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Multiscale assessment of structured coated abrasive grits in belt finishing process

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ABSTRACT

This paper outlines the link between grit morphology and surface roughness of belt-finished workpieces. It features a comparative analysis of a new generation of abrasive belts with diverse abrasive structures, and a multi-scale roughness characterization of abrasive belt wear on a variety of finished surfaces. The ultimate thickness of the mechanically deformed layer and surface profile projections depends, to a great extent, on the abrasive mechanisms of friction and wear employed in the finishing process. By modifying the physical mechanisms (cutting, plowing or sliding), it is possible to achieve a concomitant change in the rate of material removal and, consequently, to the specific surface roughness of the finished parts.

Our research shows that the active roughness scale resulting from belt finishing is strongly dependent on the grit orientation and the binder distribution. The results are promising for increasing the efficiency of the abrasion processes and for improving the surface texturing of finished parts.

1. Introduction

The main objectives in the automotive industry for the improvement of environmental efficiency in vehicle engines are to reduce oil consumption and to limit noxious emissions. Various manufacturing processes are used to achieve this goal, which are generally based either on using lightweight material to reduce load, reducing heat losses due to exhaust and conduction through engine body, or by improving the frictional loss in the mechanical contact, particularly inside the engine [1].

In a passenger car engine, about 30% of the total frictional loss is accounted for by the bearings alone [2]. One of the ways to reduce friction is to act on surface morphology. In practice, this is achieved by using anti-friction coating technologies, texturation technology like in the honing process, or more traditionally, by reducing surfaces roughness. Nowadays, on passenger car crankshafts, the latter option is the most commonly employed. The process engineering departments have to maintain specific geometrical specifications and a very strict surface finish. Moreover, high volume production and cost reduction requires the utmost efficiency in the manufacturing process, especially for finishing and superfinishing operations.

In this regard, the advanced belt finishing process is remarkably simple and inexpensive [3]. Its principles of operation are well known: pressure-locked shoe-platens circumferentially press an abrasive coated belt on a rotated workpiece. This abrasive machining process is used extensively in the automotive industry to superfinish crankshaft journals and pins, which allows for the reduction of surface irregularities, improves the geometrical quality, and increases wear resistance and fatigue life. However, one of the major industrial issues with this manufacturing process is its efficiency and robustness. The superfinishing of crankshaft journals and pins is generally achieved by processing three steps of belt-finishing while successively decreasing the grits' size, which involves substantial manufacturing costs.

One of the most promising ways to reduce this cost is by controlling the distribution and morphology of the abrasive grits. Recently, a new generation of abrasive belts coated with structured and shaped agglomerated grits has become commercially available. These belts promise to be more efficient and would have a better wear resistance compared to the traditional coated abrasive belts. The present study aims to analyze these new belts and to investigate the link between their morphologies, the surface finish of belt-finished workpieces, and the physical mechanisms which govern their wear performance.

2. Experimental procedure

In this work, the belt structure is qualitatively characterized by SEM observations before and after belt finishing operations. Then,

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Nomenclature

t_c	cycle time (s)
D	initial workpiece diameter (mm)
R	initial workpiece radius (mm)
L	belt finished width (mm)
E_s	total specific energy (J mm^{-3})
ΔP	power of the belt finishing machine (W)
ΔV	removal volume (mm^3)
Δh	removal thickness (μm)
R_{pk}	reduced peak height (ISO 13565) (μm)
R_k	core roughness depth (ISO 13565) (μm)
R_{vk}	reduced valley depths (ISO 13565) (μm)
R_z	maximum height of roughness profile (ISO 4287) (μm)
$Mr1$	material portion corresponding to the upper limit position of the roughness core profile (ISO 13565) (%)
$Mr2$	material portion corresponding to the lower limit position of the roughness core profile (ISO 13565) (%)
M_a	multiscale arithmetic roughness average (μm)
MPS	Multiscale Process Signature

the effect of the abrasive belt structure on roughness is identified using standard functional parameters and a multi-scale analysis in a wide-scale range. An energy analysis is applied to identify the cutting ability related to the abrasive structure of the coated belts. Finally, a global belt finishing process efficiency analysis is conducted to discuss the functional relevance of each belt structure.

The test rig consists of a conventional lathe, a belt finishing apparatus, and a power transducer allowing the measure in-situ of the power dissipated during the superfinishing process. The belt finishing apparatus is composed of two horizontal arms equipped with special pressure assisted shoe-platen (see Fig. 1).

With this type of shoe-platen, each insert can be moved in a radial direction by hydraulic cylinders pressing the abrasive belt against the periphery of the workpiece with a locally known value of the contact pressure. One of the benefits of this technology is its flexibility since belts with different thicknesses can be fit on the shoe-platens without significantly changing the contact surface between inserts and workpiece, which is not the case when traditional shoe-platens with motionless inserts are used. Since the feed pressure of the hydraulic cylinders is the same, a constant pressure distribution is obtained along the abrasive belt/workpiece contact angle (approximately 320°). This pressure value does not change during the process and it can be easily controlled using the feed pressure of cylinders in the shoes. The tests are performed on wet conditions varying the abrasive belt structure while other working parameters are kept constant (see Table 1).

Four types of structured abrasive belts with the same grits size range (about 30 μm) are considered in this study. The different belt structures studied are as follows:

- *Type I:* A common structure often used to superfinish crankshaft journals and pins (see Fig. 2(a)). The abrasive belt is constituted of a large amount of calibrated grits electrostatically deposited on a polyester backing coated by a layer of synthetic or water based resin. With this deposition process, the grits are oriented perpendicularly to the backing and their cutting edge offers an important material removal capacity. Moreover, this kind of belt can have an anti-slip layer on the backside, which allows for a better hold of the belt during the belt finishing operations. Three belt models with this structure (5902, 372 L and 272 L) are considered.
- *Type II:* A structure composed of lapped grits (see Fig. 2(b)). The abrasive belt is constituted of grits partially or completely covered by resin. The cutting edges are flattened, well oriented, and less aggressive.
- *Type III:* A shaped structure constituted by a thick web backing on which is deposited half-spherical agglomerates (see Fig. 2 (c)). Each half-spherical structural element is composed of 30 μm grits bounded together by a resin. The grit density is very high as compared to the other structures considered. In addition, this belt type has a small contact area between the abrasive structure and the surface of the workpiece.
- *Type IV:* A shaped structure constituted by a plasticised web backing on which pyramidal agglomerates are deposited (see Fig. 2(d)). Each pyramid has a square base and is constituted of 30 μm grits bound together by a resin. As with the Type III belts, only the summits are in contact with the workpiece.

Table 1
Belt finishing working conditions.

Workpiece rotation speed	100 rpm
Normal force of the shoe-platens	600 N
Oscillation frequency of shoes	265 cycles per min
Oscillation amplitude of shoes	1 mm
Cycle time	12 s
Lubrication fluid	Neat oil
Feedrate of the abrasive belt	None

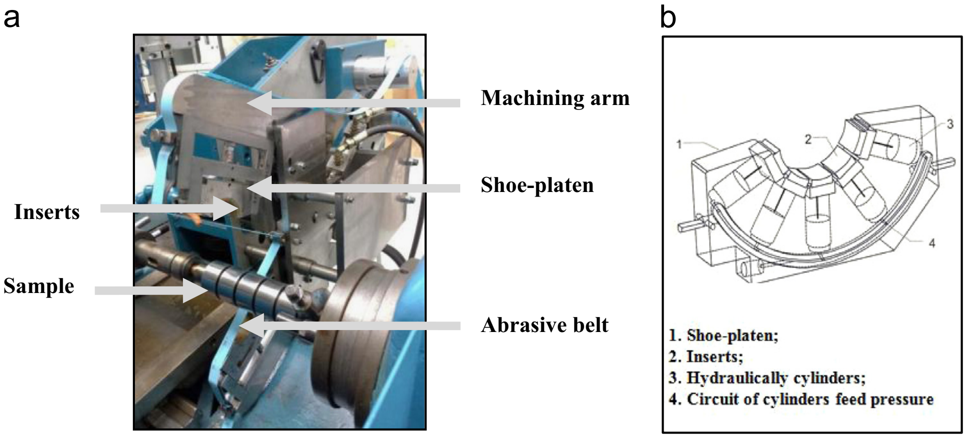

Fig. 1. Belt finishing apparatus (a) and pressure assisted shoe-platen (b).