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Traceable surface characterization using replica moulding technology

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Abstract

Characterization of ultra-finely finished surfaces (e.g. mirrored surfaces or polished specimens) is nowadays challenging due to possible part damage if a contact instrument is used or due to scattered light if the measurements are performed with optical instruments. In order to prevent these problems, surface replication is considered as a method to make feasible the characterization of the polished specimens. This paper focuses on the investigation of surface characterization based on replication methods using soft and hard polymer casting. The study deals with the evaluation of the replication degree between the master and the replica as well, the different replication materials involved, the different instruments used and the calculation of the measurement uncertainty for both sub-micro surface topography and micro geometrical measurements.

Keywords: Replication, Micro manufacturing, Reference standard, Uncertainty.

1. Introduction

Challenges in the characterization of ultra-finely finished surfaces and new techniques for near-surface characterization are emerging, especially regarding the difficulties in measurement, or when the definition of new, sound procedures are required [1]. To avoid damages of the surface, non contact measurements are usually preferred amongst other methods. Unfortunately this is not always possible because low roughness on metallic materials, as polished surfaces, quite often results in mirror-like surfaces that invalidate the optical measurements. One solution is to reproduce these surfaces using a polymer material to avoid these problems and to make feasible the measurement of polished specimens. In this paper reference artefacts are used in order to evaluate the replica moulding techniques using soft and hard polymer casting for both sub-micron roughness and micro dimensional measurements.

2. Reference artefacts

Three artefacts were chosen as masters: two for surface characterization and one for geometrical evaluation.
The first two are calibrated roughness standards with the same nominal Ra, but different profiles. One presents a periodic triangular profile with a Ra equal to 0,503 µm ± 0,013 µm (expanded uncertainty, k=2, confidence

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level=95%), see Fig.1a. The other one has a random profile repeated every 4 mm with a Ra equal to 0,481 ± 0,012 µm (expanded uncertainty, k=2, confidence level=95%), see Fig. 1b.

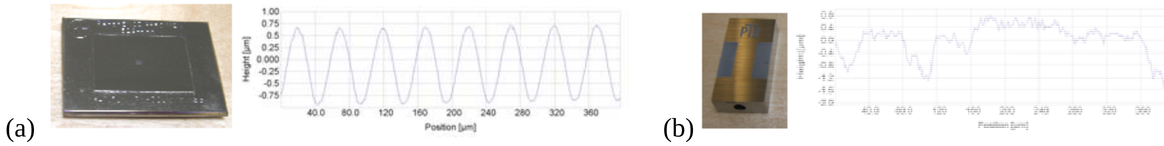

Fig. 1. (a) Roughness standard with a periodic triangular profile; (b) Roughness standard with a random profile.

The third artefact is a contour profile developed by PTB [2] characterized by several different geometries like cylinders, wedges, height steps or grooves. The investigated section is underlined by the red circle (see Fig. 2) and it is highlighted by 6 regions: 3 height steps (S2, S4, S6) and 3 grooves (S1, S3, S5) with nominal vertical dimensions values of 250 µm, 500 µm, 1000 µm and an uncertainty equal to 0,75 µm (expanded uncertainty, k=2, confidence level=95%).

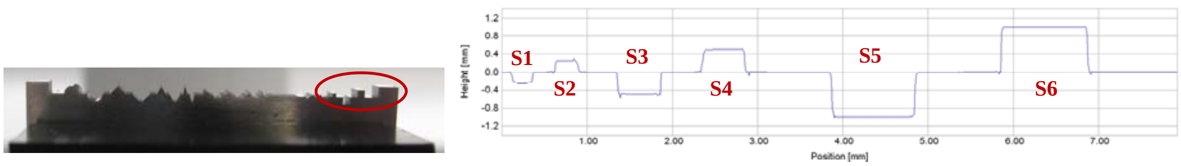

Fig. 2. Contour profile. The red circle highlights the profile section where the investigation is focusing.

3. Replica process

The replica production was performed using a compound supplied in cartridges containing both the polymer and the curing agent, which are automatically mixed in a disposable static-mixing nozzle during the application to the surface. Three compounds were involved: a blue hard material made by acrylic resin, glass powder and silica used for dental applications; a grey soft silicone material and a red soft silicone compound, see Fig. 3 and 4. The blue material and its stability were previously investigated for widths of 2-4 mm in [3; 4].

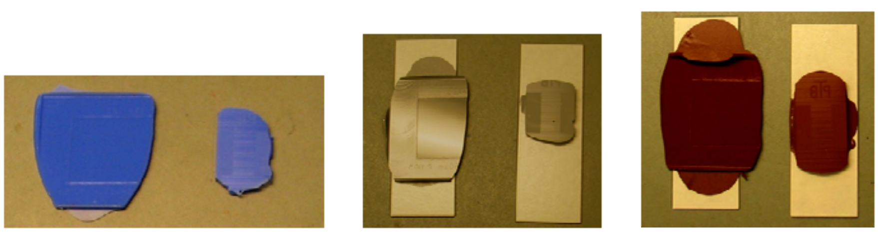

Fig. 3. Replica of the roughness artefacts using the three compounds involved.

Fig. 4. Replica of the contour profile using the three compounds involved.

4. Measurements

The involved measuring instruments have been a contact and an optical instrument. The contact instrument used is a reference stylus which has been established to provide testing and calibration services under accreditation with a

declared uncertainty of 2%. The optical instrument, based on focus variation, combines small focus depth of an optical system with vertical scanning.
Regarding the roughness specimens, the reference standard and the blue replica were measured using the contact instrument; while the grey and the red replicas, since they are soft, were measured using the optical machine. 3D measurements of 300 x 300 μm^2 have been carried out in five well defined areas on the specimens.
Regarding the contour profile, five measurements for each of the six sections, depicted in Fig. 2, were performed using the optical instrument and compared with the calibration certificate values [2].

5. Results

5.1. Results roughness artefacts

Fig. 5 shows the results for the two roughness reference standards and their replica characterization. The replication degree achieved is around 4-5% which falls inside the uncertainty range of the reference standard (0,029 µm for the periodic profile and 0,057 µm for the random profile).

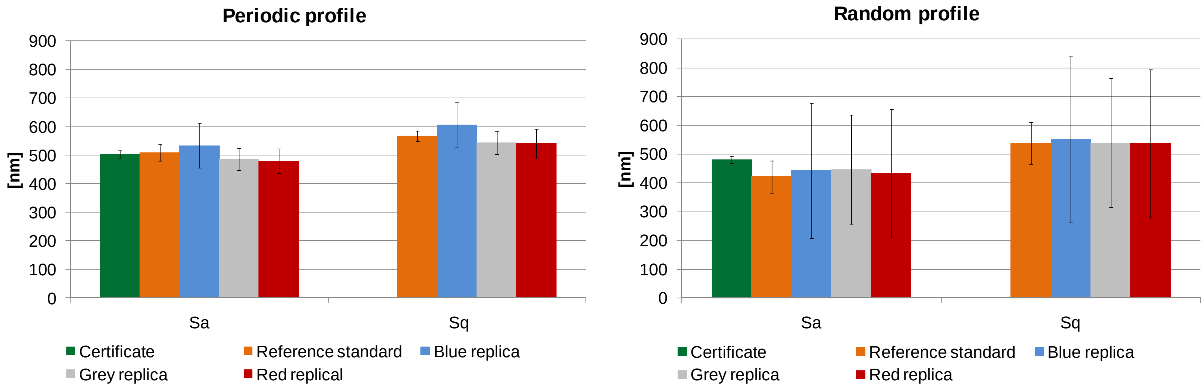

Fig. 5. Sa and Sq values obtained from the periodic and the random profile carried out using different instruments.

5.2. Results contour profile

Fig. 6 shows the results for the contour profile standard and its replica characterization. In the present investigation, the replication degree achieved is different from material to material: for the blue replica it is around 9%; for the grey one 8% and for the red replica 1%. Moreover it seems that using the blue and the grey material, the valleys and the grooves are replicated lower and less deep than the reference one.

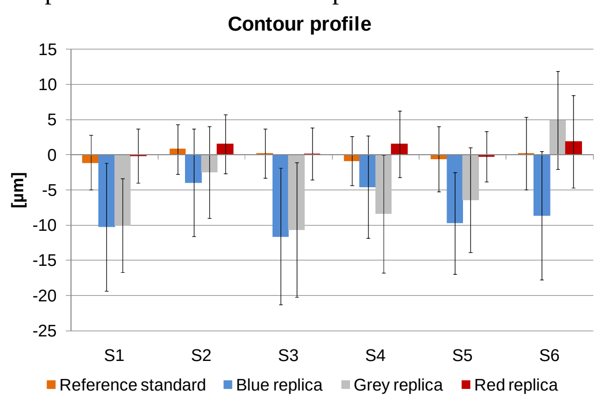

Fig. 6. Deviation of the measurement values from the nominal ones of the heights (S2, S4, S6) and the grooves (S1, S3, S5).

6. Uncertainty

6.1. Uncertainty roughness measurements

The uncertainty budget of the roughness measurements on the periodic and on the random artefacts was estimated following ISO 15530-3 [5] and the results are summarized in Table 1. The expanded uncertainty was calculated using a confidence level of 95% (k = 2) and four contributors were considered (see equation (1, 2)):

- calibration uncertainty (u_{cal}): given by the calibration certificate if the measurements are performed using the tactile instrument (on the reference standard and on the blue replica). In case of optical instruments (on the grey and on the red replica), the calibration values was given by measurements carried out on the reference specimen and on the replica itself using an atomic force microscope;
- resolution uncertainty (u_{res}): the z-vertical resolution used during the optical measurements;
- instrument uncertainty (u_{instr}): the declared instrument uncertainty of the contact profilometer;
- repeatability of the measuring process (u_{rep}): the standard deviation of the measurements on the five defined areas of the specimens.

$$U_{contact} = k \cdot \sqrt{u_{cal}^2 + u_{instr}^2 + u_{rep}^2} \quad (1) \qquad U_{optical} = k \cdot \sqrt{u_{cal}^2 + u_{res}^2 + u_{rep}^2} \quad (2)$$

Looking at the results for the periodic profile, larger uncertainties are obtained from the blue replica and the main contribution is the repeatability of the measurements. This leads to the conclusion that the hard material is less suitable for roughness replication, taking into account also the replication degree which is in the order of -5%. The uncertainties obtained from the other specimens prove that the optical measurements are adequate and therefore the roughness random artefact can be verified even if the measurements are focussed only on a measuring range of 300 µm instead of the length of 4 mm defined by ISO 4288 [6]. This explains the considerable uncertainties which come from the measurements performed in five different areas of the random profile specimen.

Table 1. Standard uncertainty contributors for the roughness measurements on the periodic and random artefacts.

[µm]	**Sa (Periodic profile)**				**Sq (Periodic profile)**			
	Reference	Blue	Grey	Red	Reference	Blue	Grey	Red
U	0,029	0,078	0,038	0,043	0,018	0,077	0,040	0,050
	Sa (Random profile)				**Sq (Random profile)**			
[µm]	Reference	Blue	Grey	Red	Reference	Blue	Grey	Red
U	0,057	0,234	0,190	0,223	0,072	0,288	0,224	0,257

6.2. Uncertainty contour profile measurements

The uncertainty budget of the dimensional measurements was also estimated following ISO 15530-3 [5] and the results are summarized in Table 2. The expanded uncertainty was calculated using a confidence level of 95% (k = 2) and four contributors were considered (see equation (3)):

- calibration uncertainty (u_{cal}): given by the calibration certificate of the PTB contour profile [2];
- resolution uncertainty (u_{res}): the z-vertical resolution used during the optical measurements;
- repeatability of the measuring process (u_{rep}): the standard deviation of the five measurements performed on the specimen.

$$U_{optical} = k \cdot \sqrt{u_{cal}^2 + u_{res}^2 + u_{rep}^2} \quad (3)$$

Looking at the results, the specimen having values compatible with the reference ones is the red replica. The blue replica shows the largest uncertainty. The main contributor of the uncertainty is the repeatability of the measurements: approximately 4 µm, half of the combined expanded uncertainty.

Table 2. Standard uncertainty contributors for the measurements on the contour profile.

[µm]	**S1**				**S2**				**S3**			
	Reference	Blue	Grey	Red	Reference	Blue	Grey	Red	Reference	Blue	Grey	Red
U	3,9	9,1	6,6	3,8	3,5	7,7	6,5	4,2	3,5	9,7	9,6	3,7
[µm]	**S4**				**S5**				**S6**			
	Reference	Blue	Grey	Red	Reference	Blue	Grey	Red	Reference	Blue	Grey	Red
U	3,5	7,3	8,4	4,7	4,6	7,2	7,4	3,6	5,2	9,1	7,0	6,6

7. Conclusions

Surface replication is considered as an alternative method to prevent problems regarding the verification of difficult-to-measure specimens, as polished or mirrored surfaces which could not be measured using either optical or contact instruments. The high reflection of the light invalidates the optical results, while the verification using a contact profilometer leads to scratches on the surface and therefore damages on the specimens.

This paper focused on the investigation of surface characterization based on replication methods using soft and hard polymer casting of two roughness artefacts (nominal Ra = 0,5 µm) and a contour profile (with height/depth of 250-500-1000 µm). Results of the roughness standards showed a replication degree equal to 4-5% and uncertainties in the order of the reference standard. For the contour artefact, the replication degree is in the order of 8-9% for the hard replica and 1% for the soft-red replica. In both case studies the better material is the soft one due to its high replication fidelity on every kind of surface. On the other hand its soft nature does not permit contact measurements. The hard material is useful for verification using profilometers or contact instruments as CMM, but the replication technique is more difficult and time consuming.

Acknowledgements

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References

[1] P.M. Lonardo, D.A. Lucca and L. De Chiffre, “Emerging Trends in Surface Metrology”, Annals of the CIRP, 2002, 51(2): 701-723.

[2] Calibration certificate - Micro-contour standard, reference number: PTB-05.4021640, 2005.

[3] L. De Chiffre, S. Carmignato, A. Cantatore, J. D. Jensen, “Replica calibration artefacts for optical 3D scanning of micro parts”, Proceedings of the Euspen International Conference – San Sebastian - June 2009, vol. 2, p. 352-355.

[4] A. Cantatore, L. De Chiffre, S. Carmignato, “Investigation on a replica step gauge for optical 3D scanning of micro parts”, Proceedings of the Euspen International Conference – Delft - June 2010, vol. 1, p. 200-203.

[5] ISO/TS 15530-3: “Geometrical Product Specification (GPS) – Coordinate measuring machine (CMM): Technique for determining the uncertainty of measurement – Part 3: Use of calibrated workpieces or standards”, 2004.

[6] ISO 4288: “Geometrical Product Specifications (GPS) – Surface texture: Profile method – Rules and procedures for the assessment of surface texture”, 1996.