EAN 2014
52nd conference on experimental stress analysis

FEM Simulations and Experimental Tests of Flank Breakage on Tooth of Gears with Respect to Different Nitrided Depth

PETR Karel[1,a], DYNYBYL Vojtěch[1,b] and KŘEPELA Jan[2,c]

[1]Czech Technical University in Prague, Faculty of Mechanical Engineering, Technicka 4, 166 07 Prague 6, Czech Republic

[2]Wikov MGI a.s., Zbecnik 356, 549 31 Hronov, Czech Republic

[a]Karel.Petr@fs.cvut.cz, [b]Vojtech.Dynybyl@fs.cvut.cz, [c]jkrepela@wikov.com

Keywords: Gear-mesh, elastic-plastic deformation, FEM, tooth breakage, flank breakage, nitrided depth, experimental tests.

Abstract. This article deals with the reasons for gear failure - Flank breakage on tooth of spur gears with helical and straight involute gears. Gear flank breakage can be observed on edge zone-hardened gears. The creation of flank and tooth breakage and FEM simulation of flank breakage on tooth are described in this article. In the article are also described and short photo documentation from real load tests on mechanically closed stand for testing of gearing with helical gears and different nitrided depth.

Introduction

For current state of the problems of gears failure are very dangerous a pitting, a tooth breakage and a flank breakage (Fig. 1). The flank breakage is described in the first part of this article.

In the second part of this article is described the methodology, calculations and results of gear-mesh by finite element method (FEM) for spur gears with straight teeth and with different NID.

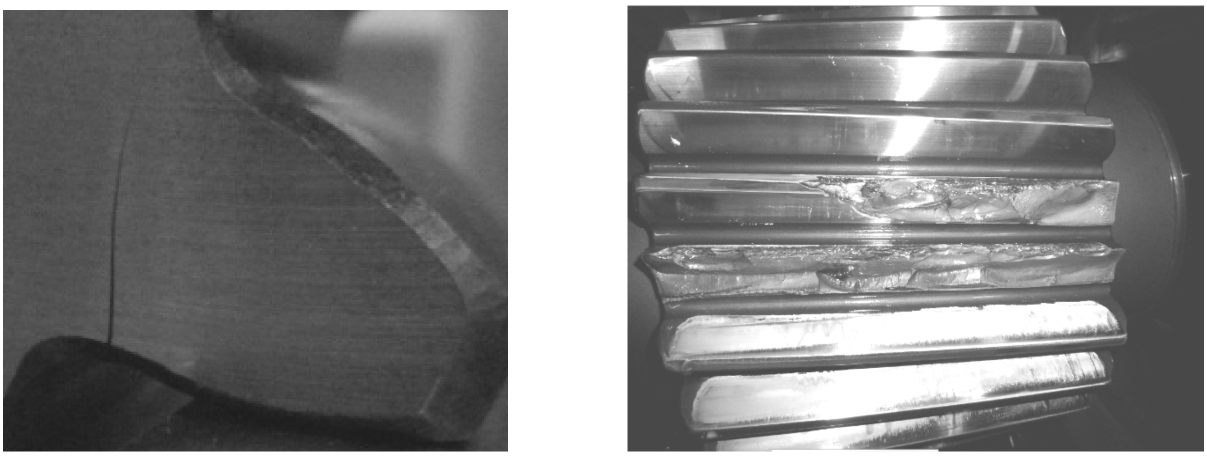

Fig. 1. Examples of tooth breakage – initializations of damage and examples of flank breakage.

In the third part of this article is described comparison of FEM simulations and experimental tests of gears with respect of different NID and pressure angle.

The Flank Breakage of Tooth

The flank breakage on tooth of gears is a complex stress problem in the tooth which is caused by shear stress from the rolling friction. Distribution of the internal residual stress, shear stress from the tangential force, bending stress and additional internal stress caused by non-quality material – see Fig. 2.

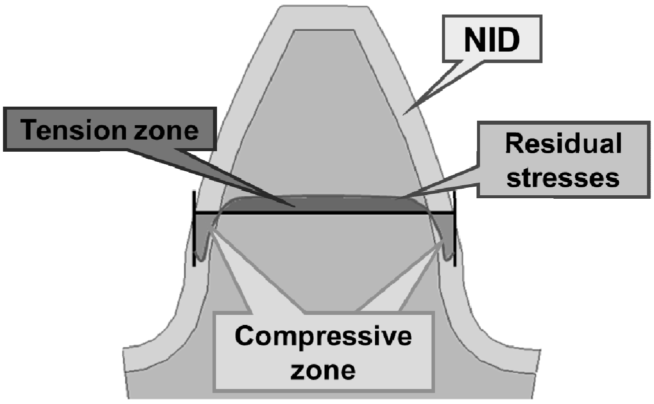

Fig. 2. The shape of residual stress and identification of tension and compressive zones.

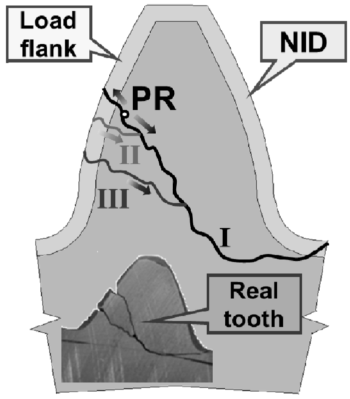

Fig. 3. Path of the fatigue crack.

The flank breakage of tooth is began inside the tooth (under NID). The primary crack starter (PR) is located in the region of the pitch diameter and can be found underneath the nitrided depth (X_{PR} = 1.5·NID), where the stress is significantly lower than within the nitrided depth (NID) – see Fig. 3.

FEM Model and Calculation of Gear-mesh

FEM model and calculation of gear-mesh is the difficult contact problem. The solution of the contact problem is created in the part of gearing (2D FEM model – see Fig. 4) [1].

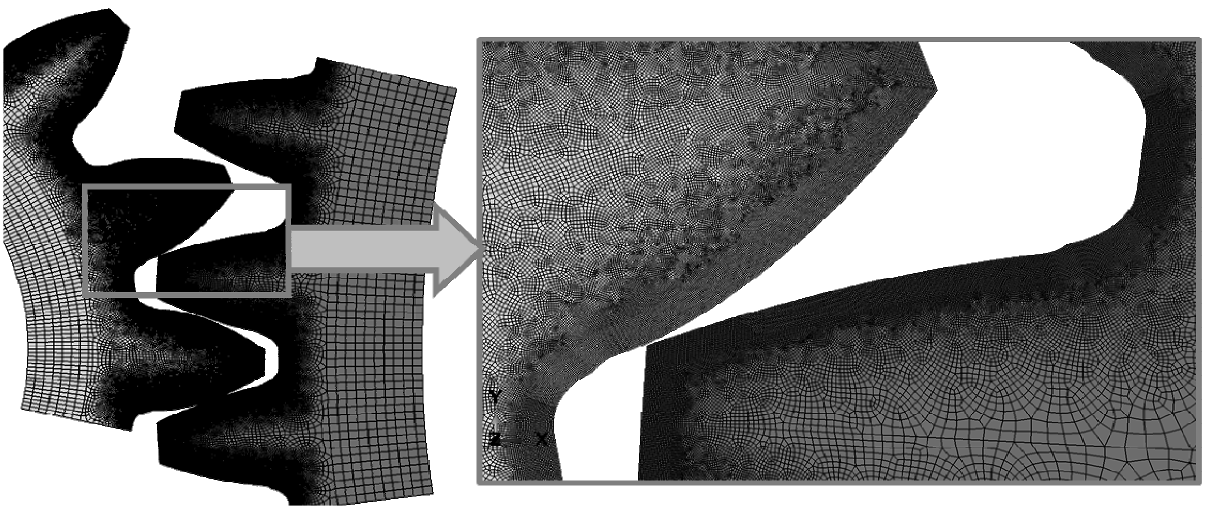

Fig. 4. FEM model in Abaqus (gear and pinion).

The contact bond among tooth flank is added to the model and meshed. The gear and pinion are connected with the self-center point of rotation with help of bond type “Coupling”. The subsequent rolling of the pinion and the implementation of moment on gear are applied through these points. Simulation of gear-mesh is performed quasi-statically [2,3].

Nitrided layers are created as elastic-plastic material model, with application Ramberg–Osgood model of plasticity – Fig. 5.

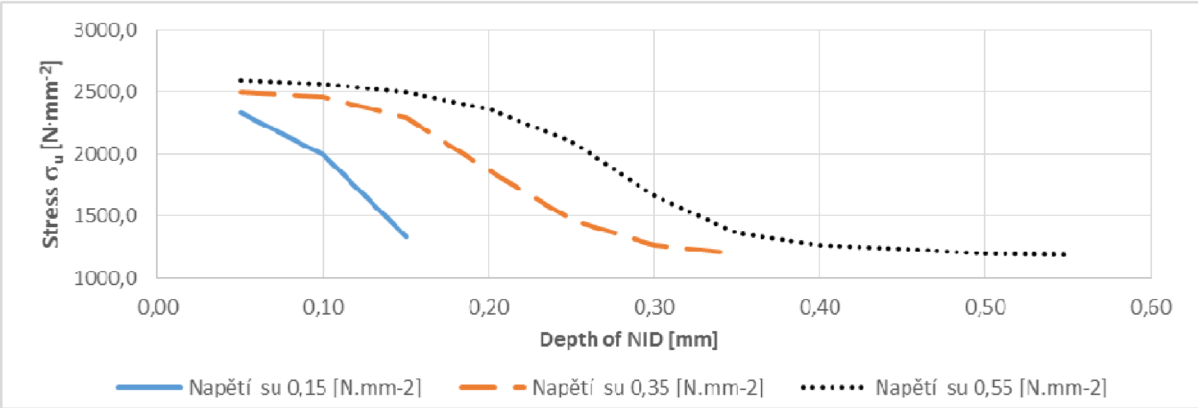

Fig. 5. Distribution of stress over nitrided depth (Ramberg–Osgood model of plasticity).

Comparison of FEM Simulations and Experimental Tests of Gears with Respect of Different NID and Pressure Angle

Experimental tests of gearing carried out on mechanically closed test stand (flank breakage of tooth).

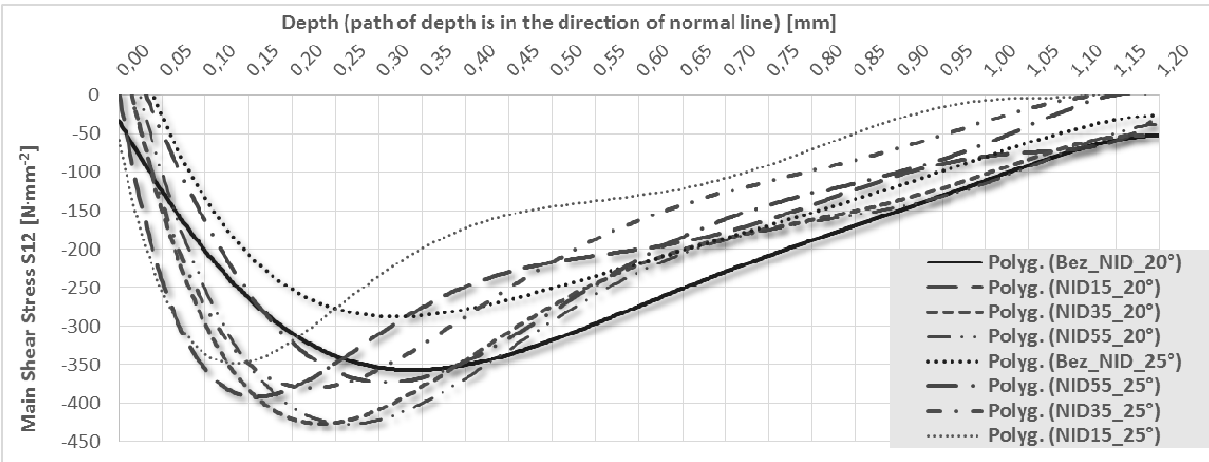

Fig. 6. Distribution of main shear stress over the depth (path of depth is in the direction of normal line) – NID 0 mm, 0.15 mm, 0.35 mm a 0.55 mm.

In the Fig. 6 is shown, than for NID15 (NID = 0.15 mm) is value of maximum shear stress nears to transition of NID and core (for 20°) and directly on the transition (for 25°). For NID35 (NID = 0.35 mm) is value of maximum shear stress inside NID, but still very nears to transition of NID and core. For NID55 (NID = 0.55 mm) is value of maximum shear stress approximately in the middle of NID.

In Table 1 are shown value of cycles to the destruction of nitrided layer for three NID and example photo. In Fig. 7 are shown distribution of main shear stress (black area on right side) for different nitrided depth.

Table 1. Cycles to the destruction of nitrided layer for three NID.

NID [mm]	Pitting – destruction of nitride layer [cycles]	Example photo
0.15	5 500	
0.35	62 000	
0.55	90 000	

NID15 NID35 NID55

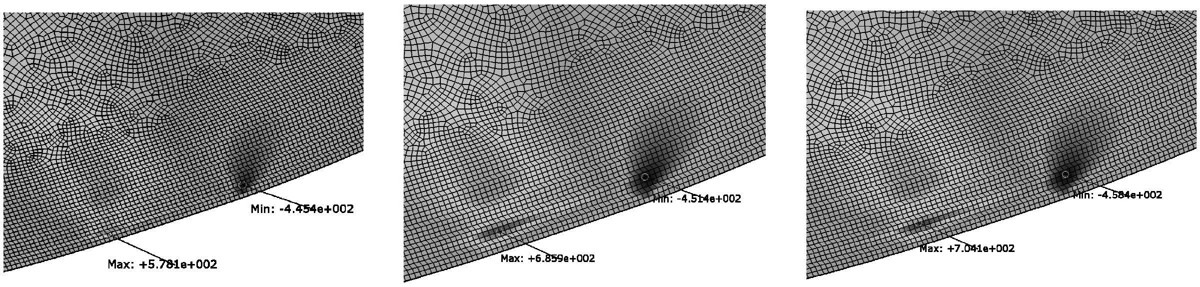

Fig. 6. FEM calculation - the main shear stress for different nitrided depth.

Conclusions

From this analysis suggests that when using a greater pressure angle than angle 20°, is necessary to calculate with the fact that position of the maximum main shear stress is moved towards from tooth flank to core. A positive aspect of a greater pressure angle is a greater resistance to bending stress. The reason for using of gears with pressure angle 20° is moved value of maximum shear stress nears to tooth flank (inside NID).

The best results would be achieved for gears with NID55 or NID35.

Acknowledgments

The research work reported here was made possible by Ministry of Industry and Trade of the Czech Republic grant No. FR-TI4/054.

References

[1] K. Petr, V. Dynybyl, M. Dub, FEM Simulation of Flank Breakage on Tooth of Gears and Experimental Photos, in: Proceedings of the 54th International Conference of Machine Design Departments, Technická univerzita v Liberci, Hejnice, 2013, pp. 259-264.

[2] K. Petr, J. Kanaval, V. Dynybyl, Modification and Non-standard Methods of Increasing Tooth Flank Resistance of Gears, in: R.B. Höhn (Ed.), Proceedings of International Conference on Gears, VDI-Society for Product and Process Design and TUM, Munich, VDI Verlag GmbH, Düsseldorf, 2010, pp.1439-1142.

[3] K. Petr, P. Žák, V. Dynybyl, J. Kanaval, FEM Optimization of Gear Flanks Shape Modifications, in: A. Mihailidis (Ed.), Proceedings of the 3rd International Conference Power Transmissions, Sofia Publications Thessaloniki, Kallithea, 2009, pp. 93-100.