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Influence of some Superfinishing Processes on Surface Integrity in Automotive Industry

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Abstract

Due to the increasing demand on many transmissions parts, such as synchronizing gears, crankshafts or camshafts, surface integrity along with appropriate fatigue performance is becoming a key issue in automotive industry. This paper proposes an experimental study covering the influence of three superfinishing processes on surface integrity of a SAE 5120 steel: belt-finishing, ball burnishing and mass-finishing. Surface and sub-surface properties, i.e. residual stresses, near surface microstructure, surface roughness and bearing parameters, have been analyzed to highlight the influence of different process parameters, to compare each process to another and assess the benefits compared to conventional turning.

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Keywords: Residual stresses, topography, finishing

1. Introduction

The energy consumption of the transport sector is becoming ever more important to our society. It accounts for 27 % of the global energy use, produces 6.7 Gt-CO2 direct emissions representing 14 % of global greenhouse gas emissions in 2010, with 50 % of them arising from light vehicles [1]. Growing awareness of the environmental consequences of the automotive industry is driving efforts to reduce the environmental impact of their products. One of the goals has been to develop alternative powertrain solutions and especially to improve the efficiency of internal combustion engines [2]. New advances, such as improved fuel injection or supercharging, led to a significant down-sizing of engines. Fatigue life is also now becoming a greater concern for components such as camshafts [3], crankshafts [4] or gears [5], and is directly related to the way they are manufactured.

On such components, which are primarily manufactured from quenched and tempered or even case-hardened steels, turning is a major finishing operation, usually followed by grinding. Grinding is known to affect the surface and subsurface of the workpiece, i.e. formation of white layers and most of the time leading to tensile residual stresses [6]. Combining turning/hard turning with subsequent superfinishing processes has been presented as an efficient alternative [7], but industry is still reluctant to adopt them as these processes are not fully understood and their benefits are not clearly highlighted. Several studies on burnishing [8], belt-finishing [9] or mass/vibratory finishing [10] have already emphasized the ability of these processes to improve the surface integrity. However, few studies reported their effects on the same workmaterial with the same initial workpiece conditions.

The present study thus aims at investigating the influence of three superfinishing processes on the surface integrity after turning of a quenched and tempered automotive steel. Ball burnishing, belt-finishing and mass-finishing are studied and their benefits compared to conventional dry turning are assessed.

2. Materials and methods

2.1. Workmaterial

Experiments have been performed on a 27MnCr5 automotive steel. Typically employed after case-hardening for gears, the material has been here used in a quenched and tempered state (280 ±20 HB) to maintain the versatility, fundamental aspects and potential applications (Fig. 1).

2.2. Turning and superfinishing processes

Initial specimens have been finished with a single dry turning operation, carried out on an ultra-precision facing lathe (trademark PRECIMAB) with Sandvik CCMT 09 T3 04-PF 4215 inserts fitted on a SCLCL 2020K16 tool holder (Fig. 2b).

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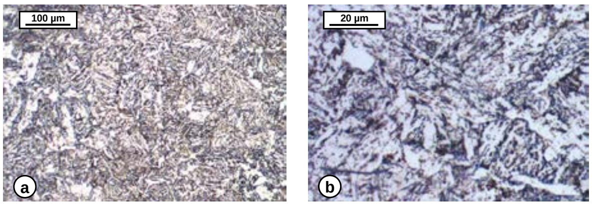

Fig. 1. Microstructure of the quenched and tempered 27MnCr5.

Cutting parameters were : cutting speed Vc = 200 m/min, feed rate f = 0.23 mm/rev and depth of cut ap = 0.5 mm.

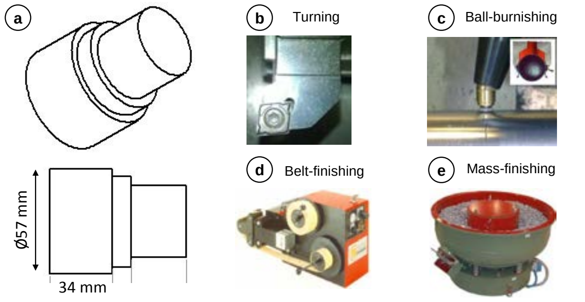

Fig. 2. Geometry of the specimens and processes used in this study.

The following superfinishing processes have been applied:

- Ball-burnishing (Fig. 2c) is not a material removal process. A high contact pressure is applied through a ceramic ball moving on the surface with a given feed and speed (50 m/min in this study). It has been performed using a special tool equipped with a 6 mm diameter ball and mounted in the turret of a NC lathe. The normal load was exerted by an hydraulic pressure and controlled prior to each test under static contact conditions.

- Belt-finishing (Fig. 2d) consists of applying an abrasive belt, made of alumina abrasive grains, between the surface to be finished and a polymer roller with a hardness of 70 shores. A normal load is applied via a pneumatic jack to adjust the resulting contact area and contact pressure. The workpiece is rotating at 448 RPM whereas the belt and roller system is axially oscillating with an amplitude of 0.5 mm and a given frequency of 12 Hz. A belt feed of 2.5 mm/s was also applied in order to regenerate the abrasive grains into the contact. Experiments have been performed with and without lubrication during a time period of 15 s.

- Mass-finishing (Fig. 2e) is a mechanical process in which the parts are submerged in an abrasive media within a vibratory finishing machine. Vibrations induce a circular motion of the part and abrasives inside the bowl. The resulting sliding contact of the abrasive media on the workpieces is used for deburring, radiusing or polishing. The machine used in this study was a Rosler R 180/DL with a circular bowl of D950 mm x 550 mm lubricated with pulsed water and rotating at 1500 RPM. Two types of ceramic abrasives were employed: RS6G 6 mm balls (SPH) and RXX6/10ZS 30° angle cut cylinders (ACC) from Rosler. Experiments have been performed with water lubrication during two time periods of 1.5 and 3 hours.

2.3. Surface and subsurface characterization

Surface roughness parameters (Ra, Rz) as well as bearing parameters (Rpk, Rk, Rvk) have been measured with a MAHR MarSurf profilometer. A Gaussian filter was applied with a cut-off length set to 0.8 mm and an evaluation length of 4.8 mm.

The residual stresses measurements have been performed with an X-Ray Diffraction (XRD) system equipped with a 2-mm diameter collimator with the following configuration:

- Cr Kα radiation with 18 kV, 4 mA;
- λ = 0.229 nm, planes 211;
- Braggs angles: 2θ = 155.00°;
- Ω acquisition mode;
- 7 β-angles (from -30° to +30°);
- β oscillations: ±6°.

Stresses were calculated using the elliptic treatment method with the following radio-crystallographic elasticity constants: $\frac{1}{2}$ S2 = 5.92 $\times 10^{-6}$MPa^{-1}, S1 = 1.28 $\times 10^{-6}$MPa^{-1}.

An electrochemical polishing system has also been used to measure the stress profile by successively etching ultra-thin layers along the depth.

In order to observe the microstructure of the material, some specimens have been cut, mounted, polished with SiC grinding paper up to 1200 grit size followed by diamond based suspensions down to 1 μm and finally etched in 2% Nital solution.

3. Results and discussion

3.1. Highlights of some influential parameters

Fig. 3 shows the effect of three main belt-finishing parameters: abrasive grain size, normal load and lubrication. A grain size of 30 μm appears to be an interesting compromise as it provides over the 15 s interval a higher abrasive capability than the 9 μm abrasive size and lower Rz values due to the larger grains for 80 μm. Increasing the normal load to 800 N can improve this performance, decreasing both Rk and Rvk, whereas removing the lubrication results in higher Ra, Rz and Rk.

Ball-burnishing is an efficient process to produce fine surfaces with a Ra < 0.5 μm and Rz < 2 μm and low bearing parameters (Fig. 4). The sensitivity to the different parameters is not significant but increasing the contact pressure or decreasing the feed beyond a certain value can worsen the surface finish.

Considering its complexity, only two parameters of the mass-finishing process have been investigated: the geometry of the abrasives and the process time (1.5 and 3 hours). Mass-finishing is effective for deburring and it is shown here by the low measured Rpk values (Fig. 5b). Using the spherical media resulted in a better surface finish, lower Ra, Rz, especially after 3 hours of processing.