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# Step-height measurements on sand surfaces: A comparison between optical scanner and coordinate measuring machine

Kamran Mohaghegh, Seyed Alireza Yazdanbakhsh, Niels Skat Tiedje, Leonardo De Chiffre

*Department of Mechanical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark*

*Email: kamoh@mek.dtu.dk*

**Abstract**

As with other manufacturing processes, modern casting is aiming at higher precision. To this, traceable measurements on sand moulds have become necessary. Optical 3D scanning offers a high degree of flexibility but suffers from lack of traceability, in particular when the object is sand. In this work step-heights ranging from 0.1 mm to 5.0 mm were made on 6 customised sand samples with an average grain size of 230 µm, produced using a hard binder that can be scanned both by tactile and optical probes. The step-heights were measured using a CMM with ø8 mm tactile probe. An optical 3D scanner based on triangulation principle using fringe projection was also used to measure the step heights resulting in a point cloud for each scanning. A similar measurement procedure with scanner was made using the scanners software to simulate a ball probe with the same size of CMM probe and following the same routine to touch the different positions on the polygonised mesh. Each measurement was repeated 5 times. The results of step height measurements on sand surfaces showed a maximum error of ± 12 µm for CMM, while scanner shows only ± 4 µm. Generally speaking, optical step height values were measured up to 27 µm larger than CMM measurements. A conclusion from this investigation is that CMM cannot be used to ensure traceability of optical measurements on this type of surface.

Keywords: metrology, traceability, optical 3D scanning, sand

## 1. Introduction

Dimensional measurement on sand moulds for automatic casting lines is investigated. The type of sand used in this production, green sand, has a low mechanical strength and is therefore not suitable to withstand the force of a tactile CMM. Recent advances in optical 3D scanning have given the authors the possibility to open up a new field in dimensional investigation of sand moulds without contact. Furthermore optical scanners are mobile, so the mould can be measured on the moulding unit. Finally the optical scanning process is much faster compared to tactile measurements; therefore it has the potential to serve on-line dimensional quality control. The main challenge to implement optical scanning is how to make the measurements traceable. The proposed solution is to make use of substitution method described in ISO 15530-3 [1] by manufacturing a sand sample with the same surface cooperativeness (colour and texture) but using a hard binder, which could be used for optical scanner and tactile CMM enabling an instrument comparison study on sand. Use of optical 3D scanning with fringe projection based on triangulation was examined in this paper in connection with the measurement of step heights made of sand. Purpose of the investigation was to assess the optical results by comparing them with traceable tactile measurements.

## 2. Experiments

The sand samples were made using the hard binder to substitute the ordinary green sand samples. Figure 1 shows surface visualization on the hard sample using variable focus microscope. The average grain size was 230 µm and the surface height variation was in the range of 500 µm (*Ra = 60 µm).*

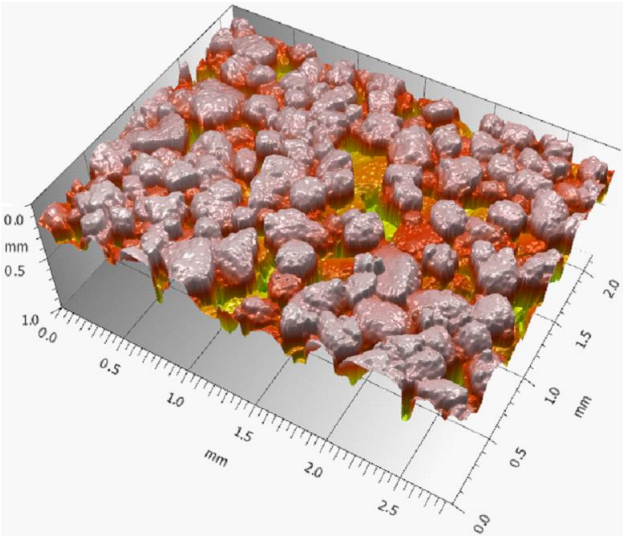


**Figure 1.** Surface of a sand sample measured with a variable focus microscope. Horizontal dimensions: 3 mm x 2 mm, Vertical range: 500 µm.

Six step height sand samples (0.1, 0.2, 0.5, 1, 2, 5) mm with 50 mm diameter were made with two surfaces A and B. Measurement of the step height was performed on a Zeiss OMC 850 tactile CMM. The maximum permissible error of the CMM was $\mathrm{MPE} = 3 + \mathrm{L}/250$ µm. The probe configuration was a vertical probe with 8 mm diameter and 16 mm length. Environmental temperature was measured in the range 20.1 °C to 20.6 °C. A 2 mm gauge block with a calibration uncertainty of 0.1 µm (k=2 for 95 % confidence level) was used as calibration reference. The optical experiments were performed with ATOS III triple scanner (rev. 02) with blue light fringe projection and analysis of the point clouds was made using the GOM-inspect professional software. The system used had two 8 mega pixel

CCD cameras, a measuring volume of (320 x 240 x 240) mm and 0.104 mm distance between measurement points. The optical scanner was calibrated on black and white reference panels under the same laboratory conditions as the CMM.

Each sample was first fixed on the CMM and aligned based on the lower plane A (fig. 2). A fixed program including 50 touch points per each plane was performed and was repeated 5 times. The sample was not replaced between repeated measurements. Optical scanning was performed by scanning around the sample in 4 fixed positions and scanning parameters were kept the same. The point clouds were polygonised and aligned in the same way as for CMM measurements (fig. 2). The CMM ball probe was simulated in the software and used for calculation of the 50 contact points with the mesh for surfaces A and B for each scanning. Scanning was repeated 5 times for each sample to examine the repeatability. The surface of the sand is very rough fig.2 (top-right), but a polygonised mesh (fig. 2 bottom-right) is smoother than the real sand surface, which is due to low resolution of the scanning (0.104 mm) compared to the average grain size of the sand (0.230 mm).

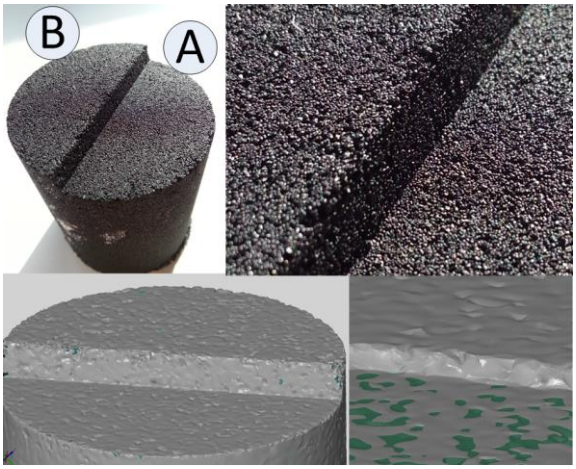


**Figure 2.** Top-left: The step height sample made with the hard binder; Top-right: closer view of the step on sand; Bottom-left: polygonised mesh; Bottom-right: closer view of the polygonised mesh.

### 3. Results and discussion

A total of 12 sand surfaces (two step surfaces in 6 step height samples) have been investigated by both CMM and scanner each with 5 repetitions. The maximum STD of height in 5 repetitions for each surface is shown in figure 3.

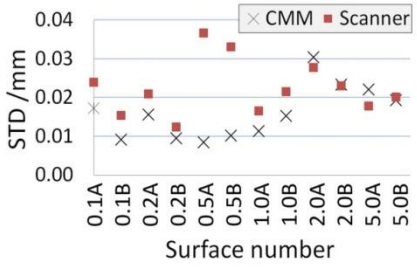


**Figure 3.** Maximum STD of height for 50 points with 5 repetitions for each sand surface.

Figure 3 shows that under the worst conditions STD of optical scanning on this type of sand surface cannot exceed 37 µm. The maximum STD for height measurements by CMM is 30 µm.

The location of each surface in this study is defined by the average of 50 measured points.

In figure 4 the height values for each surface is separately presented. For each surface (i.e. step sample 0.1 side A) the CMM measurement is set as zero and only an error bar in gray is shown. Then the measured value by optical scanner is presented on the right side as a column presenting bias and a solid error bar. The value for each error bar in this figure is based on 95 % confidence level.

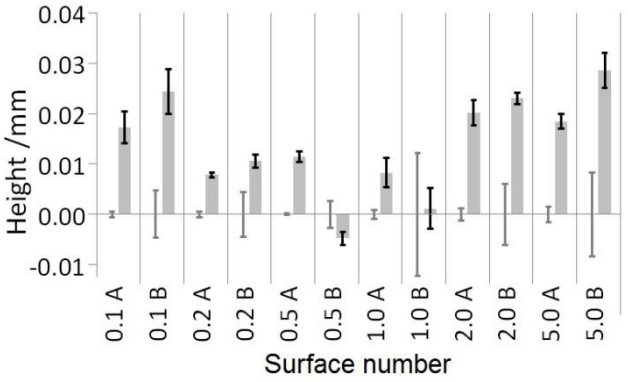


**Figure 4.** Bias and error of the optical measurements (solid error bars) compared to CMM (light error bars) in hard samples.

The maximum error of the CMM measurements among all surfaces shown in figure 4 is ± 12 µm (occurred in step height 1 mm, surface B), while scanner had ± 4 µm respectively (step height 0.1 mm, surface B). Bias of the optical scanner was generally positive up to 27 µm. In the case of step height 5 mm the maximum bias of the optical scanner was 32 µm.

### 4. Conclusion

In this paper a comparison has been made between optical scanning and CMM on sand surfaces which represent the green sand surfaces (Ra 60 µm) commonly used in the casting industry. Results of measurements on 12 flat sand surfaces, each with 5 repetitions show that the maximum STD of the CMM with Ø 8 mm probe and scanner was in the same range (STD = 30 µm for CMM and STD = 37 µm for scanner).
The results of step height measurement showed that between steps ranging from 0.1 mm to 5 mm made of sand, the maximum error of CMM was ± 12 µm, while scanner showed only ± 4 µm. Therefore it can be concluded that traceability of optical scanning on sand surfaces cannot be stablished through CMM measurements. The bias of optical measurements was usually positive and variable up to 27 µm higher than CMM measurements.

### Acknowledgments

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#### References

[1] ISO 15530-3: 2011, “Geometrical product specifications (GPS)-coordinate measuring machines (CMM): technique for determining the uncertainty of measurement-Part 3: Use of calibrated workpieces or standards” (Geneva).