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Characterization of the surface roughness of milled carbon fiber reinforced plastic structures

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Abstract

The surface topography of carbon fiber reinforced plastic composites after machining processes like milling or grinding has a complex character due to the inhomogeneous material structure.
The usual procedure to evaluate the surface topography is given with the usage of parameters that describe one or more specific features of the surface. In mechanical engineering, for example, the roughness parameters Ra, Rz, Rmax and Rt have been established with tactile-based roughness measurement devices. However, the applicability of several parameters is not always suitable for composites.
In this work the influence of the measurement positions, the distribution of the measured values and the behavior of these values in respect to the machined surface structure are analyzed by means of optical as well as tactile surface measurements. This work results in recommendations for the measurability of machined surfaces of carbon fiber reinforced plastics by using tactile profile methods and an assessment of the derived roughness parameters.

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Keywords: surface analysis; roughness; surface topgraphy; machining; composite; fiber reinforced plastics

1. Introduction

Nowadays carbon fiber reinforced plastics have become an integral part in the field of lightweight construction or the aerospace industry. Therefore the quality requirements are particularly high for these high-tech applications. It is a challenge to describe the surface shape by suitable objective measurement methods. Generally the tactile roughness measurement technique is used to specify the quality since corresponding specifications are given on technical drawings.

2. State of the art

A description criterion of the surface shape is given with the Ra parameter as the arithmetic mean of the magnitude of the deviation of the profile from the mean line.

Nomenclature

Ra	[µm]	Arithmetical mean deviation of the profile
Rz	[µm]	Average maximum height of the profile
Rmax	[µm]	Maximum height of the profile
Rt	[µm]	Total height of the profile
λ_c	[mm]	Cut-off wavelength
λ_s	[µm]	Shortwave profile filter
lr	[mm]	Sampling length
lt	[mm]	Traverse length
f_z	[mm]	Feed per tooth
a_p	[mm]	Depth of cut
a_e	[mm]	Width of cut
v_c	[m/min]	Cutting speed
PCD		Polycrystalline Diamond
RTM		Resin Transfer Moulding

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This parameter is used for the assessment of turned [1] and milled [2] glass-fiber reinforced plastic structures, wherein a repetition of the measurement is recommended. This procedure is also suitable for carbon fiber reinforced plastic (CFRP) structures [3]. Another suitable parameter for laminated composites is recommended with the ten-point average height Rz [4], which was also used for analysis in micromachining [5].

With the application of standardized roughness parameters, there is on the one hand the need to exclude untypical surface imperfections such as scratches or voids within the evaluation or rather to evaluate them separately [6] and on the other hand it is required to take account of the 16% rule [7].

Various approaches have been adopted to take account of the heterogeneous material structure by measurement. One attempt is being advanced with the development of new measurement and evaluation methods for heterogeneous materials combining optical as well as tactile methods [8].

Spatial based evaluations in accordance with ISO 25178 or pictures of planar topography machined surfaces are also normatively supported, which have been obtained by measurements with a 3D optical profilometer [9].

Since the current research focuses on suitable methods and parameters for the adequate description of machined surfaces of CFRP, this study is intended to illuminate the applicability of common surface parameters for the surface characterization more deeply. The applicability of different surface parameters is discussed using the example of a segment of a machined surface.

3. Experimental conditions

The experiments to machine the segments were conducted with the process of end milling of grooves with an end milling cutter (Fig. 1). A Mikromat 4V HSC with an andronic CNC control 2060L was used as the CNC machining center. The cutting material for the two-edged milling tool was PCD.

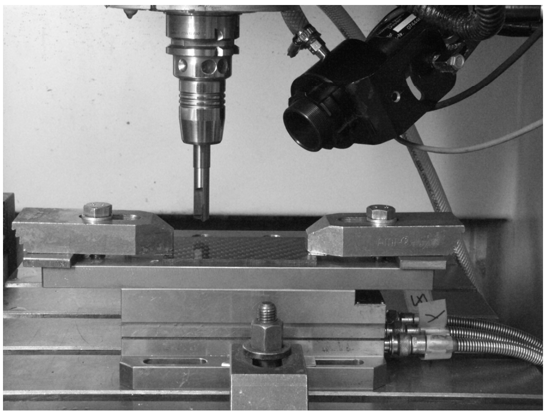

Fig. 1. Experimental set-up for groove milling with a PCD end mill

The experimental material developed at the Technische Universität Dresden in the form of a carbon-fiber reinforced plastic was manufactured with the RTM process.

The composite is characterized by the following structure:

- Epoxy resin system LY556-HY906-DY062
- Twill weave 2/2 with TENAX Fiber HTS 40/12k Style 404 (600 g/m²)
- 8-layer construction with two orientations (orientation: 0°/90° and -45°/+45°)
- Single layer thickness: 600 µm
- Stack sequence (0°/90° $\triangleq$ α; -45°/+45°$\triangleq$ β): αβαβαβαβ

The surface topography was measured with a tactile system Hommel Etamic W5 (Tip radius 2 µm, Cone angle 90°) with nine surface profiles per sample. The surface has been analyzed optically with the Leica DCM 8 system with both the confocal technology and the technology of the focus variation with nine surface profiles each. The cut-off wavelength in connection with a Gaussian filter was chosen with λ_c= 0.8 mm as a high pass and with λ_s= 2.5 µm as a low pass to compensate the tip radius for the optical measurements. All the measurements were repeated at different positions parallel to the feed direction of the tool.

The size of the total measuring field for the optical analysis was adjusted with 4.8 x 4.8 mm². For this stitching was necessary. The reference values for all the measurements on fiber composite regarding the parameters Ra, Rz, Rmax and Rt were acquired by the tactile measurement. All the measurements for the surface profiles were performed parallel to the feed direction.

4. Results and discussion

Before assessing the CFRP surfaces, a method comparison on their measurement and result characteristic of a roughness standard Hommelwerke RNDH 3 for the roughness parameters Ra, Rz, Rmax and Rt was conducted.

This standard made with a fly cutting process was measured tactually parallel to the feed direction of the machining. The optical evaluation, done on the basis of surface scans, was geared to the method of the tactile measurements. Objective lenses with magnifications 20x and 50x were used for the measurements with the focus variation method. For the confocal method exclusively a lens magnification was used with 50x.

With respect to the indications on the roughness standard, it is noted that the tactile measurement on one hand has a deviation of less than 3.5% for both the Ra as well as the Rz value (Table 1).

On the other hand, it is to be noted that the values of the individual measurements carried out at different positions disperse very little so that the variation coefficients are less than 0.01.