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Procedia Structural Integrity 13 (2018) 2036–2039

Structural Integrity Procedia

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ECF22 - Loading and Environmental effects on Structural Integrity

Experimental Study on Fatigue Fracture Damage of Symmetric Spur Gear Tooth

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Abstract

There are many studies on the involute profile symmetric gears in the literature. In many studies done, the critic tooth root stress was emphasized. Studies have been carried out on the calculations of tooth root stress and these studies have been tried to be verified by using the finite element method. Although there are different approaches to calculate the tooth root stress, the most widely used equations are those expressed in ISO and AGMA standards.

The studies in the literature have mostly been carried out on the gears that have trochoid curve in the tooth root. In parallel with these studies, experimental studies were done to determine the fatigue life performance of these gears.

In this work, involute gears tooth root was manufactured using the circular fillet method which have better tooth root stress than trochoid according to static analyses in literature. Fatigue damage on symmetric gear tooth under cyclic loading and effect of material hardness on fatigue life of gear tooth were investigated.

Fatigue tests were performed with specially designed single-tooth bending fatigue test (STBFT) apparatus. The results obtained from fatigue tests at low cycles and high cycles were evaluated comparatively.

Peer-review under responsibility of the ECF22 organizers.

Keywords: Symmetric gear; Fatigue; Cyclic loadings; STBFT

1. Introduction

Symmetric gears are usually manufactured with a 20° pressure angle. According to needs they can be designed with

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2452-3216
Peer-review under responsibility of the ECF22 organizers.
10.1016/j.prostr.2018.12.212

different pressure angles as 14,5°, 25° etc. While at the small pressure angles strength of gear tooth root decreases, the contact ratio and the tooth tip thickness decrease as the pressure angle increases. To improve gear tooth root strength, there are a few methods like profile modification, change of cutting tool radius, using circular fillet in tooth root.

In this work, we have designed and manufactured symmetric involute spur gears with a 20° pressure angle. Circular fillet method was used in the forming of tooth root curve. It is known that the curve obtained by the circular fillet method in the tooth root increases the tooth thickness in critical section of tooth. Spitas et al (2005, 2007) and Kapelevich (2016) showed that the curve obtained by the circular fillet method in the tooth root increases some the tooth thickness in critical section of tooth root according to trochoid curve.

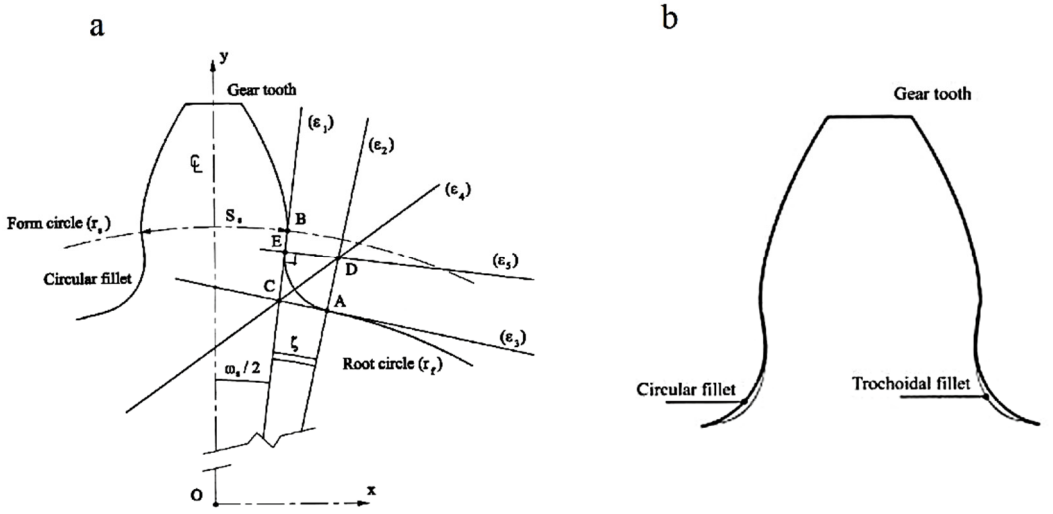

Figure 1. Generation of root curve by circular fillet method (a), comparison of circular fillet curve with trochoid curve (b) Spitas et al (2005, 2007)

Nomenclature

b	Face width (mm)
m	Module (mm)
s_F	Critical tooth thickness (mm)
h_F	Bending moment arm (mm)
σ_{F0}	Stress of the critical point at the tooth root (MPa)
ρ_F	Tooth root radius (mm)
α_L	Load angle (°)
α_n	Pressure angle (°)

2. Experimental method

2.1. Fatigue Test Equipment

As improved version of patent application design by Demet et al. (2015), the testing apparatus developed to do single-tooth bending fatigue test gears is shown in Figure 2. The gear tooth is subjected to a variable loads and undergoes tooth damage due to fatigue in progressive cycles.

The portion of the load application part that is in contact with the tooth has an involute profile and the same pressure angle with the test tooth.

The test gears that were made of AISI 4140 have a pressure angle of 20°, 3mm module and 24 teeth. In the single-tooth bending fatigue tests adjacent tooth are not tested. This prevent the test results to be affected from deformations that can occur in next tooth. In this study, one of the three tooth was identified as test tooth. The manufactured gears were heat treated in two different hardness as 38 and 48 HRC. According to the coordinate measuring method gears have 7

quality numbers according to the DIN 3962. The tests were performed on the Instron fatigue tester through the apparatus shown in Figure 2. During the fatigue tests the stress ratio was applied as 0,1. Tests were performed at 50 Hz frequency.

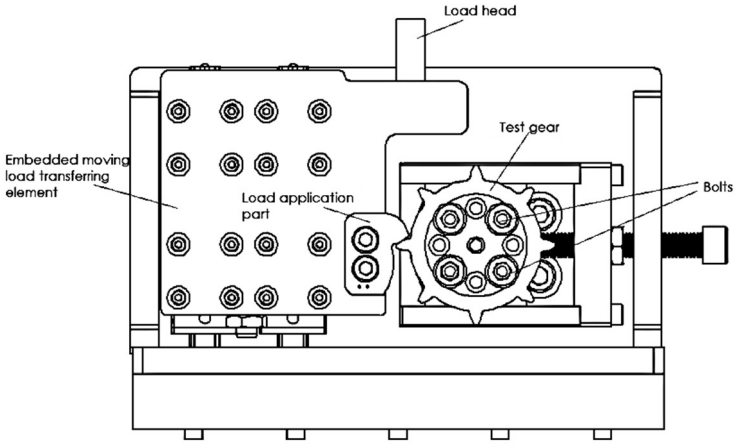

Figure 2. Gear test equipment.

3. Equations

Analysis of tooth root strength of symmetric gears is done by standard approaches such as ISO 6336, AGMA 908-B89. The theoretical studies are compared with the FEM analyses and interpretations are made on the accordance of the results. To analyse the tooth root stress in test gear, we referred to the ISO 6336.

$$\sigma_{F0} = \frac{F_t.Y_F.Y_S}{b.m} \tag{1}$$

Tooth form factor: Y_F:

$$Y_F = \frac{6.h_F.m.\cos\alpha_L}{{s_F}^2.\cos\alpha_n} \tag{2}$$

Stress correction factor: Y_S:

$$Y_s = (1{,}2 + 0{,}13.L).{q_s}^a \tag{3}$$

$$L = \frac{s_F}{h_F} \tag{4}$$

$$q_s = \frac{s_F}{2.\rho_F} \tag{5}$$

$$a = \left[1{,}21 + \frac{2{,}3}{L}\right]^{-1} \tag{6}$$

During the test, the loads were applied from the high point of single tooth contact. This is the point where the load has the greatest effect on the tooth with normal contact ratio.

4. Results

The single tooth bending fatigue test results of the symmetric gears tested are given in Figure 3. According to the

results obtained, gears with 48 HRC hardness have lower fatigue strength than gears with 38 HRC hardness. This can be explained by the change of tensile residual stress on the surface after the heat treatment process. According to Subaşı et al. (2011), with the hardness increases, the tensile residual stress on the surface increase. This situation reduces the strength of the surface and worsens the fatigue performance under variable loading.

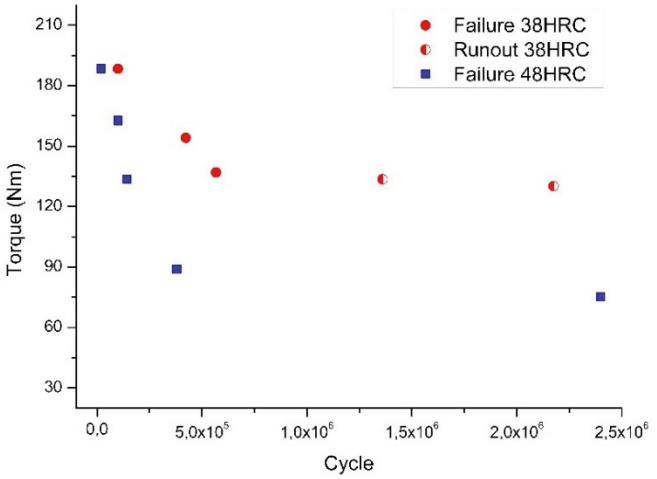

Figure 3. Single tooth bending fatigue test results of test gears

In single-tooth bending fatigue tests, fracture is expected in gear tooth from the tooth root in progressive cycles depending on the load. Because there is no wear or friction in single-tooth fatigue test. Two type of damages were encountered on the tooth and these are explained as follows:

1. In the gear tooth with 48 HRC hardness, due to high residual tensile stresses on the tooth root, cracks and breakage due to fatigue on the root occurred under variable loading at low cycles.
2. In the tooth with 38 HRC hardness, the residual tensile stresses on the root are somewhat lower, so fatigue life of these gear tooth damaged at the longer cycle than gear tooth with 48 HRC hardness.

Acknowledgements

This study was supported by Selcuk University with project 2014-ÖYP-057.

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