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A new strength test for ceramic cylinders—The Notched Roller Test

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Abstract

A new tensile strength test for ceramic rollers (cylinders) is presented, following the idea of the previously published and since that time standardized notched ball test. The specimen is prepared by cutting a long narrow notch along the symmetry plane of the roller, perpendicular to the end faces. By applying compressive forces perpendicular to the notch, tensile stresses are induced in the outer surface region of the roller opposite to the notch, mainly pointing in tangential direction with respect to the roller axis. The stress amplitude is proportional to the applied force and depends also on the test geometry and the Poisson' ratio, which has been analyzed carefully with FE methods.

Strength tests have been performed on two different qualities of commercial silicon nitride rollers of 10 mm diameter and length. According to their specification a significant difference in the strength has been obtained.

Keywords: Strength testing; Mechanical characterization; Structural ceramics; Hybrid bearings; Notched Roller Test

1. Introduction

There is a growing demand for cylindrical roller bearings with ceramic rolling elements in different application areas. One reason for the growth of ceramic rollers in rolling bearings can be found in the superior material properties compared to bearing steel like low mass, electrical insulation, high hardness, good refractory properties and corrosion resistance. The main material used for hybrid rolling bearings (ISO 5539 Amd1[1]), which has been established for balls already in international standardization is silicon nitride (ISO 26602[2]). Another reason for growing business for ceramic cylindrical roller bearings (CRB, Fig. 1a) is that many bearing systems on a shaft use a ball bearing (as a locating bearing) in combination with a CRB (non-locating bearing, Fig. 1b). The situation on the market is that ceramic ball bearings are already used more often than roller bearings. In fact, more complex machining steps are needed to manufacture a ceramic roller compared to a ceramic ball; therefore, the resulting costs are higher for such a roller.

One application example is hybrid cylindrical roller bearings in gearboxes for Formula 1 cars (Fig. 1b), where low mass due to high speeds produces lower inertia forces. Besides that the high hardness gives better performance under probably particle contaminated lubrication conditions in the gearbox after some time in service. Further high speed applications for ceramic cylindrical rollers are micro turbines for aerospace, where also low mass and the demanding lubrication situation are limiting performance factors. The high speed capabilities of ceramic rollers and balls are further used in machine tool spindle bearings. In these applications the higher Young's modulus of ceramics allows the realization of a stiffer bearing system, which leads to higher accuracy of the machine. Also grease life is increased in machine tool spindle bearings due to the hybrid contact.

Another application field for hybrid cylindrical roller bearings is traction motors (see Fig. 1c) for railway applications like trams. In traction motors ceramic roller bearings are used beside ceramic ball bearings for electrical insulation against bearing currents. In addition to this the grease life is improved significantly compared to cylindrical rollers made of bearing steel.

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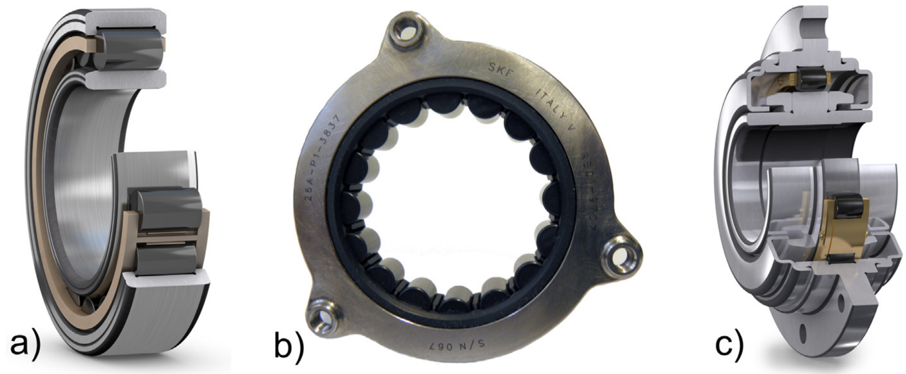

Fig. 1. (a) SKF hybrid cylindrical roller bearing (CRB), (b) SKF hybrid cylindrical roller bearing used in Formula 1 gearboxes (on shaft system), (c) SKF hybrid traction motor bearing unit (TMBU).

An application where the corrosion resistance of ceramics is playing a dominant role is cylindrical roller bearings for sour gas compressors, where also hybrid bearings are used. In such compressors natural gas consisting of corrosive impurities is to be pumped. Under such environment normal bearing steel is failing very early due to hydrogen stress cracking. A working solution is to use a special stainless steel in combination with ceramic rollers and balls.

The use of ceramic components and their influence on bearing life in comparison to steel rollers is not straight forward and mainly determined by the strength and the brittle failure behaviour of ceramics.

In rolling contact especially the surface of the rollers is highly stressed and near-surface defects can lead to failure of the entire bearing system. These defects – such as scratches, cracks or other contact damage – are mainly produced by the manufacturing process (e.g. grinding and polishing). Additionally pressing defects or other pre-damage may not completely be removed by the grinding process.

Since strength is sensitive to these defects, it is necessary to test the strength directly with a sample of original components, and not specially worked out specimens (such as bending bars). The strength of the surfaces may identify contact damaging introduced during transport or handling and can also be used to distinguish between different grinding processes.

For surface testing, the original surface of the component must not be influenced by the sample preparation. Amongst others this condition is achieved in a special strength test for ceramic balls – the so-called Notched Ball Test[3–5] (NBT) – which was also recently standardized.[6]

The same principle can be applied to cylindrical components: the Notched Roller Test (NRT) that is presented in this work.

2. The Notched Roller Test

2.1. General aspects

A long and narrow notch with a depth of about 80% of the roller diameter is cut symmetrically along the mid-plane of the roller, perpendicular to the end faces. The roller is squeezed together diametrically and perpendicular to the notch. The testing configuration is shown in Fig. 2. Tensile stresses, which are used to determine strength, occur in the surface region opposite the notch root. Fracture starts from defects which exist in this region. It is important to note, that in this area the notched roller still has its original surface, whereas defects in the notch root originating from the notch preparation are under compression and, therefore, not relevant for failure.

Furthermore the tensile stressed region is far from the areas in the roller, where the load is applied. Therefore the details of the load application, e.g. some plastic deformation of the jig and exact contact conditions have negligible influence on the stress field in the ligament.

2.2. Modelling

To interpret failure force in terms of strength a corresponding relationship has to be defined. Due to the relatively complicated test configuration the analysis of the stress states in notched rollers having different notch geometries has been performed numerically by using the commercial finite element program package ANSYS classic, version 13. A quarter-model is built up parametrically by programming an input code with the programming language APDL (APDL: Ansys Parametric Design Language). The mesh of the modelled roller is defined fully by hexahedral-shaped elements (i.e. SOLID186, cf. Fig. 3).

Fig. 2. Typical test setup in the Notched Roller Test. The roller is squeezed diametrically – the loading direction is perpendicular to the notch plane.