston, bushing and slipper of radial and axial piston units. As an example with highly distinctive stresses of non-proportional character a piston of an axial piston unit is chosen.

Material testing under proportional stress conditions supplies, despite all open questions regarding non-proportional stresses, a number specific for ceramics data which are essential for the calculation of life expectancy. The basic idea for a near-application testing is to use ring-shaped specimens under internal pressure (Fig. 2). In corresponding hydraulic test rigs typical environmental conditions of hydrostatic machines (fluid, pressure and temperature) are given. The specimens' shape in combination with hydrostatic load induction allows one to use inner and outer surfaces in "as-fired"-conditions. In contrast the load induction by solid objects (balls or cylinders) is problematic when applied to the surfaces with low tolerance requirements. Local peaks of contact stresses can occur in such cases. On the other hand, when using soft objects additional tensile stresses can occur due to dilatation.

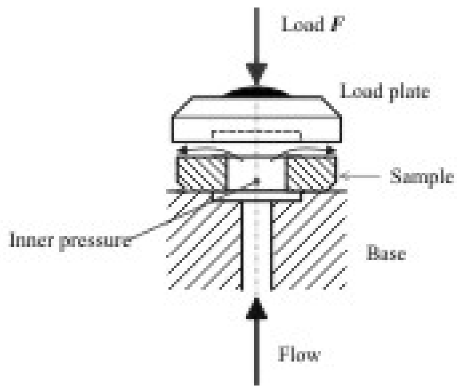

Fig. 2 Principle of internal pressure testing with pressure controlled by force *F* [2]

Randomly distributed, sized and oriented imperfections in ceramic components like cracks, pores, inclusions etc. in combination with the brittle material behaviour lead to material dependent scattering of the component strength (Fig. 3). In case of known crack growth parameters and knowing the most critical imperfection it should be possible to calculate the lifetime of the component. Premises for the lifetime calculation, e.g. the knowledge of the type and distribution of the cracks in the component, are not state of the art so that another method has to be found for a reliable prediction of the component life. One possible approach is the application of a proof-test which is described in the paper [3] in detail.

The use of solid ceramic parts in axial piston machines is the subject of Donders, Kane und Seifert [3] of

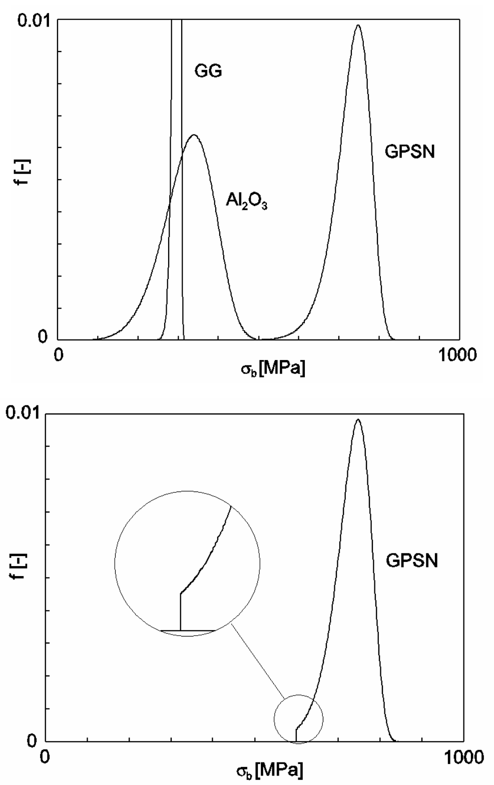

Fig. 3 Distribution densities of bending strength of a component made of GPSN, Al2O3 and GG (above), distribution density for GPSN after proof-test at 600 MPa (below) [2]

Bosch Rexroth AG. Questions of environmental acceptance lead to new legal regulations as for instance the EU-regulation for cars going to scrap (EU-Altautoverordnung) and other regulation to protect the environment. It can be seen that for the long range the substitution of lead containing brass and bronze alloys will be necessary, materials which today are used because of their tribological performance with steel as a partner in pumps and valves in the fluid power industry. This was the background for evaluations and ideas to investigate the possibility of an alternative material like ceramic in fluid power components.

The materials for components in hydraulic machines have to fulfil the following requirements:

- the materials must be resistant against aging and corrosion;
- alternative materials must not interfere with the function of the machine and there must not be an elevated wear due to mechanical contamination of the hydraulic media;
- the materials are not allowed to have negative impact on humans and on the environment;
- processing of the materials must be unproblematic and the materials and manufacturing of parts from these materials must be of low cost.

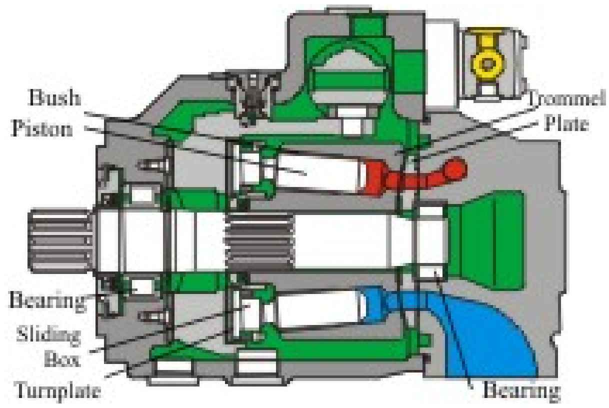

Fig. 4 Investigated A4V axial piston machine with the typical wear areas [1]

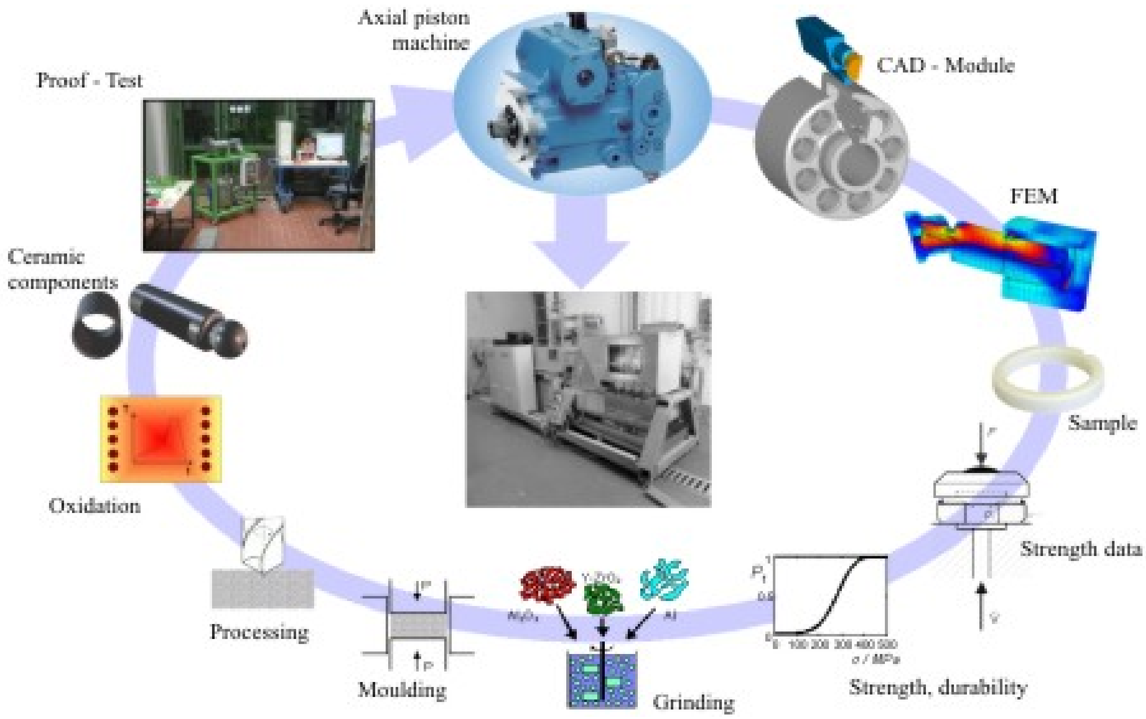

Fig. 5 Development process for a piston-bushing assembly

Fig. 4 shows the areas of wear in an axial piston machine where ceramic materials may be applied. Schöpke [4] has tested with success the tribo-system-valve-plate and bearing-plate using silicon nitride as material (comparable to Trommel-Steuerspiegel in Fig. 4). The presentation in this session deals with the result of investigations about the ceramic piston and ceramic bushing assembly in an axial piston pump of type A4 VSO 40. Fig. 5 describes the steps of the development process for the piston-bushing assembly.

A rotating group equipped with silicon nitride pistons and zirconia bushings was tested for 400 hours under varying loads (pressures up to 320 bar, speeds up to 2000 rpm). After this a visual control showed no wear on pistons and bushings. The total efficiency of the machine was slightly lower compared to the standard machine, but can be improved, because in the present case the gap width between ceramic piston and bushing was large and can be reduced, thus improving the volumetric efficiently. A second rotating group with the same material combination was tested for more than 100 hours up to now, confirming the results of the first test.

3. Ceramic metal components

Thin coating out of ceramic materials are the subject of the scientific paper of Scharf und Murrenhoff [5] from Institute for Fluid Power Drives and Controls (IFAS) in their presentation PVD coatings for tribological systems in hydrostatic displacement units.

The use of fluids based on native resources which are biologically degradable leads to the increasing wear and friction, because additives, which are highly toxic in the most cases, have to be avoided. But they provide the system with important functions like reduction of friction and wear. So these tribological functions have to be transferred to the solid parts of hydrostatic units. A very useful way is the coating of tribological contact surfaces with ZrC.

The choice of PVD coating process is based on the fact, that low temperature of the process does not effect a change of the structure of substrate material. The PVD process allows to realize material films of only a few µm. This means that a well prepared substrate surface is mapped identical. Coated surfaces like this are quite easy to handle in tribological systems with high surface qualities and very narrow gap heights (between 5 µm and 10 µm).

To reduce the friction with the coating, carbon, which is a solid lubricating element, is chosen to be part of it. The successful experiments, which will be mentioned later on, with ZrC approve this theory.

To get an idea of the critical points of coated parts in hydrostatic displacement units experiments on a pump test bench are carried out. With a light additivated ester a standard pump with brass/steel combination in tribological contacts has been tested as well as pumps, where pistons and valveplate were coated and the counterbodies consisted of 42CrMo4 heat treated steel.

The standard reference pump shows heavy traces of friction and wear after the addition of particle contamination to the fluid. Especially the cylinder block and the valveplate lost a lot of material in the contact zone. On the uncoated piston a characteristic wear structure is visible, while the coated piston shows nearly not any wear (Fig. 6).

On the piston the coating still shows some points of weakness. In the areas of high pressure, which is at both ends of the piston, the coating shows typical forms of abrasion.

The experiments underline high potential of PVD coatings for tribological contacts in displacement units. But it reveals weak points of the ZrC coating on the piston, which is, concerning the calculation and the prediction of the load, the most complex tribological system within the displacement unit.

Rühlicke [6] shows in his scientific paper, which of the today available and used coatings for piston rods is best for different applications of hydraulic cylinders. For galvanic coatings, welded coatings, thermal application and plastic coatings he describes the process, the materials which are used and typical applications. He points out, that metal-oxide coatings are standard for piston rods of hydraulic cylinders.

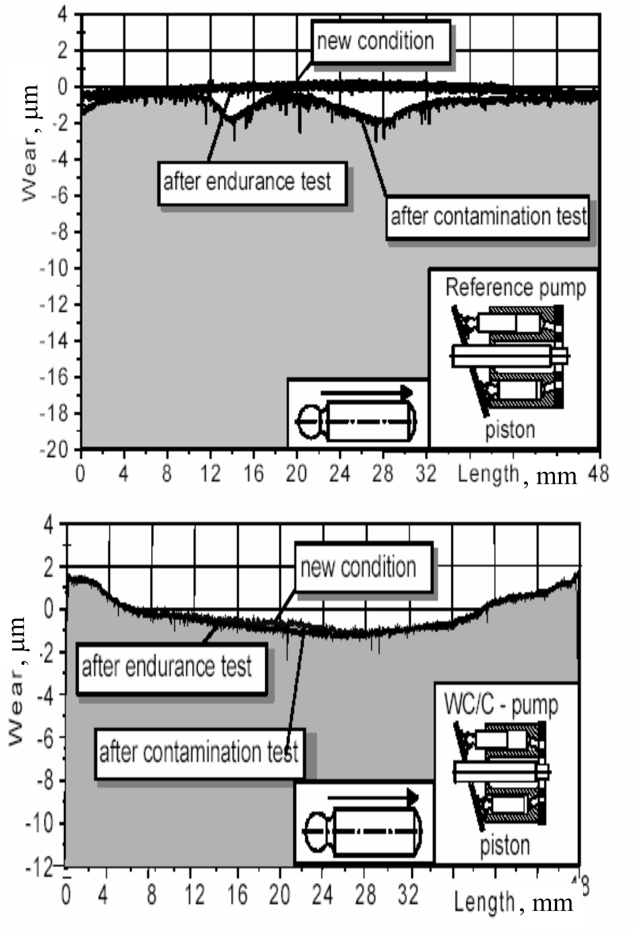

Fig. 6 Wear on an uncoated piston (above) and on the coated piston (below) [5]

4. Conclusion

The selection of appropriate material for certain application and the application of the material in accordance with its properties is important for successful products in fluid power. The scientific paper shows that there is a potential for future developments by the use of ceramic materials which are already known and used in non-fluid power applications and by improvements in design and processing of already known and typically used materials.

The paper also shows that development and research is necessary to achieve progress in the field of materials for fluid power applications and that projects of cooperation between industry and research institutions can significantly support and speed up developments. Projects of this kind show that material specialists must work close with designers and people in manufacturing; this is the only way to come to successful product.

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KERAMINIŲ MEDŽIAGŲ PANAUDOJIMAS HIDRAULINIŲ MAŠINŲ KOMPONENTAMS

R e z i u m ė

Straipsnyje apžvelgiama Hamburgo-Harburgo Technikos universiteto veikla, tiriant keraminių (tradicinių ir naujai sukurtų) medžiagų stiprį bei projektuojant mechaniškai apkrautas hidraulinių mašinų detales pradedant nuo detalių apkrovų ir įtempimų ir baigiant metalo parinkimu, detalės dizainu, ilgaamžiškumo skaičiavimais, detalės gamyba ir jos patikrinimu realiose mašinose esant tipinėms apkrovoms. Daugiau dėmesio skiriama konstravimo klausimams.

D. G. Feldmann

THE USE OF CERAMIC MATERIALS FOR FLUID POWER COMPONENTS

S u m m a r y

The paper presented gives an insight in the activities at Technische Universität Hamburg – Harburg dealing with basic research about strength of ceramic materials (conventional and newly developed types of ceramics) and the development of mechanically loaded parts for fluid power machinery from the investigation of loads and stresses on the part to material selection, part design, life calculation, part manufacturing and testing of real machines under typical load conditions. A focus is set to the questions of interest for the designer.

Д. Г. Фелдман

ИСПОЛЬЗОВАНИЕ КЕРАМИЧЕСКИХ МАТЕРИАЛОВ ДЛЯ ДЕТАЛЕЙ ГИДРАВЛИЧЕСКИХ МАШИН

Р е з ю м е

В данной работе дается представление об исследовательской деятельности ученых в Техническом университете Гамбурга-Гамбурга при изучении прочности керамических материалов и проектируя механически нагруженные детали гидромашин начиная с нагрузок и напряжений до подборки металла, дизайна, подсчета долговечности, изготовления детали и проверки в реальных условиях при типичных нагрузках. Большее внимание уделено вопросам конструирования.

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