Tribologically-optimized sliding bearings of sintered silicon carbide

In many applications, the materials used in modern high-performance pumps are subject to increasingly critical demands. This is particularly the case when pumping corrosive and/or abrasive fluids, where high-speed parts such as axial and radial bearings or mechanical seals are at high risk from mechanical loads and chemical attack. In this paper ESK look at how life-time maximization can be ensured even under difficult and continuous operating conditions for relatively long periods of one-to-two years. This whilst handling aggressive chemicals at high temperatures and pressures.

Fig. 1. Thermal oil pump with sliding bearings in EKasic® C Silicon Carbide.

General Properties Of Sintered Silicon Carbide

The outstanding wear and corrosion resistance of sintered silicon carbide (SSiC) and its unique thermal and mechanical properties give it a range of advantages over other widely used materials, such as silicon-infiltrated silicon carbide (SiSiC), aluminum oxide, zirconium oxide, graphite or hard metal [1]. In order to achieve optimum running of high-speed bearing systems, bearing clearances, for example, are often of the order of hundredths of a millimeter. If this precision fit is widened as result of continual wear of the material by solids contained in the pumped fluid, the imbalance can rapidly lead to system failure. This damage mechanism can often be seen in parts made of relatively soft graphite. In just the same way, weakening of the material by chemical micro-corrosion increases its risk of failure and reduces the reliable operation required by strict modern legislation. In this aspect, too, the properties of SSiC are vastly superior to those of other high-performance ceramics. Hard metal has the serious disadvantage that, apart from its high specific weight, it can be costly since prices of raw materials have increased enormously in recent years. In summary then, the special physical and tribological properties of SSiC allow it to be used in a wide range of application conditions. This allows pump manufacturers to offer their end-customers a universal material solution for bearing and seal systems that can resist almost any process fluids, under even the most difficult operating conditions. The pumps can be used more flexibly and do not need to be adapted to different application areas at the material selection stage. The use of uniform SSiC components thus offers manufacturers cost savings during development, since there is no need to test different materials and design the parts accordingly. Moreover, the purchasing and manufacturing process for standard models is simplified. Optimization of the batch sizes in this way can offset the often higher manufacturing costs for SSiC parts compared to aluminum oxide or graphite components, and thus offers a solution that is not only technically superior but also cost effective.

EKasic® Materials Range

The properties of SSiC can be adjusted for use in different parts or applications. As mentioned above, standard SSiC materials have a range of advantages over other high-performance ceramics. Furthermore, the SSiC microstructure can be selectively modified to achieve further improvements in the material.

ESK Ceramics has therefore developed a range of SSiC materials for use in new, extremely challenging fields of application.

Some of these materials have been specially optimized for use in pump manufacturing. They include EKasic® G silicon carbide, a material characterized by outstanding load capacity to withstand even extreme pressures and shearing forces. EKasic® G has graphite particles with sizes from 20–50 µm homogeneously dispersed in its microstructure. This reduces the coefficient of friction considerably and improves the wear behavior under extreme mixed lubrication. The self-lubricating effect of the graphite particles permits temporary dry running. The coarse-grained microstructure durably prevents hot-water corrosion. The material is thus ideal for tribological applications with extreme mixed lubrication, for example in sliding bearings and mechanical seals.

EKasic® C, another material, also holds a number of advantages. It is highly corrosion resistant and even resists attack by

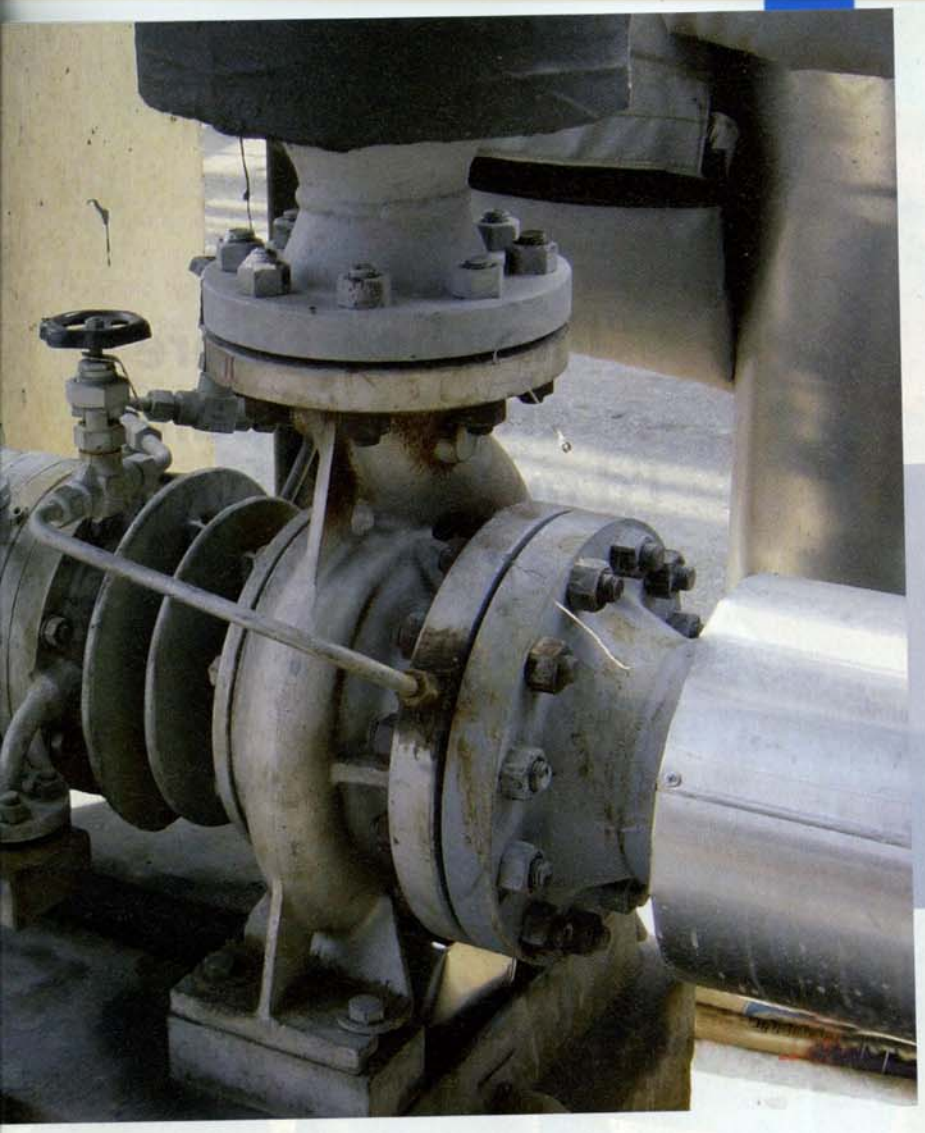

Fig. 2. Axial bearing of EKasic® G with lubrication grooves and hydrodynamically active structuring.

Fig. 3. Overloaded axial bearing of standard SSiC.

hot water. The material has a high-load capacity, allowing the contact pressure to be increased in tribologically loaded systems and guaranteeing optimum quiet running. With its very good wear behavior, as well, it can considerably extend the application ranges of pumps and seal systems.

Moreover, selective modification of the surface of its silicon carbide sliding bearings significantly improves the hydrodynamics of the lubricating fluid. The surface is laser structured to introduce micrometer-sized slots. This provides hydrodynamic support of the liquid film and a high degree of homogeneity in the fluid distribution. This effect can be used to further increase the load capacity of the system. This additional benefit of micro-structuring is not only useful in sliding bearings. Mechanical seals and rotary feedthroughs can also profit lastingly from the phenomenon.

Improving Existing Systems

Applications in gas and oil extraction

With its high-performance EKasic® materials portfolio, in combination with newly developed innovative structuring and coating technologies, the applications engineers of ESK Ceramics have been able to significantly improve existing bearing and seal systems. This is necessary because of continually increasing demands on modern pump systems, which result from strict environmental regulations and ever tougher operating conditions. For example, new gas and oil reserves must be tapped at ever greater depths with higher temperatures and pressures. Pumping out highly abrasive and corrosive oil sludge mixtures from the borehole requires a resistant, high-performance pump with carefully designed bearings and seals made of tailored materials.

After it was found that harsh stresses were severely reducing the lifetimes of borehole pumps equipped with conventional SSiC systems, and consequently the operating costs of the complete boring rig had increased significantly, a pump manufacturer together with ESK decided to develop a new bearing system of EKasic® C. It was not only possible to exploit the corrosion resistance of this material and its resistance to wear by the solid particles in the oil sludge, but the optimized, ceramic-oriented design of the parts considerably improved performance, with lifetimes increased by orders of magnitude.

EKasic® components for cargo pumps

A similar task faced a manufacturer of magnetically coupled cargo pumps for loading and unloading, and cleaning out tanker ships. Beside the necessity for pumping a large number of different fluids with variable viscosities and solids contents as fast as possible, the possibility of incorrect operation had to also be taken into account in this application. For example, the pump may be started up without opening the shut-off valves or the system may be shutdown too late after the tanks are empty, leading to an interruption of the fluid flow and dry running of the process fluid-lubricated bearings. Such operating conditions inevitably meant that the critical loading limits of the SSiC axial bearings used were regularly exceeded (see Fig. 3).

The downtimes that this cause are unacceptable in view of the high berthing fees and tight deadlines that are now usual. A possibility therefore had to be quickly found to greatly increase the critical load capacity of the axial bearings so as to minimize pump downtimes. ESK was able to exploit its EKasic® G SSiC-material for this purpose. Besides its extreme load capacity, it also has improved dry running and mixed lubrication properties (see Fig. 4). As a special material for use in systems with high tribological loads, EKasic® G has already proved valuable in many sliding and frictional systems. In the case of the cargo pump, too, the loading limit could also be shifted well above the critical value. Another increase in load capacity of the axial bearings was produced by the laser-induced application of hydrodynamically active fine structures on the sliding surface of the axial bearing (see Fig. 2).

Such optimization of the liquid behavior in the sliding gap leads to improved lubrication, even when there is insufficient process fluid present. The homogeneous lubrication film that is produced acts as a spring buffer, helping to intercept axial thrust peaks in the bearing system. Overall, the changes introduced both to the design and the material used have increased the critical loading limit by more than tenfold.

Developments & Tomorrow's Products

With its 30 years' experience with SSiC in the field of seals and bearing technology, ESK has access to a variety of design solutions for use in a range of applications and fields of use. They not only take the form of the unique and varied pallet of EKasic® materials. Experienced applications consultants can recommend the optimum material combination according to the operating conditions and loading case. As early as the design phase, they provide support for ceramic-oriented part design and advise on cost-relevant factors, such as geometry, tolerance, surface quality and batch-size effects. The range of services for developing custom solutions also includes surface structuring and coating techniques to enhance components for use in critical application fields. Furthermore, ESK performs material and failure analyses in its own laboratory and carries out tribological tests to investigate the sliding and frictional behavior of the materials. Besides 3D design, the engineers make regular use of finite element analysis (FEA) where necessary to carry out mechanical and thermal peak-load studies and design optimization.

Other solutions are in development or being prepared for launch. At the company, this currently includes the widening of the materials portfolio with new, complementary grades, and continual improvement of material properties. It goes without saying that the price/performance ratio is continually being increased as a result of ongoing process optimization measures. ●

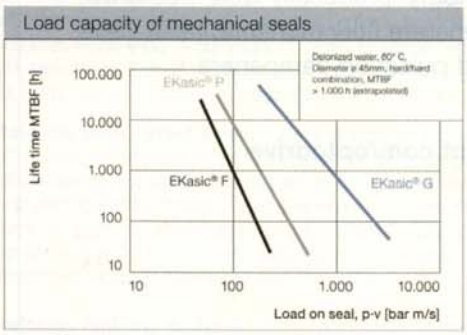

Fig. 4. Load capacity of different EKasic® materials.

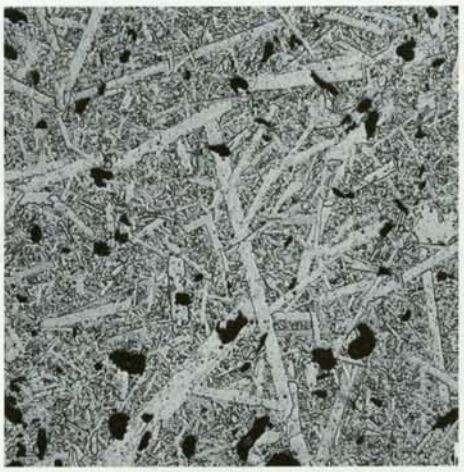

Fig. 5. Microstructure of EKasic® G with graphite inclusions to improve dry running characteristics.

References

[1] Woydt, Mathias: Tribologie keramischer Werkstoffe (Grundlagen – Werkstoffneuentwicklungen – Industrielle Anwendungsbeispiele); in co-operation with 12 co-authors (e.g. Michael Fundus, Josef Kracker), 2001, Expert Verlag, ISBN 3-8169-1744-5.

About the company

ESK, a subsidiary company of Ceradyne, Inc. is a worldwide acting company specialized in the production of products made from ceramic materials. It is experienced and innovative in the fields of advanced ceramics, ceramic powders, boron compounds and frictional coatings, and "produces new technology solutions for challenging applications". The company manufactures customer-specific products according to internationally certified standards at its two plants in Kempten (Germany) and Bazet (France). It's quality and cost-optimized production processes are enhanced through modern methods of management (innovation, productivity and knowledge management). The company develops, manufacturers and markets advanced technical ceramic products and components for defense, industrial, automotive/diesel and commercial applications.

Products, materials, industries

Ceramic products

Seals and bearings, nozzles, evaporation boats, side-dams, riser tubes, thermocouple sheaths, heating tubes, break rings, electrical insulators, ceramic powders and suspensions, abrasives, pellets, plates, microreactors, heat exchangers, friction shims.

Materials

Boron carbide, boron nitride, calcium hexaboride, silicon carbide, silicone nitride, titanium diboride, zirconium diboride.

Functional coatings

Based on an electroless nickel layer in which hard particles of defined size and concentration are embedded. Depending on the function of the coating, the particles are diamond, silicon carbide or others.