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Fracture mechanics description of the defect in rolling cylinder

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Bearing elements (e.g. cylinders) made of polymer materials are very common in a wide variety of engineering applications. These elements are typically made of semi-crystalline thermoplastics like polyamide (PA), polyoxymethylene (POM) or polyetheretherketone (PEEK). It is typical for these thermoplastics to shrink significantly when cooling down [2] and develop internal stresses after solidifying from the melt. A widely used manufacturing process for this type of parts is injection moulding. The injection moulding offers high production rate while maintaining low production cost. However, shrinkage defects occur frequently in the injection moulding production of bearing elements. Although the manufacturers put effort into removing these defects by the so-called holding pressure applied after filling the cavity however, inside defects keep appearing. This contribution deals with a case of a bearing cylinder with a crack that initiated from a shrinkage defect. The conditions of the crack growth are assessed, simulation is carried out and fracture mechanics parameters are calculated in order to calculate lifetime predictions for these elements later on.

The component in question is a rolling cylinder compressed between two planes. A crack is considered in the middle of the cylinder. When the element is rolling, the orientation of the crack to the load direction changes gradually. Pure mode I (crack opening) in compression loaded cracked cylinder only occurs when the plane of a 2-dimensional crack and the load are aligned [1] (rolling angle 0°, see Fig. 1 on the left). During the rotation the situation changes from pure mode I to distinct mixed-mode conditions (all three modes are present at rolling angle 45°, see Fig. 1 on the right). Thus, the contribution of mode II and mode III cannot be neglected in this case. However, mixed mode conditions in bulk polymeric components are usually ignored. Hence, little information about the material characterization under shear crack opening (mode II and mode III) is available.

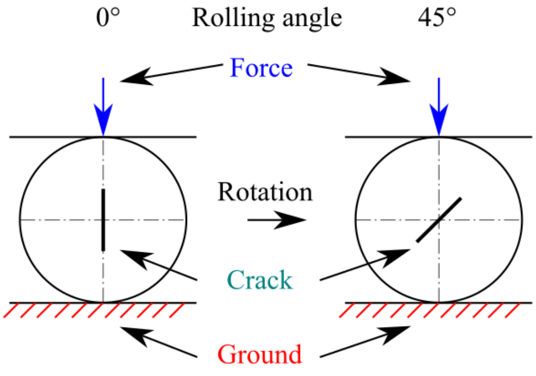


Fig. 1. Schematic illustration of rotation of cylinder and boundary conditions

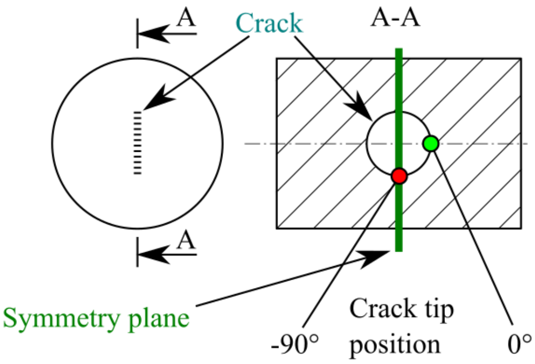
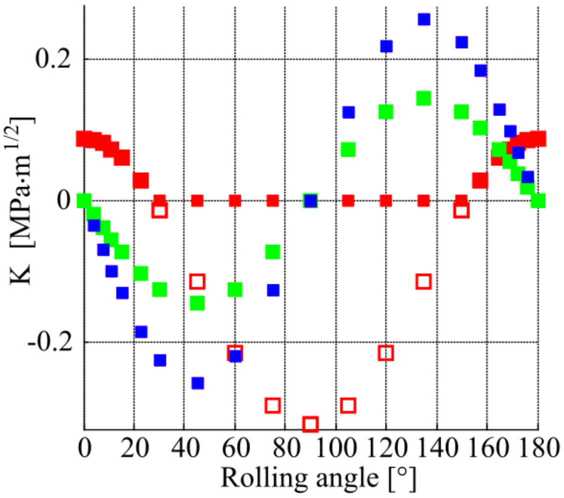


Fig. 2. Schematic illustration of cross-section of cylinder with internal central crack



	Stress intensity factor	Crack tip position
□	K_I	0°, -90°
🟥	K_I	0°, -90°
🟦	K_{II}	-90°
🟩	K_{III}	0°

Fig. 3. Stress intensity factor for two different positions at crack tip, crack length 0.25mm, force 350N

Parametrical finite element model was developed in order to simulate different combinations of crack lengths, rolling angles, dimensions of cylinder and forces. ANSYS software was used, taking advantage of APDL and its capability of programming macros. Model was created with one possible symmetry plane (showed in Fig. 2) to reduce number of elements as well as computing time. Nevertheless, the whole model contains about from 40000 up to 325000 elements, depending on crack length.

The model consisted of three solid parts all represented by linear elastic isotropic material –two steel plates (Young’s modulus of 210 GPa and Poisson’s ratio of 0.3) and a cylinder between them with a flat crack (Young’s modulus of 3.6 GPa and Poisson’s ratio of 0.45). Dimensions of simulated cylinder are 6 mm for both diameter and length. The crack length was considered 0.25 mm (a/W = 0,083) to 1.75 mm (*a/W* = 0.583). Rolling was assessed by changing the angle between the crack plane and the applied force from 0° to 180°. Force 350 N was applied at the top of upper steel plate and the bottom plate was fixed (Fig. 1). Parts was connected by contacts for mutual interaction. Contact between crack faces was also considered. Stress intensity factors K_I, K_{II}, K_{III} for the rotating part were calculated.

Results from the model with the contact between crack faces are shown in Fig. 3 (filled points). In order to identify the cycle asymmetry, variants without contact on the crack faces were also solved. In Fig. 3, these values of K_I are shown using empty points. Stress asymmetry is close to -3.5, in the case of mode I loading. Asymmetry for loading modes II and III is equal to -1. However, shear modes are in out-of-phase loading with opening mode I. Minimal and maximal values for shear modes are observed in 45° and 135° of rolling angle respectively however in different crack tip position.

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