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A Proposition for New Quality 3D Indexes to Measure Surface Roughness

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Abstract

The average absolute roughness S_a presented in ISO 25178, commonly used in the industry, is not a reliable discriminator of different surface texture types. This paper presents new quality indexes for a 3D characterization of surface texture of diamond cut die inserts used for injected plastic optics in lighting applications. The proposed surface quality indexes, namely floor and ceiling surface quality index ($FSQI, CSQI$) were tested on nineteen different die insert samples. The results of the analysis demonstrate that $FSQI$ and $CSQI$ provide a better understanding and improved discriminator of the texture of different high precision diamond cutting processes than S_a .

Keywords: Plastic lenses; 3D Roughness; Surface integrity; Machining; Precision

1. Introduction

Surfaces are not perfectly smooth and always contain certain irregularities. From a tribological point of view, typically there is an optimal roughness which ensures the best application of the principles of friction, lubrication and wear between interacting surfaces in relative motion. When characterizing surface quality, one must distinguish between form, waviness and roughness. The form represents the shape of the surface (long wavelength) while the roughness represents small irregularities on top of that shape (small wavelength; micrometer scale). The roughness is an indication of the extent asperities can penetrate the opposite surface. It also influences the surface stress conditions, the lubrication regime, the friction and the wear. There are also other reasons to measure surface roughness. For example, in surface finishing, it is important to define the appearance of a surface, how smooth it is and how smooth it needs to be for different engineering applications.

Despite the breadth of available three dimensional (3D) surface topography measurement parameters, professionals continue to evaluate and characterize surface finish solely on the value of the average absolute roughness (S_a). One of the major problems with this approach is that, different profiles can still have close to S_a values [1]. Specifically, a surface with sharp spikes, deep pits, or general isotropy may all yield the same S_a. Therefore, there is a clear need for a list of significant parameters to distinguish the surface texture characteristics created by every individual machining process which also take into account the workpiece's material. The problem becomes even crucial when high precision components need to be machined for high tech applications. In 2010, Petropoulos *et al.* [2] provided an overview of the current knowledge on the association of surface texture with machining, along with recent advances in surface characterization and evaluation. In their study, various texture parameters, adopted or not by ISO standards and their distinctive impacts, were considered for their distinctive power. In 2013, Deltombe *et al.* [3] proposed a multiscale surface topography decomposition method as a new methodology to select, without preconceived notions, the 3D roughness parameters relevant for discriminating different topographies. The material used in the above study was a rolled stainless steel and machined using electrical discharge tool. In 2015, a study of variations of areal parameters on machined surfaces were reported by Pawlus *et al.* [4]. They studied tendencies of parameter variations for various types of

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measured surfaces and selected 3D parameters that were stable for surfaces, but sensitive to surface irregularities.

In the present paper, two surface quality indexes ($SQIs$) are proposed as an alternative to S_a for 3D characterization of surface texture of diamond cut die inserts used for injected plastic optics in lighting applications. The remainder of this paper is organized as follows: The proposed surface quality indexes, namely floor and ceiling surface quality index ($FSQI, CSQI$) are presented in Section 2. Section 3 describes an experimental surface analysis carried out on nineteen different manufactured die inserts followed by a comparison between S_a and the proposed $SQIs$ and a discussion of the results. Finally, a summary is provided in Section 4.

2. The proposed surface quality index

Two surface quality indexes, named Floor Surface Quality Index ($FSQI$) and Ceiling Surface Quality Index ($CSQI$), are proposed as an alternative to S_a. $FSQI$ is a 3D parameter expanded from the roughness (2D) parameter *e* proposed by Kandlikar et al. [6]. In their work, they proposed three roughness (2D) parameters for characterizing the surface roughness feature effect on fluid flow:

- Two parameters from the ASME B46.1-2002 standard [7]: The maximum profile peak height (R_p) and the mean spacing of profile irregularities (R_{sm}).
- A new 2D parameter $e = R_p + F_p$; where F_p is the floor distance to mean line as shown in Fig. 1.

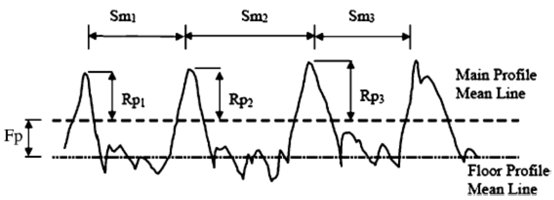

Fig. 1 Illustration of roughness 2D parameters proposed in [6]

The surface can be imagined as a two-dimensional function $Z(x, y)$ defined on the entire $\mathbb{R} \times \mathbb{R}$ domain.

Measurements taken by the confocal microscope sample this function, at discrete points in a finite area. Let Z be a real matrix of heights $Z_{i,j}$ defining the surface where $i = 0, 1,2, \dots N - 1$ and $j = 0,1,2 \dots M - 1$ as presented in Fig. 2.

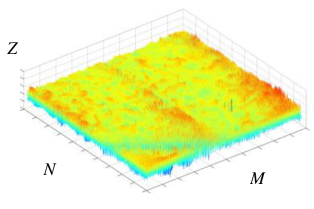

Fig. 2 Surface representation

S_a is a 3D parameter expanded from the roughness (2D) parameter R_a [5] and is presented in equation 1.

$$S_a = \frac{1}{NM}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}|Z_{i,j}| \tag{1}$$

The $Mean\ Plane$ is defined as:

$$Mean\ Plane = \frac{1}{NM}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1} Z_{i,j} \tag{2}$$

Let $z_p \subseteq Z$ be a real matrix of heights $z_{p_{i,j}}$ defining the surface where $i = 0, 1,2, \dots n_p - 1$ and $j = 0,1,2 \dots m_p - 1$ such that all $z_{p_{i,j}} = Z_{i,j}$ if and only if $Z_{i,j} < Mean\ Plane$.

The proposed $Floor\ Plane$ is then defined as:

$$Floor\ Plane = F_p = \frac{1}{n_p m_p}\sum_{i=0}^{n_p-1}\sum_{j=0}^{m_p-1} z_{p_{i,j}} \tag{3}$$

The proposed $FSQI$ parameter is defined as the distance between the $Floor\ Plane$ (F_p) and the maximum peak height (S_p) values of the surface as shown in Fig. 3.

$$S_p = \max_{i,j} Z_{i,j} - Mean\ Plane \tag{4}$$

$$FSQI = S_p + F_p \tag{5}$$

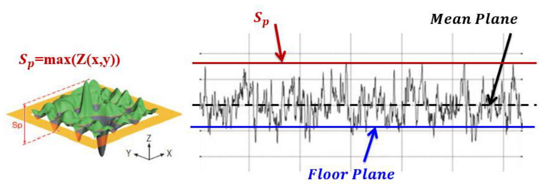

Fig. 3 Floor Surface Quality Index ($FSQI$)

Let $z_c \subseteq Z$ be a real matrix of heights $z_{c_{i,j}}$ defining the surface where $i = 0, 1,2, \dots n_c - 1$ and $j = 0,1,2 \dots m_c - 1$ such that all $z_{c_{i,j}} = Z_{i,j}$ if and only if $Z_{i,j} > Mean\ Plane$.

The Ceiling Plane (C_p) is then defined as:

$$Ceiling\ Plane = C_p = \frac{1}{n_c m_c}\sum_{i=1}^{n_c-1}\sum_{j=1}^{m_c-1} z_{c_{i,j}} \tag{6}$$

The proposed $CSQI$ parameter represents the distance between the $Ceiling\ Plane$ (C_p) and the maximum valley depth (S_v) of the same surface as shown in Fig. 4.

$$S_v = \min_{i,j} Z_{i,j} - Mean\ Plane \tag{7}$$

$$CSQI = S_v + C_p \tag{8}$$