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Use of roughness probability parameters to quantify the material removed in plateau-honing

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ABSTRACT

This paper presents a new methodology for quantifying the material to be removed in the finish honing operation of plateau-honing using the roughness probability parameters to obtain a specified surface roughness. An estimated Abbott–Firestone curve is obtained, starting from the specified roughness values, which are defined by the roughness probability parameters: the transition bearing ratio (R_{mq}), the valley roughness (R_{vq}) and the plateau roughness (R_{pq}). To evaluate the accuracy of probability parameters for estimating the Abbott–Firestone curve, a series of cylinders were machined via plateau-honing under different conditions. The difference in area between the experimentally obtained curve and the estimated curve, generated from the measured values of R_{mq}, R_{vq} and R_{pq}, was then calculated. This difference was found to be sufficiently small to enable the use of probability parameters and of the estimated Abbott–Firestone curve. In the experiments performed, different grain sizes were used for the rough strokes (64, 91 and 181 [FEPA standard]), and a grain size of 20 was used for the finishing strokes. The roughness of each cylinder was characterised by measuring roughness at nine different points. The average Abbott–Firestone curve of the nine curves was then determined once the extreme curves had been eliminated according to Chauvenet's criterion. The Abbott–Firestone curves obtained from the experiments were averaged by using as height reference the heights of Abbott–Firestone profiles corresponding to 92.5%, 95%, 97.5% and 100% of material. The resulting average curve was compared to the estimated Abbott–Firestone curve. The difference in area between the average curve and the estimated curve was calculated. The smallest difference in area between these curves was found for the reference profile height corresponding to 97.5% of the material. This difference was found to be sufficiently small to enable the use of the probability parameters and of the estimated Abbott–Firestone curve. The average differences in area were 9.2% for a rough grain size of 64, 2.1% for a rough grain size of 91 and 2.3% for a rough grain size of 181. The difference in area between the Abbott–Firestone curve corresponding to the rough honing and the estimated Abbott–Firestone curve corresponding to the finish honing is proportional to the quantity of material to be removed in the finishing operation. This methodology will be used as a preliminary step in future work aimed at predicting the parameters that control the process as a function of the specified roughness.

1. Introduction

Plateau-honing is an ultra-finishing process consisting of two machining operations: rough honing with large abrasive grain size and subsequent finish honing with small abrasive grain size (for partially eliminating peaks on the surface of the piece obtained with the rough machining) (Fig. 1). Plateau-honing implies a multi-Gaussian probability distribution of surface topography, with a primary structure provided by rough honing and a secondary structure provided by finish honing [1,2].

Plateau-honing provides a roughness texture with a good tribological behaviour on two surfaces with relative motion between them, such as cylinders and pistons of internal combustion engines. The oil flows on the cylinder surface through a network of channels formed by the valleys of the surface roughness (cross-hatched pattern) reducing wear between the cylinder and the piston ring, while the low peaks provide tightness between them [2–4]. Although plateau-honing is mainly used in the automotive industry for obtaining cylinder liners and cylinder bores [2,5], it may also be employed for manufacturing hydraulic cylinders [6].

The roughness obtained in the plateau-honing processes is affected by many parameters: type and grain size of the abrasive; density of the abrasive in the stone; type of binder; and pressure, linear speed and tangential speed of the machining process, etc.

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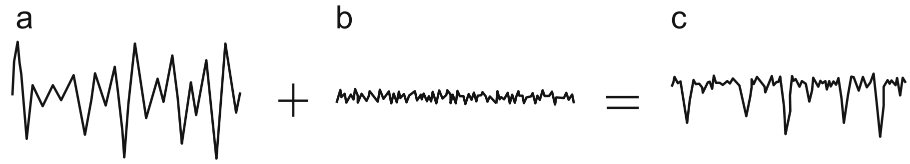

Fig. 1. Roughness profile: (a) rough honing; (b) finish honing and (c) plateau-honing.

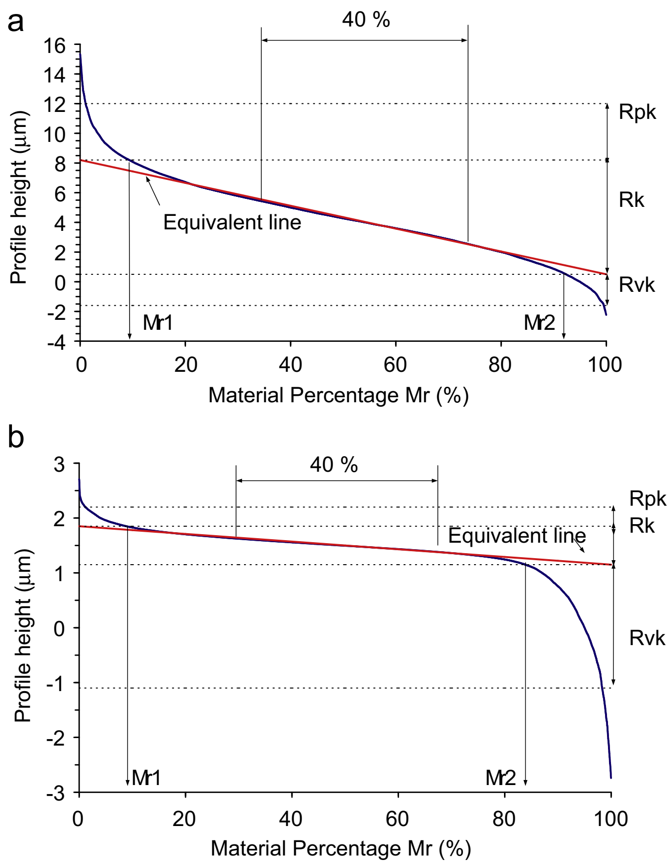

Fig. 2. Abbott–Firestone curve (or material percentage curve) of: (a) a rough honed surface and (b) a plateau-honed surface.

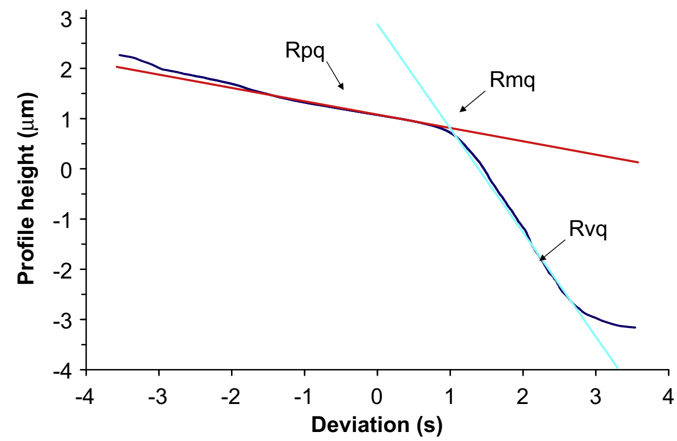

Fig. 3. Material probability plot [8].

[7,8]. Characterising roughness in plateau-honing is difficult, since it is the result of superimposing two roughness patterns: one corresponding to the rough machining and another corresponding to the subsequent finishing [9]. Current analytical models for honing machining [10,11] only provide qualitative information about the roughness obtained; they do not provide the quantitative data required to determine which process parameter values are required for obtaining a predetermined surface finish via plateau-honing.

In most applications, surface roughness is characterised based on roughness parameters such as R_a, R_t, *RMS* and t_p. The Abbott–Firestone curve, or *material percentage curve*, (Fig. 2) [12] has typically been used for surface characterisation in plateau-honing [3,13]. The method for obtaining this curve is described in ISO standard 13565-2 [14].

After rough honing, the roughness profile is quite symmetrical with respect to the mean line. Therefore, the values of R_{pk} and R_{vk} are not too different (Fig. 2a). After plateau honing, the roughness profile shows predominantly deep valleys. As such, parameter R_{vk} is higher than parameter R_{pk} (Fig. 2b). In addition, the slope of the equivalent line is lower for plateau honing than for rough honing.

The main drawback of using the Abbott–Firestone curve to characterise the surface obtained from plateau-honing is the fact that it does not provide knowledge on the respective contribution of each machining process (the rough honing and the finish honing) to the final roughness. In contrast, when roughness probability parameters are used for this task, they enable calculation of the respective contributions of each of these sub-processes to the overall surface roughness. Since material removal in honing is assumed to be random by many researchers, a Gaussian model can be used to describe the roughness of honed and plateau-honed surfaces [15–17]. According to standard ISO 13565-3:1998 [18], an experimental probability curve is obtained as a Gaussian representation of the material percentage or Abbott–Firestone curve (Fig. 3). For stratified surfaces consisting of two Gaussian distributions such as the plateau-honed ones, the probability curve shows two straight zones. Two straight lines are then fitted to the experimental values in order to obtain the estimated material probability plot [13,19]. The usual software employed in profilometers allows obtaining the probability plot as well as the probability parameters defined in the standard from a roughness profile.

The roughness probability parameters listed below are defined by ISO standard 13565-3:1998 [18].

- R_{pq}: the slope of the regression line in the flat zone (plateau); it corresponds to R_q in fine honing.
- R_{vq}: the slope of the regression line in the valley zone; it corresponds to R_q in rough honing.
- R_{mq}, the percentage of material at the plateau–valley intersection (transition bearing ratio).

Moreover, Clark and Grant found that the probability parameters correlate to plateau-honing variables better than do other parameters: R_{pq} relates to the grain size of the finishing stage; R_{vq}, to the grain size of the rough stage and R_{mq}, to the plateau-honing time [20].

In the present work, the estimated Abbott–Firestone curves were obtained from the measured probability parameters and