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ACCURACY OF REPLICATION OF SURFACE TEXTURE WITH A CONTACT PROFILE METHOD

NATANČNOST PONOVITVE POVRŠINSKE TEKSTURE S KONTAKTNO PROFILNO METODO

Gorana Baršić*, Bernard Nujić, Vedran Šimunović

Faculty of mechanical engineering and naval architecture, University of Zagreb, Ivana Lučića 1, 10000 Zagreb, Croatia

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Surface texture is of great importance in specifying the function of a surface. The surface finish of products influences the friction performance, wear resistance, bearing, sliding, lubricating properties, functionality, etc. Replicas of surface textures are widely used in many industries for evaluating the condition of textures when no measurable surfaces are available for measurements or in the case of non-dismantled objects of immense dimensions. The replication's reliability and accuracy are significant concerns in actual applications. Although there are several parameters, *Ra* and *Rz* are still most often defined in technical product documentation as the indicators of whether a surface texture is within certain tolerance limits. In real production conditions, tactile stylus profilometers are still the most common instruments for measuring surface texture. For all the reasons mentioned above, the accuracy of the Technovit® 3040 replica was analysed. The quality of the Technovit® 3040 replica was researched on 15 samples processed with six conventional machining methods. Average roughness parameters *Ra* and *Rz* were measured on original surfaces and then compared to replica surfaces. A qualitative comparison of the profile geometries of original surfaces and their replicas was discussed.

Keywords: surface texture, stylus profilometers, replica, accuracy, Technovit® 3040

Tekstura ali morfologija površine je zelo pomembna za določitev njene funkcije. Finiš oziroma gladkost površine vpliva na trenje, odpornost proti obrabi, nosilnost, drsenje, mazanje, funkcionalnost itd. Replike različnih površin se pogosto uporabljajo v mnogih industrijah za ovrednotenje stanja teksture, ko so površine ki jih želimo ovrednotiti ali izmeriti težko dosegljive, ali v primeru odstranitve zelo velikih objektov. Zanesljivost repliciranja in njena natančnost sta zelo pomembni za dejanske aplikacije. Na razpolago imamo nekaj parametrov hrapavosti površine kot sta naprimer *Ra* in *Rz* s katerimi najbolj pogosto opišemo površino v produktni dokumentaciji za ovrednotenje površine, ali je ta oziroma ni znotraj zahtevanih toleranc. V realnih pogojih produkcije (proizvodnje) so profilometri s tipalom, pisalom oziroma tanko iglo, ki drsi po površini (angl.: tactile stylus profilometers) najbolj pogosti inštrumenti za merjenje teksture površine. Avtorji zaradi vseh razlogov opisanih zgoraj v tem članku opisujejo analizo natančnosti replik izdelanih z maso Technovit® 3040, ki je hitro sušeča smola na osnovi metil metakrilata. Avtorji so kakovost replik izdelanih s Technovitom® 3040 ocenjevali na 15-tih vzorcih. Replike so odvzeli s površin, ki so bile izdelane s šestimi klasičnimi postopki mehanske obdelave (struženje, ploskovno in bočno brušenje, lepanje in rezkanje). Na originalnih površinah in na replikah teh površin so določili parametra hrapavosti *Ra* in *Rz* ter jih nato primerjali med seboj. V članku nato razpravljajo in kvalitativno primerjajo profilne geometrije originalnih površin z njihovimi replikami.

Ključne besede: površinska tekstura, profilometri s pisalom, replika oz. kopija, primerjava, natančnost, Technovit® 3040

1 INTRODUCTION

Based on the results obtained from a replica, we can determine the condition of surface roughness of the original surface. Therefore, it is essential to reliably determine the quality of the achieved reproduction. There are different replica materials currently available on the market. They differ with respect to the material, the application method and the type of the measuring instrument to be applied.

F. Baruffi et al. investigated the reproduction quality of the commercial silicone replica material RepliSet, manufactured by Struers GmbH, on two specifically designed micro-milled samples made from mould steel.[1] The analysis was based on comparing the values of areal parameters *Sa*, *Svk*, *Spk*, and *Sk*, measured using a confocal microscope. A qualitative comparison between the original surface and their replicas showed that a replica could accurately reproduce the appearance of the micro-milled surface texture. A numerical comparison revealed that the measurements on replicas had consistently overestimated the average roughness of the original surface. However, the analysis of 34 cases out of 36 showed that the replication media RepliSet is suitable for characterising micro-milled surfaces when using a non-contact measuring instrument.

P. Szawara and R. Ostrowski analysed the suitability of RepliSet F5, manufactured by Struers GmbH, to replicate the surface textures of a shaft, tool and grinding wheel.[2] The measurements were carried out using a focal variation microscope and a tactile stylus profilometer. Analysis was focused on the comparison of roughness parameters *Ra* and *Rz*. The authors concluded that RepliSet F5 is not suitable for evaluating the wheel porosity of the grinding wheel used in the research. Due to its high viscosity and fluidity, it penetrates too deep into

*Corresponding author's e-mail:
gorana.barsic@fsb.hr (Gorana Baršić)

the pores and affects the results. However, comparing roughness parameters *Ra* and *Rz* obtained on original surfaces and replicas of four shafts showed the RepliSet F5 suitability for replicating the original surface accurately.

Y. C. Liu et al. investigated three replica materials – Repliset, Technovit and Press-O-Film on four ground surfaces with average roughness values ranging from 0.2 µm to 1.6 µm.[3] Measurements were performed using a tactile stylus profilometer and focus optical microscope. Since RepliSet and Press-O-Film replicas are soft, they were measured using a non-contact method, i.e., a focus optical microscope. Technovit replicas are hard and suitable for measurements using a contact method – a tactile stylus profilometer. The obtained results showed that on the Technovit replica, the *Ra* deviation was within 5 % throughout the analysis measurement range. RepliSet and Press-O-Film replicas exhibited high accuracy in replicating surfaces with *Ra* ranging from 0.4 µm to 1.6 µm; however, they were not suitable for a smooth surface with *Ra* at the level of 0.2 µm.

A literature review revealed that very few published papers analyse the quality and accuracy of replicas in surface roughness metrology, especially replicas that can be measured with contact methods.

It is well known that different machining processes result in different, but for each process characteristic, surface topographies. The typical topography of an original surface can influence the quality of surface reproduction. Therefore, in this study, an analysis was carried out on surfaces processed with six different conventional machining processes.

In real production conditions, tactile stylus profilometers are the most widely used instruments for evaluating the surface roughness and roughness parameters *Ra* and *Rz* are commonly used to measure the surface texture. Therefore, in this study, measurements of roughness parameters *Ra* and *Rz* were carried out using a tactile stylus profilometer.

Most replicas have properties that can only be measured with non-contact methods. One of the rare replica materials, which can be measured, according to its manufacturer Kulzer GmbH, with a contact method, is Technovit® 3040, a two-component resin based on methyl methacrylate.[4] Therefore, the above product was applied to 15 samples produced with six conventional machining processes as the material for making replicas.

2 EXPERIMENT

Samples were selected from five measurement surfaces (N2, N4, N6, N8 and N10) from three different groups processed with conventional machining (groups A, B and C) as presented in **Figure 1**. In group A, the N2, N4 and N6 surfaces were processed by grinding, while N8 and N10 were processed with a side milling procedure. In group B, the N2 and N4 surfaces were processed by lapping, while N6, N8 and N10 were processed with a face milling procedure. And in group C, the N2 and N4 surfaces were processed with superfinishing, while N6, N8 and N10 were processed with a turning procedure.

According to the instructions by the manufacturer Kulzer Technik, the Technovit® 3040 replica material was prepared and applied to the selected surfaces.[5] Technovit® 3040 is a two-component methyl methacrylate resin based on a powder and a liquid component. In this experiment the ratio of powder to liquid was 2:1. A plexiglass mould was made, as shown in **Figure 2**, to facilitate the application of the prepared replica material.

After the replica material had been mixed and poured on measurement surfaces, five minutes were taken to cure the material. Replicas were detached easily from the original surfaces. The replicas of the surfaces from **Figure 1** are presented in **Figure 3**.

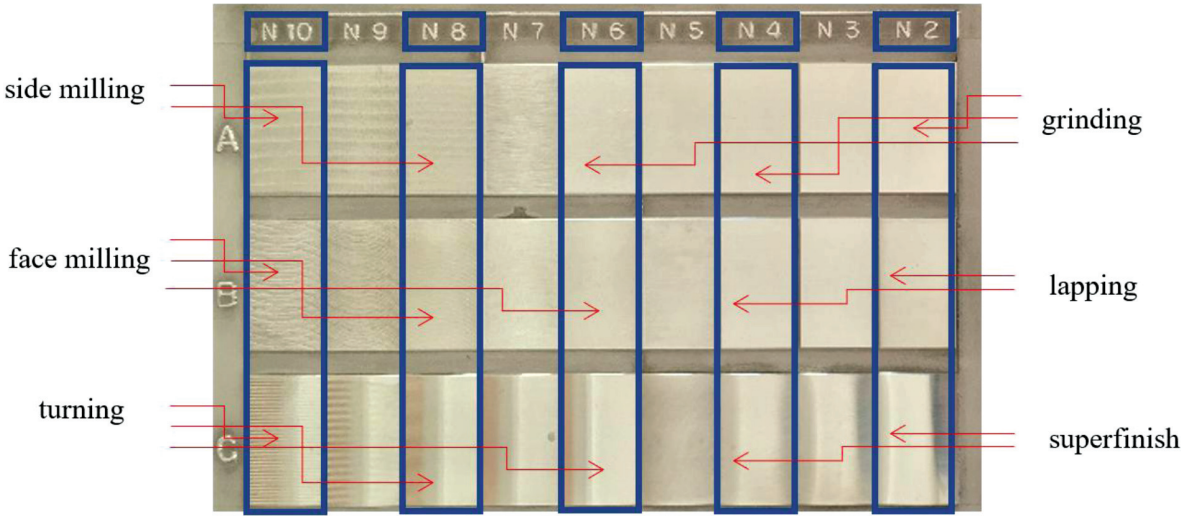


Figure 1: Original surfaces

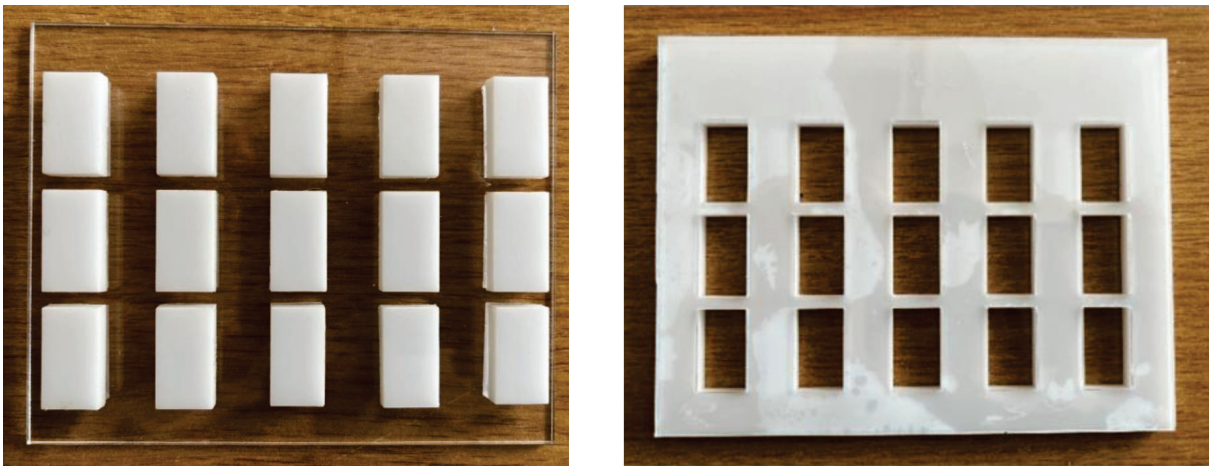


Figure 2: Plexiglass mould

Sign ' was added to distinguish the surface replicas from the original surfaces. Measurements were performed in the Croatian National Laboratory for Length (FSB-LPMD) using stylus instrument Perthometer S8P, manufactured by Mahr Perthen. The stylus instrument was traceably calibrated using the Croatian state standards for roughness. During the measurement, a stylus with a 5 μm radius was traversed normally to the surface at a constant speed and measuring force of 1.3 mN. Filtering was done using a Gaussian filter with the cut-off value of λ_c and evaluation length *ln* as given in **Table 1**.

Table 1: Measurement conditions

Surfaces	λ_c, mm	*ln*, mm
N2, N2'	0.25	1.25
N4, N4'	0.8	4.0
N6, N6'	0.8	4.0
N8, N8'	0.8	4.0
N10, N10'	2.5	12.5

Cut-off values and evaluation lengths were selected according to the texture conditions on all surfaces except for N10 and N10' due to the sample size limit, on which no sufficient trace length could be recorded. However, when measuring the original surfaces and their replicas the same measurement conditions were applied, and reproducibility conditions were fulfilled.

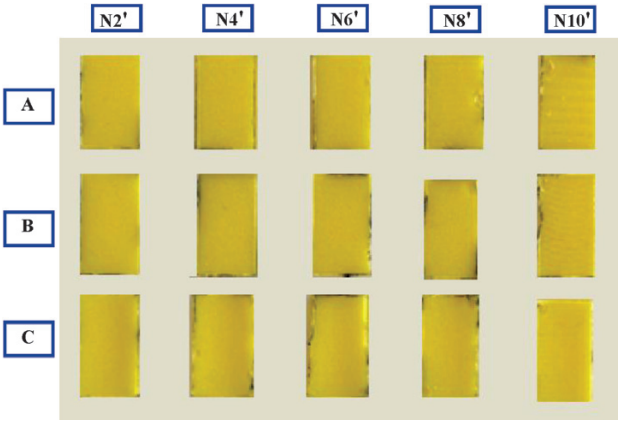


Figure 3: Surface replicas

3 RESULTS AND DISCUSSION

Using the measurement conditions defined in the previous section, five roughness profiles were taken on each measurement surface, and the arithmetical means of roughness parameters *Ra* and *Rz* were calculated and presented in **Table 2**. The results obtained on the original surfaces are marked as N2 to N10, and the results obtained on their replicas are denoted as N2' to N10.'

Table 2: Arithmetical means of *Ra* and *Rz* parameters for original surfaces and replicas

	Group A		Group B		Group C	
	Ra (μm)	*Rz* (μm)	*Ra* (μm)	*Rz* (μm)	*Ra* (μm)	*Rz* (μm)
N2	0.0338	0.3036	0.0514	0.4438	0.0430	0.2784
N2'	0.0458	0.3158	0.0540	0.3782	0.0448	0.2856
N4	0.1622	1.1660	0.1538	1.3638	0.1438	1.5522
N4'	0.1706	1.2346	0.1914	1.4636	0.1982	1.6516
N6	0.6828	4.5984	0.7642	4.6392	0.6736	3.3676
N6'	0.7514	4.8994	0.7162	4.3024	0.6628	3.3658
N8	1.3004	7.2014	3.0340	16.4480	3.3038	12.3800
N8'	1.4986	8.1006	2.8760	16.8300	3.2380	13.6760
N10	14.426	54.634	14.102	64.924	14.530	58.526
N10'	10.346	49.412	12.572	65.744	13.512	55.548

From the results in **Table 2**, relative deviations were calculated and presented in Table 3.

Table 3: Relative deviations of *Ra* and *Rz* parameters for original surfaces and replicas

	Group A		Group B		Group C	
	Δ *Ra* (%)	Δ *Rz* (%)	Δ *Ra* (%)	Δ *Rz* (%)	Δ *Ra* (%)	Δ *Rz* (%)
N2	30.2	3.9	4.9	15.9	4.1	2.6
N4	5.1	5.7	21.8	7.1	31.8	6.2
N6	9.6	6.3	6.5	7.5	1.6	0.1
N8	14.2	11.8	5.4	2.3	2.0	9.9
N10	32.9	10.0	11.5	1.3	7.3	5.2

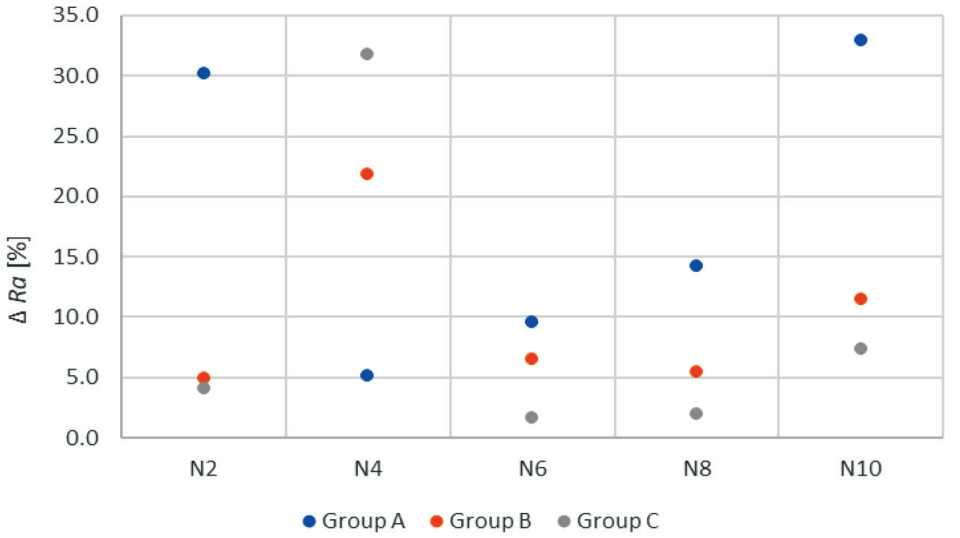


Figure 4: Relative deviations of *Ra* parameter

The results from **Table 3** indicate minor relative deviations of the values of parameter *Rz* compared to relative deviations of the values of parameter *Ra*. Apart from Δ *Rz* obtained on the N2 surface of Group B (lapping) and N8 surface from Group A (side milling), relative deviations of *Rz* parameter are equal to or below 10 %.

Two surfaces from Group A – N2 surface (grinding) and N10 surface (side milling) – and one surface from Group C – N4 surface (superfinishing) – had Δ *Ra* values above 30 %. **Figures 4** and **5** give graphical presentations of relative deviations of the measured roughness parameters.

The relative deviations of parameters *Ra* and *Rz* indicate that the accuracy of the replicas is not dependent on the type of machining process, nor the level of surface finish defined by the N grade ranging from N2 to N10.

To determine whether the uniformity of the texture of a replica was preserved compared to the original surface, a comparison of the ranges of *Ra* and *Rz* values obtained on five roughness profiles on each sample was made. The obtained results are presented in **Table 4**.

Table 4: Ranges of *Ra* and *Rz* parameters on original surfaces and replicas

Ranges (μm)	N grade	Group A		Group B		Group C	
		Original	Replica	Original	Replica	Original	Replica
R (*Ra*)	N2	0.001	0.006	0.004	0.005	0.007	0.005
R (*Ra*)	N4	0.015	0.018	0.015	0.012	0.014	0.006
R (*Ra*)	N6	0.101	0.055	0.255	0.023	0.030	0.016
R (*Ra*)	N8	0.339	0.151	0.521	0.340	0.120	0.150
R (*Ra*)	N10	2.29	1.4	5.08	1.16	0.48	0.14
R (*Rz*)	N2	0.066	0.105	0.068	0.065	0.220	0.042
R (*Rz*)	N4	0.128	0.239	0.358	0.094	0.181	0.046
R (*Rz*)	N6	0.270	0.972	1.320	0.159	0.154	0.172
R (*Rz*)	N8	2.058	1.788	2.350	3.740	0.430	4.900
R (*Rz*)	N10	4.61	3.99	17.93	2.51	1.45	0.66

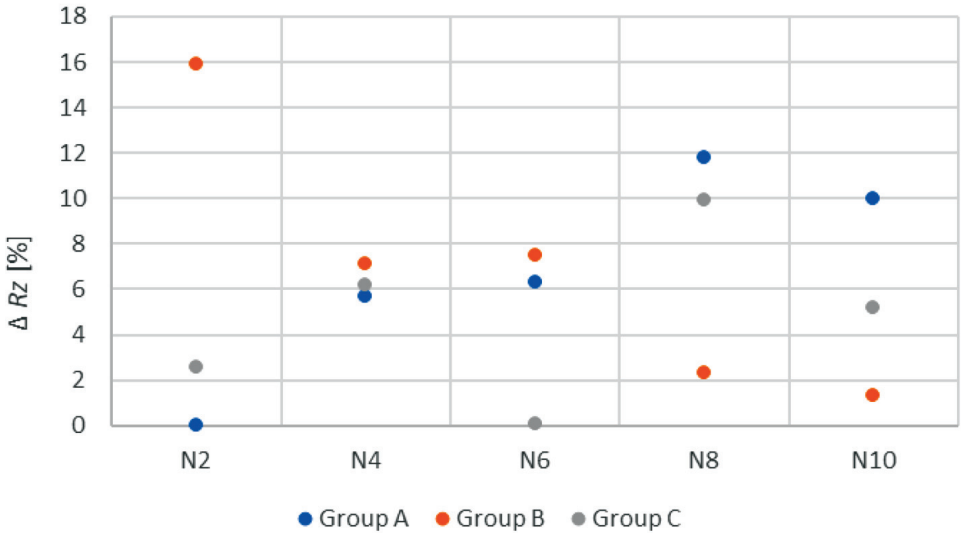
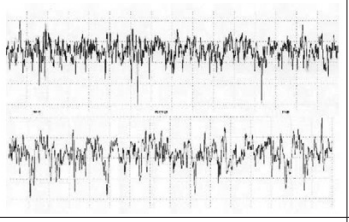
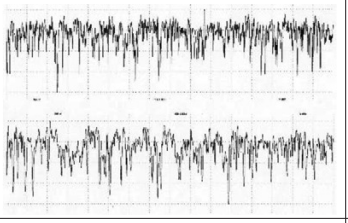
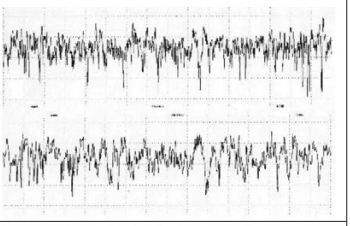
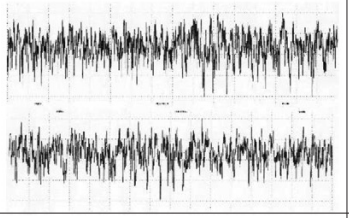
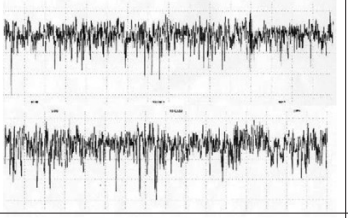
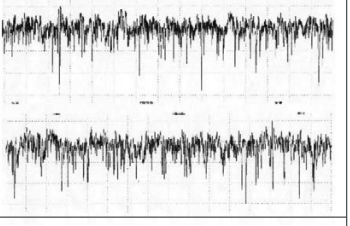
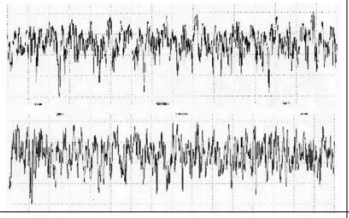
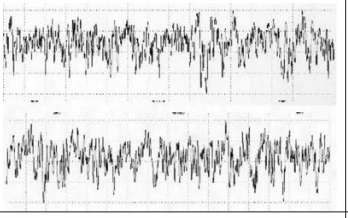
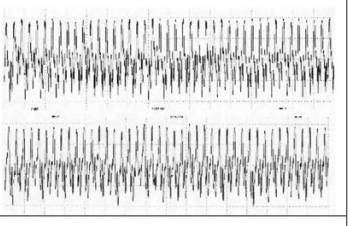
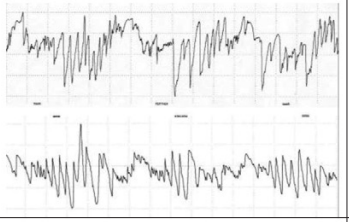
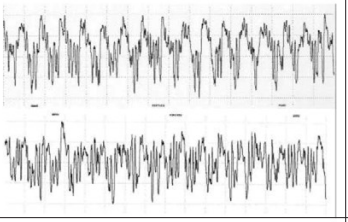
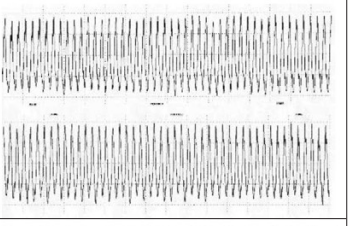
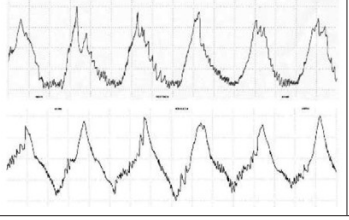
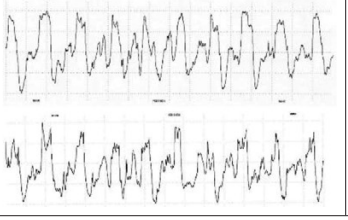
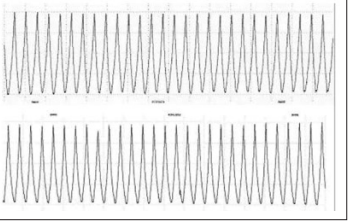


Figure 5: Relative deviations of *Rz* parameter

Table 5: Roughness profiles on original surfaces and replicas

	Group A	Group B	Group C
N2			
N2’			
N4			
N4’			
N6			
N6’			
N8			
N8’			
N10			
N10’			

As expected, by increasing the N grade, range values are also increasing. However, the values of the range, for the *Ra* parameter and *Rz* parameter, do not show any trend in terms of increasing or decreasing their values achieved on the replica surfaces as compared to the original surfaces. Both parameters are reasonably close for the original surfaces and their replicas. The geometries of roughness profiles in **Table 5** also support this conclusion.

From the roughness profiles presented in **Table 5**, a good reproduction of characteristic geometries of roughness profiles for different machining processes was determined. This corroborates that the applied replica material did not violate the surface textures.

4 CONCLUSIONS

Surface texture is of great importance in specifying the function of a surface. The surface finish of a product obtained with a manufacturing process influences the friction performance, wear resistance, bearing, sliding, lubricating properties, functionality, etc. Therefore, surface properties are checked to be within certain roughness limits in the manufacturing industry. The surfaces outside these limits would result in failures in the performance of the product.

When surfaces are challenging to access with measuring instruments or when parts are difficult to be dismantled for measurement, the only way to determine the condition of a surface texture is to apply a replica. In that case, it is necessary to have quantitative information about the accuracy of the reproduction.

A literature review found very little published research on the accuracy of replicas made of commercially available replica materials. A review of commercially available replica materials found that the proportion of replicas that can be measured with contact methods is significantly lower than those declared to be measurable only with non-contact methods. On the other hand, in real production conditions, contact profilometers are still the most common devices for measuring surface texture.

It should not be neglected that different machining processes result in characteristic surface textures. The question can be raised to what extent an applied replica accurately reproduces a surface processed, for example, by turning or grinding.

Although there are several parameters, *Ra* and *Rz* are still most often defined in technical product documentation as the indicators of whether a surface texture is within certain tolerance limits.

For all the above reasons, an analysis of the accuracy of the Technovit® 3040 replica, which the manufacturer Kulzer Technik declares suitable for contact measurements, was conducted. The measurements were carried out using a Perthometer S8P calibrated contact profilometer. Roughness parameters *Ra* and *Rz* were measured on 15 samples processed with six conventional machining processes and with N2, N4, N6, N8 and N10 grade values. On every sample and its replica, five roughness profiles were taken, and arithmetical means of the *Ra* and *Rz* parameters were calculated. From arithmetical means, relative deviations of the *Ra* and *Rz* values were calculated.

Minor relative deviations of the *Rz* parameter values compared to relative deviations of the *Ra* parameter values were determined. Apart from Δ *Rz* obtained on the N2 surface of Group B (lapping) and N8 surface from Group A (side milling), relative deviations of *Rz* parameters were equal to or below 10 %. Only two surfaces from Group A – N2 surface (grinding) and N10 surface (side milling) – and one surface from Group C – N4 surface (superfinishing) – had Δ *Ra* values above 30 %.

A comparison of the ranges of *Ra* and *Rz* values obtained on five roughness profiles on each sample was made to determine whether the uniformity of the texture of a replica was preserved compared to the original surface. The obtained ranges for the original surfaces and their replicas are reasonably close. The results do not show any trend in increasing or decreasing the values achieved on a replica surface compared to the original surface.

It is important to emphasise that relative deviations of the *Ra* and *Rz* parameters indicate that the accuracy of a replica is not dependent on the type of machining process, nor the level of surface finish defined by the N grade ranging from N2 to N10. Also, comparing the roughness profiles obtained on originals surfaces and their replicas showed a good reproduction of the characteristic geometries of roughness profiles obtained with different machining processes.

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