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An observation on the initiation of micro-pitting damage in as-ground and coated gears during contact fatigue

V. Moorthy *, B.A. Shaw

Design Unit, School of Mechanical and Systems Engineering, Newcastle University, Stephenson Building, Claremont Road, Newcastle Upon Tyne, NE1 7RU, UK

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ABSTRACT

The effect of surface features on as-ground gears and the influence of BALINIT® C and Nb–S coatings on the initiation of micro-pitting damage have been examined in case-carburised and tempered S156 steel helical gears subjected to contact fatigue using back-to-back gear testing. The initiation of micro-pitting damage has been studied using scanning electron and optical microscopy examination. It has been observed that micro-cracks tend to initiate against the sliding direction preferentially from micro-valleys on the surface of as-ground gears, particularly when the depth of micro-valley is favourably oriented at an angle against the sliding direction. It has been found that the micro-pitting damage is drastically reduced in both coated gears. In BALINIT® C coated gears, the micro-scale surface irregularities are removed by a wear process resulting in a polished surface of the gear flank below the pitch diameter which is attributed to the effect of hard BALINIT® C coating. However, there is region of interface between the polished and unpolished regions of gear flank where there is small scale initiation of micro-pitting due to the absence of BALINIT® C coating at micro-valleys. In Nb–S coated gears, the coating tends to penetrate and fill-up the micro-valleys on as-ground surface modifying the gear flank surface. Hence, the micro-pits tend to initiate only at some micro-valley sites where the Nb–S coating is locally removed during running. This study shows that, both BALINIT® C and Nb–S coated gears show enhanced resistance to micro-pitting damage by removing localised stress concentration at micro-valleys present on as-ground gears.

1. Introduction

The progressive micro-pitting is the main mode of contact fatigue damage in gears [1–8]. It is associated with initiation and growth of micro-cracks against the sliding direction at an angle (15–30°) to the surface of the gear flank. The progress of micro-pitting damage alters the micro-geometry of gear profile which in-turn alters the contact stress distribution on the gear flank. This would introduce regions of high contact stresses and makes gear rotation less efficient and prone to fatigue failure of gear teeth through formation of macro-pits [1,6].

The origin of micro-pitting crack on contacting surfaces is not well understood. However, under a particular lubrication, temperature and gear meshing condition with substantial sliding, the micro-pitting has been observed to initiate at surface irregularities present in the form of peaks and valleys [9]. The surface roughness and surface texture on as-ground gear teeth strongly influence the micro-pitting. It is considered that, in as-ground surface, the influence of localised high contact stresses at asperities (micro-peaks) on contacting surfaces can initiate micro-cracks under micro-elastohydrodynamic lubrication condition [10]. It is also observed that these surface asperities are removed by plastic deformation after a period of initial contact regime [6]. It has also been shown that the super-finishing of gear flank surface resists initiation of micro-pitting [6,10]. This is attributed to smoothening of the gear flank reducing the irregularities on the surface. Recently, the contact fatigue performance of gears with different surface coatings was compared with uncoated gears using back-to-back helical gear testing which revealed that the BALINIT® C and Nb–S coatings provide enhanced contact fatigue performance in gears [11,12].

As a continuation, this study was mainly aimed at observing the origin of micro-pitting on as-ground gear flank surface and the effect of BALINIT® C and Nb–S coatings in modifying the gear flank surface and their behaviour under contact fatigue.

2. Experimental procedure

The gear manufacturing and the contact fatigue tests have been carried out at the Design Unit, Newcastle University.

* Corresponding author. Tel.: +44 191 222 6158; fax: +44 191 222 6194.
E-mail address: v.moorthy@ncl.ac.uk (V. Moorthy).

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The carburised and tempered S156 steel helical wheel (24 teeth) and pinion (16 teeth) gears were ground to a specified geometry using a form-grinding (profile grinding) machine. Surface roughness of these form-ground gears is found to be low with R_a value <0.5 μm. Some of the as-ground gears were coated with BALINIT® C by Oerlikon Balzers, UK [13] and with a 'Nb–S' by IonBond, UK [14] (Table 1). The coatings were applied to a thickness of ~2 μm at the pitch line of the gear flank. The helical gears were tested on a 91.5 mm centre distance back-to-back contact fatigue test rig at 3000 rpm speed with the Aeroshell oil as lubricant at 100 °C. The full details of gear tests are given elsewhere [11,12]. The analysis was carried out by examining untested and tested gear tooth flank surfaces and cross sections of gear teeth under optical and scanning electron (SEM) microscopes. The initiation of micropitting is examined at several locations on the flank surface with scattered small scale damage which are considered as early stage. Gear metrology measurements also showed that there is no loss in original flank profile at these locations indicating the presence of original surface features. The presence and absence of coatings were also analysed using EDAX measurements during SEM examination.

Table 1
Properties of BALINIT® C and Nb–S coatings.

Coating type	Coating supplier	Coating temperature (°C)	Thickness at pitch line (μm)	Hardness (GPa)	Modulus (GPa)
BALINIT® C 1000	Oerlikon Balzers, UK	<200	~2	10 (1000 HK)	–
Nb–S	Ionbond, UK	~250	~2	6–10	120

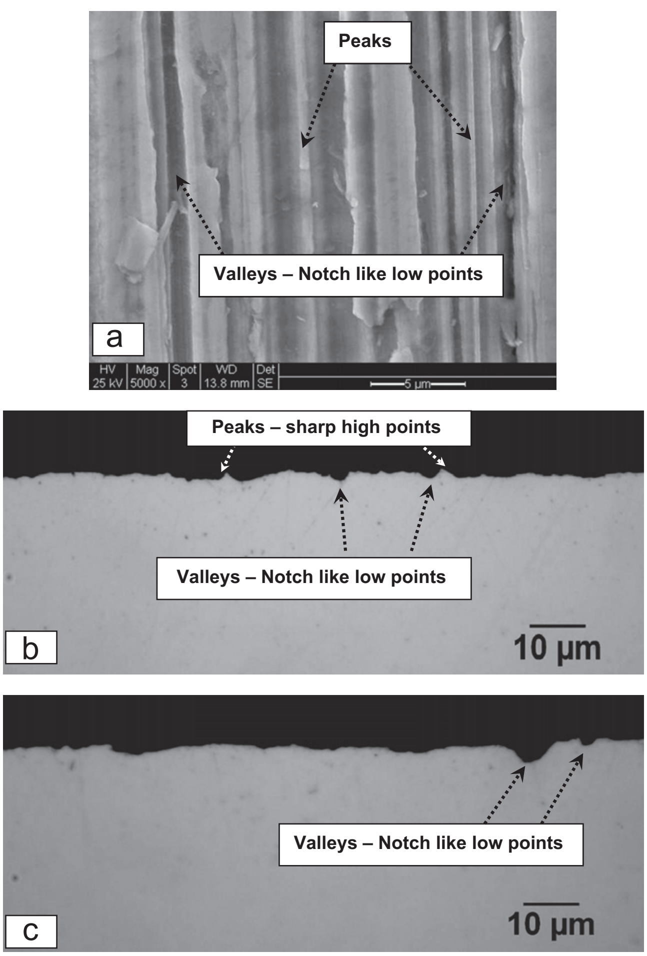

Fig. 1. Surface features observed in an as-ground gear flank (a) SEM micrograph of a gear flank surface, (b) and (c) optical micrographs of as-polished cross-section of gear tooth.

3. Results and discussion

3.1. Surface features on as-ground and coated gears

Typical features observed on the surface of an as-ground gear produced by form-grinding process are shown in Fig. 1(a–c). It can be observed that the as-ground surface has features like peaks and valleys, produced by the grinding wheel, which dominate the top surface layer over a depth range of 1–3 μm. The depth of valleys ranges as deep as ~3 μm and their orientation also vary from place to place. It is important to note that some of these small micro-features cannot be measured by conventional gear metrology measurements and even by surface roughness profile measurements due to size limitation of the stylus. It is considered that these surface micro-features can play significant role during contact fatigue.

The surface of BALINIT® C coated gear flank as observed under SEM and the cross section of a gear tooth as observed under optical microscope are shown in Fig. 2(a–c). It can be found that the BALINIT® C coating appears like congregation of micro-spheroids adherent to the flank surface. It also appears that the BALINIT® C coating does not sufficiently penetrate the sharp valleys (low points) present on the flank surface.

The surface of Nb–S coated gear flank as observed under SEM and the optical micrographs of cross section of a gear tooth are shown in Fig. 3(a–c). It can be found that the Nb–S coating forms smooth layer on the flank surface, masking the peaks and valleys

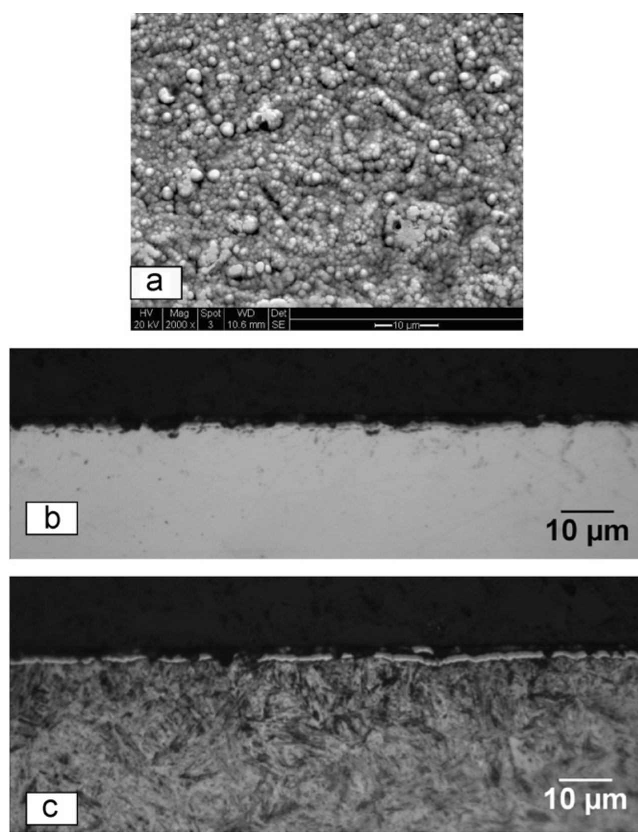

Fig. 2. BALINIT® C coated surface (a) SEM micrograph, (b) optical micrograph of as-polished cross section of a gear tooth and (c) optical micrograph of etched cross section.