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# Effects of ball burnishing on surface properties of low density polyethylene

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ABSTRACT

We have end milled surfaces and then applied ball burnishing to specimens of low density high molecular mass polyethylene (LDPE). An important objective was roughness minimization. For selected ball diameters, the influence of burnishing parameters such as force $F$ and burnishing speed $f$ on selected surface geometry parameters has been determined: roughness Ra, total height of the profile Rt, and also the two-dimensional roughness change $K_{Ra}$. We find the minimum value of Ra = 0.57 μm and the maximum value of $K_{Ra}$ = 5.1, both highly desired results. In the best case, Rt has decreased from 14.5 μm to 4.0 μm. Microhardness values, ball-on-disc wear values and scratch resistance testing all show property improvement of milled and burnished surfaces as compared to surfaces milled only. Burnishing decreases the wear rate by 58%.

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## 1. Introduction

High reliability and durability of tribological elements working under sliding conditions are important, first of all, for economic well-being of industry [1]. Such elements include bushings, cogwheels, cams, and more. Most tribology improvements concern metal or ceramic parts. Thus, coating deposition on metals and ceramics [2], nitriding of metals [3] and deformation of metals [4] have been all applied to improve tribological properties.

However, industry needs more and more good tribological properties of components made from polymers and polymer-based materials (PBMs). Advantages of PBMs based on much lower densities than metals and ceramics provide the motivation. Typically, wear is lowered in moving metal parts by liquid lubricants. This option is not available for PBMs; liquid lubricants are usually absorbed by the material, swelling and jamming of moving parts is the result. Thus, other ways of mitigating the wear have to be developed [5–14].

One of the finishing machining methods that make possible improvement of surface layers (physical and mechanical properties and service performance) is the burnishing process. During burnishing a small area of the material is deformed as a consequence of kinematic interaction of the tool with a surface [15,16]. The resulting deformation is strongly dependent on the force application configuration; see Fig. 1. One typically applies burnishing after the use of machining techniques such as turning or milling. Expected results include an increase in hardness, higher wear resistance, and improved fatigue resistance.

While most reported uses of burnishing pertain to metal surfaces, e.g. [17], a very small number of papers report on application of this technique to polymers [18–20], including thermoplastic polyoxymethylene (POM) (also known as acetal) and a thermoset polyurethane (PU). A significant decrease in roughness for both POM and PU and a small increase in hardness have been reported [18]. Some of us have applied burnishing to metal matrix composites [21] and tool steels [22]. In this situation, we have decided to apply burnishing to the most widely used polymer, low density polyethylene (LDPE).

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## 2. Experimental

We have used a high molecular mass polymer manufactured by Quadrant EPP N.V., Tielt, Belgium, called PE 500. It is used to make components subjected to impact and/or used at low temperatures such as in ice generators. PE 500 has the number average molecular weight $M_n = 0.5 \cdot 10^6$ g/mol. Its density is 0.96 g cm$^{-3}$, tensile modulus 850 MPa, tensile elongation at break $\varepsilon_b \approx 300\%$, dynamic friction (also known as kinetic friction) against dry steel determined at the load of 0.05 N/mm$^2$ and the speed of 0.6 m/s is 0.25 [23]. We recall that $\varepsilon_b$ is inversely proportional to the material brittleness [24].

First milling was performed in a DMC 75 V linear milling center at DMG Mori Seiki Polska Sp. z o.o., Pleszew, Poland, controlled in five axes. The straight milling was done with HSS-E ball nose cutter with the diameter of 8.0 mm and inclination 15°, applying the following parameters: axial depth of cut $a_p = 0.5$ mm, feed $f_z = 0.09$ mm/tooth, radial depth of cut $a_e = 0.05$ mm, and cutting speed $v_c = 115$ m/min. Milling was performed parallel to the $Y$ milling center axis with constant parameters for all fields.

The burnisher was mounted through a HSK (Hollow-Shank Taper) holder. No lubricant was applied, for reasons discussed in Section 1. We have used a ball burnisher developed in the Institute of Advanced Manufacturing Technology (IAMT), with bearing balls with the diameter of 8.0 mm. Burnishing was made with orthogonal strategy, perpendicular to the milling direction; the burnishing speed was 6000 mm/min. Burnishing forces $F$ were in turn 50, 100 and 150 N; burnishing feeds $f$ were 0.02, 0.04 and 0.06 mm. Tests were repeated three times for each selected parameters set $F$ and $f$; six geometrical surface measurements were performed to establish surface parameters of milled and burnished surfaces.

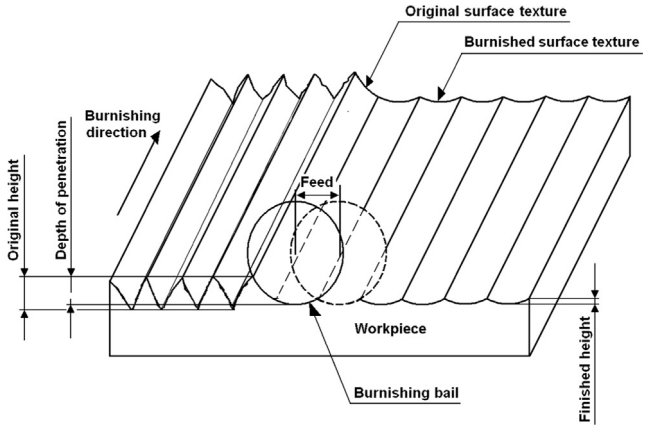



**Fig. 1.** Schematic diagram of the ball burnishing process.

Vickers microhardness $h_{Vickers}$ was determined using a Durascan tester from Struers Sp. z.o.o, Cracow, Poland. Microindentations were made using a 10.0 g load.

Scratch resistance was determined with a Micro-Combi-Tester (MCT) from CSM, Peseux, Switzerland. We used a diamond indenter with the stylus radius $R = 0.2$ mm and applied three different force levels, namely $F = 0.1$, 1.0 and 2.0 N. Young's modulus tests were also performed using the MCT device.

A UMT-2MT ball-on-disc tribometer made by CETR, Campbell, CA, USA, was used. The polymer sample (disc) was rotated against a stationary bearing 100Cr6 steel ball of 6.0 mm diameter at a speed of 477 rpm. The normal contact load $F_n$ was 5.0 N and the total sliding distance was 4000 m each time; estimated Hertzian contact stresses amounted to $\approx 60$ MPa. Samples were not lubricated and tests performed at the room temperature ( $\approx 25$ °C) in air. Specific wear rate $W_s$ was calculated by the standard formula:

$$W_s = \frac{V}{F_n \cdot L} \tag{1}$$

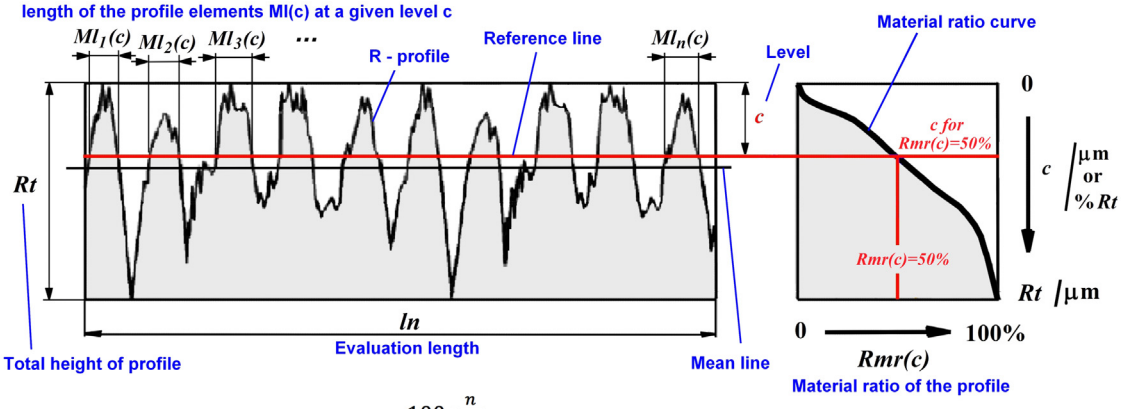
where $V$ is the volume of removed material and $L$ is the sliding distance.

Structures were observed with an optical Carl Zeiss Axiovert 100A microscope. For a given ball diameter, we have investigated the influence of burnishing parameters on selected surface geometry parameters. We have used a Hommel Tester T1000 apparatus for determination of the following parameters: Ra = the arithmetic average deviation of a real surface from the mean line within the assessment length; Rt = the total height of the profile; the mean roughness depth Rz is the arithmetical mean of single roughness depths of successive 10 sampling lengths according to the ISO 4287 standard. On the basis of Ra one can define the ratio

$$K_{Ra} = \frac{Ra'}{Ra} \tag{2}$$

where Ra′ is the value before burnishing and Ra afterwards.

The next parameter we work with is Rmr($c$); as noted in a document from Green Tweed [24], this parameter is "somewhat misunderstood". Consider, therefore, an example of a profile shown in Fig. 2. As already defined above, Rt is the vertical distance from the top of the highest peak to the bottom of the deepest valley. The evaluation length is called ln, presumably because it represents length, somewhat confusing but widely used. Now let




$$Rmr(c) = \frac{100}{ln} \sum_{i=1}^{n} Ml_i(c) \quad [\%]$$

**Fig. 2.** Rmr(c) = material ratio of the profile according to ISO 4287 standard.

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