Engineering Failure Analysis xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Experimental analysis of contact fatigue damage in case hardened gears for off-highway axles

A. Terrin [a,b], C. Dengo [b], G. Meneghetti [a,*]

[a] Department of Industrial Engineering, University of Padova, Via Venezia, 1, 35131 Padova, Italy
[b] Engineering and Innovation Department, Carraro S.p.A., Via Olmo 37, 35010 Campodarsego, Padova, Italy

ARTICLE INFO

Article history:
Received 28 August 2016
Received in revised form 29 December 2016
Accepted 3 January 2017
Available online xxxx

Keywords:
Gear contact fatigue
Pitting
Micropitting
Macropitting
Shot peening

ABSTRACT

Pitting is one of the main causes of failure in planetary gear sets of axles designed for agricultural vehicles. The high torque and the low wheel speed typical of such machines result in poor lubrication and promote the onset of contact fatigue failure by pitting, which generally occurs earlier in the sun gear than in both the planets and the ring of wheel hub planetary drives. In fact, sun gears are subjected to the highest contact pressure and, at the same time, unfavourable rolling-sliding working conditions. In this paper, six case hardened sun gears damaged by pitting during endurance tests were analysed. The aim of the analysis was to highlight the key aspects of the morphology and the evolution of pitting damage on the case hardened sun gears.

1. Introduction

Pitting is a fatigue phenomenon that affects the mating surfaces of mechanical elements characterized by non-conformal contact. In components such as cams, bearings and gears for instance, contacts occur between curved surfaces with different curvature radii, thus the load is carried by a very small contact area, resulting in high pressure. The damaging process starts with the formation of cracks caused by the repeated stress cycles generated by contact between the mating parts. Cracks grow at small angles to the surface and, eventually, curve up causing the detachment of material debris and leaving craters. Fatigue cracks may initiate either at the surface or at a small depth below the surface, where shear stresses are high enough to promote their propagation from defects or inclusions. Subsurface cracks are more common in well-lubricated pure rolling contacts between smooth surfaces and in presence of non-metallic inclusions [1–5]. On the contrary, when both rolling and sliding occur, surface cracks are more prone to form because friction forces contribute to increase the shear stress and to reduce the depth at which it achieves the maximum value [6]. Moreover, if sliding occurs, energy dissipated by friction is converted to heat, which promotes pitting damage since it reduces the lubricant viscosity and thus the load carrying capacity of the film [7,8].

Gears are typical components operating in rolling-sliding contact conditions. Contact pressure on gears is usually calculated by assuming that gear teeth can be treated as cylinders with parallel axes (Fig. 1a). According to Hertz's theory of contact between elastic bodies [9,10], all normal stress components are compressive and therefore they are not likely to promote crack propagation. Conversely, the damaging process is driven by the cyclic shear stress [11,12], which achieves the maximum value at a certain depth under the surface (Fig. 1b, c).

* Corresponding author.
E-mail address: giovanni.meneghetti@unipd.it (G. Meneghetti).

http://dx.doi.org/10.1016/j.engfailanal.2017.01.019
1350-6307/

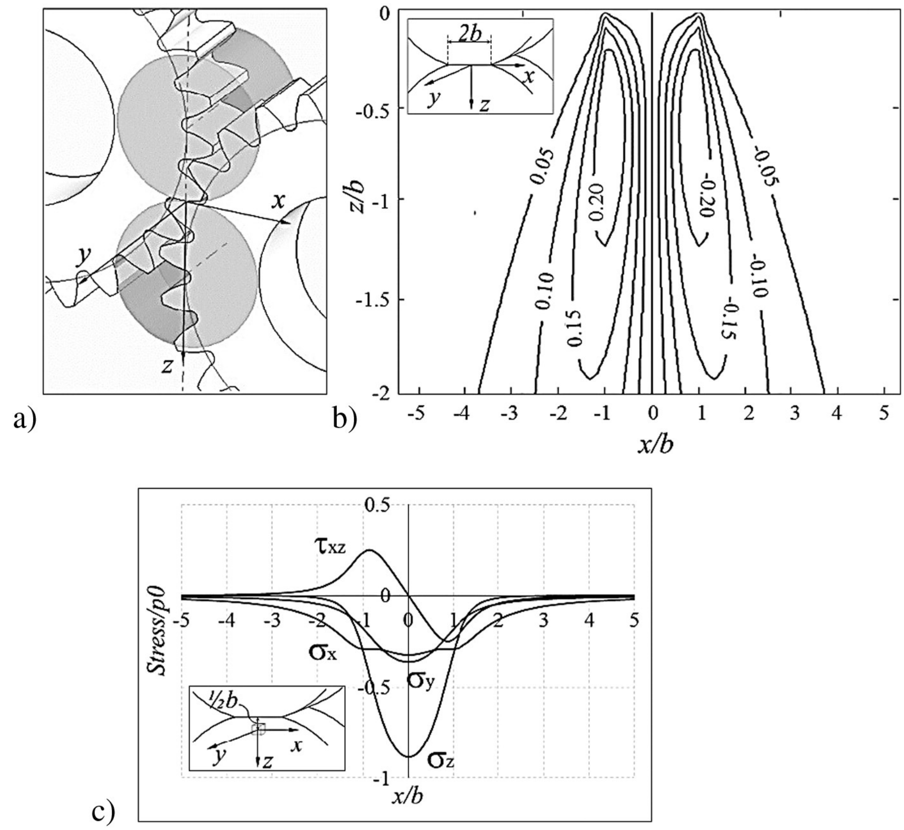

Fig. 1. Parallel cylinders resembling tooth contact (a). Contour plot of shear stress τ_{zx} below the surface arising from cylinder-cylinder contact (b). Stress field at a depth 0.5b, where b indicates the half-width of the contact strip under load (c). Stress values have been normalized by the maximum contact pressure p_0.

Hertzian contact fatigue phenomena can be classified into two major failure modes: pitting and micropitting. Although the morphology of craters is essentially the same for the two modes, they differ for the size. Pitting produces craters from about 0.5 to 1 mm, that are also called macropits. Conversely, micropits' size is on the order of tens of microns, therefore micropitting is visible to naked eye only when several pits coalesce forming a wide matt surface [13].

Referring to case hardened gears, pitting may be originated by subsurface cracks only in presence of high rolling speeds, very smooth surfaces and optimal lubricating conditions [4,14–16]. In Such cases, contact between asperities is prevented by the lubricant and the formation of subsurface cracks in correspondence of defects or inclusions [5] may occur earlier than surface originated damages. However, the lubrication film is not often thick enough to keep roughness asperities separated, so that surface cracks form as a result of plastic strains in the surface due to friction. The propagation of surface cracks is promoted by the presence of the lubricant, which is entrapped and pressurized within the crack edges by the contact with the mating surface [16–21]. Surface originated pits can be distinguished in two categories: (i) Point Surface Origin (PSO) macropitting and (ii) Geometric Stress Concentration (GSC) macropitting [22]. Some examples of damage mechanisms are shown in Figs. 2 to 5. Generally, PSO macropits originate from surface defects such as nicks, dents, grinding furrows, debris bruises and also previous-formed micropits [23,24].

Fig. 2. PSO macropitting.

Please cite this article as: A. Terrin, et al., Experimental analysis of contact fatigue damage in case hardened gears for off-highway axles, Engineering Failure Analysis (2017), http://dx.doi.org/10.1016/j.engfailanal.2017.01.019