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Towards nanoimprint lithography on free-form surfaces: A global/local modelling approach for predicting the deformation of the flexible stamp

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Introduction

In literature, nanoimprinting on simple curved surfaces using flexible materials has recently been demonstrated. [1, 2, 3]. In those papers the resolution limit due to distortion of the stamp when the pressure was applied, and complications regarding deformations of the flexible stamp, are addressed as major concerns when dealing with flexible stamps on non-planar surfaces. For the nano-structures in this study, generating a color effect [4] (see Fig. 2), a change in wave length of 1-2 % will have a huge impact of the color reflected from the surface. The deformations are therefore essential to take into account, when designing the planar silicon master stamp. The aim of the present study is to use the multi-scale modelling approach in order to predict the deformations of the nanostructures for nanoimprint lithography on larger curved surfaces using flexible PTFE stamps. Here the simulation is split into two sequentially coupled models: One taking care of the global deformations and stretches of the flexible stamp, and a coupling to a submodel taking care of the local deformations of the actual nanostructures.

Method

The local sub model is coupled to the global model by a transfer of calculated displacements of an element in the global model to pre-scribed displacement on the boundaries of the local model, see Fig. 1.

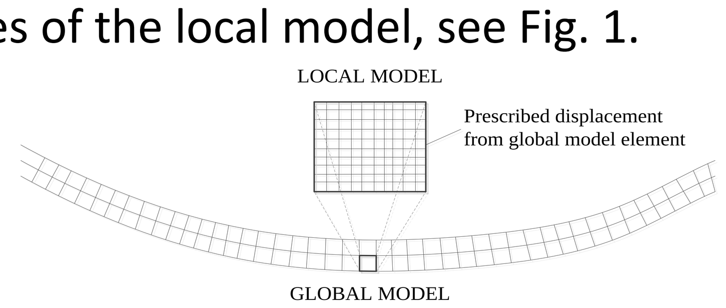

Fig. 1: Schematic illustration of how the local model is coupled to the global model.

The global and the local model were coupled through a subroutine in the general purpose finite element software ABAQUS. The PTFE flexible stamps was described by a viscoelastic constitutive model [5].

Results

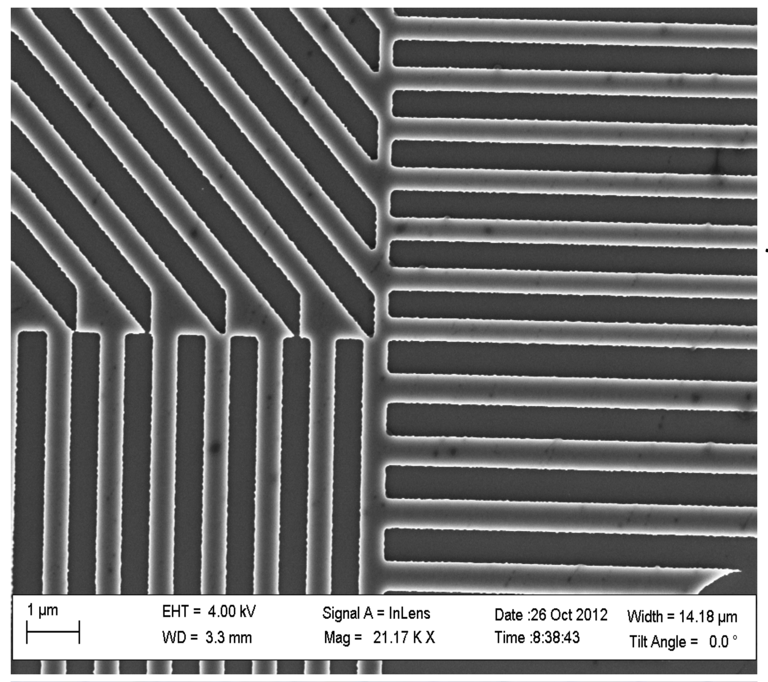

Fig. 2: Close-up SEM image of the intersection between four different areas with different periods and orientations.

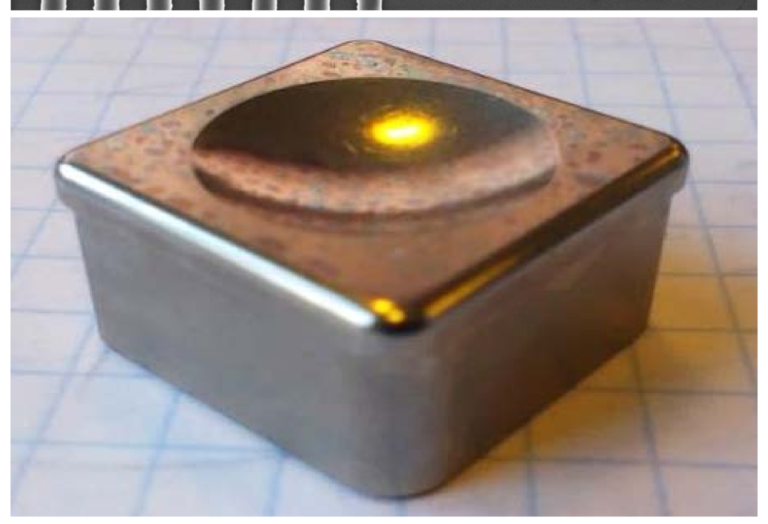

Fig. 3: Fabricated tool insert for use in this experiment.

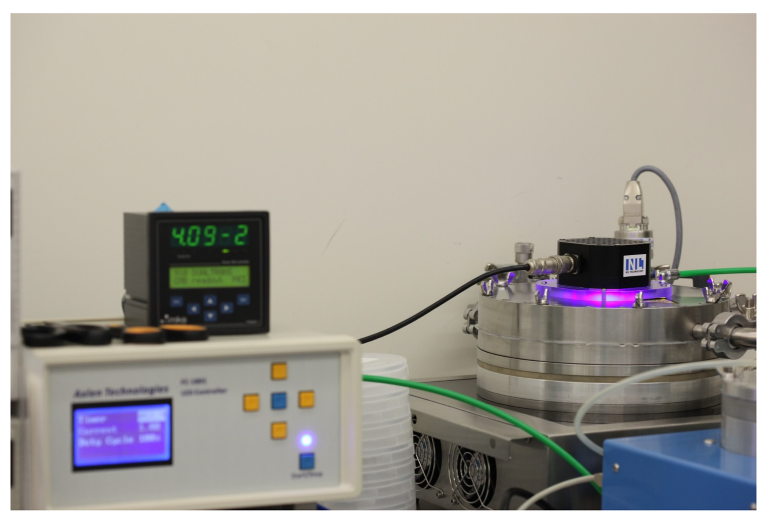

Fig. 4: The "Blow-NIL" system for making the imprint, developed by NIL Technology ApS.

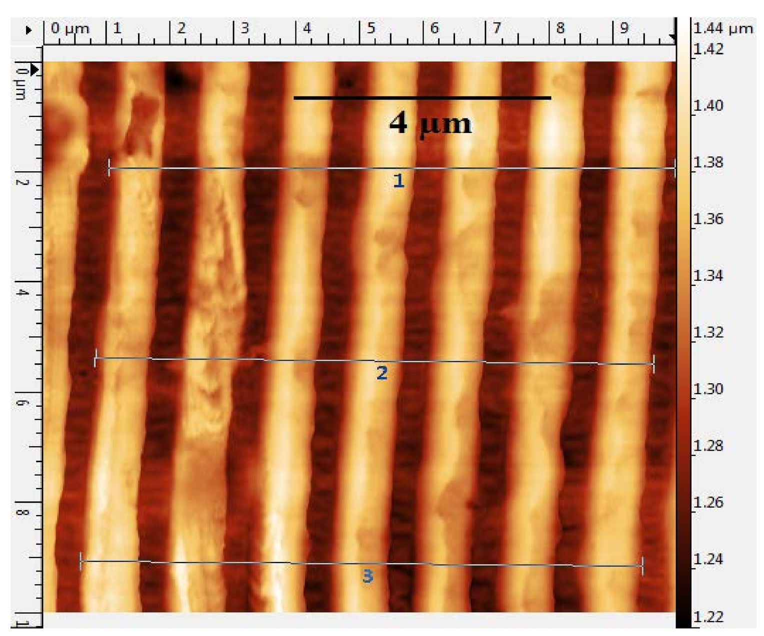

Fig. 5: One of the AFM samples from scanning of a 10x10 µm area. Three profiles are extracted from this scan for comparison with the numerical model. (Fig. 8-10).

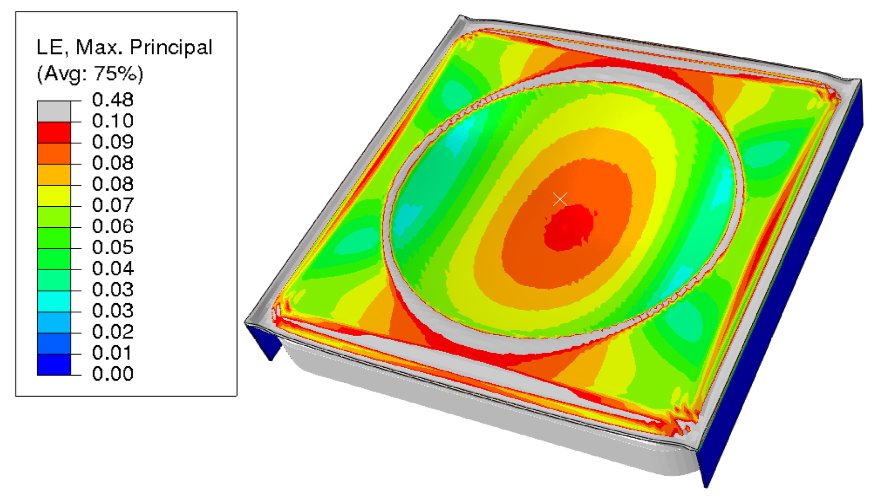

Fig. 6: Contourplot of the maximum principal strains in the flexible stamp from the global model.

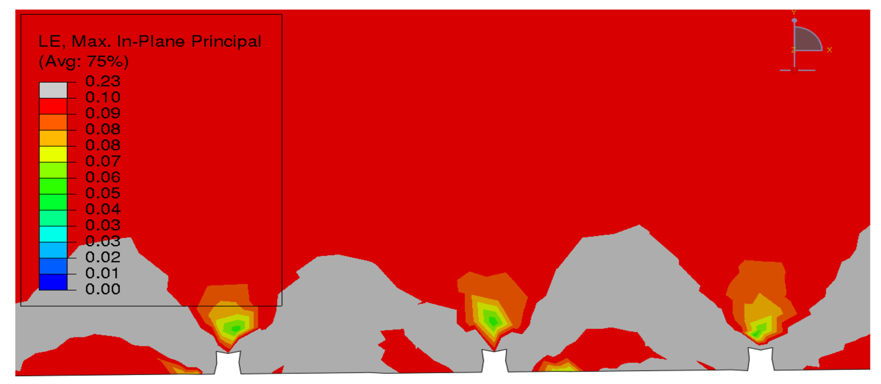

Fig. 7: The nanostructures in the local model at the final increment of the simulation.

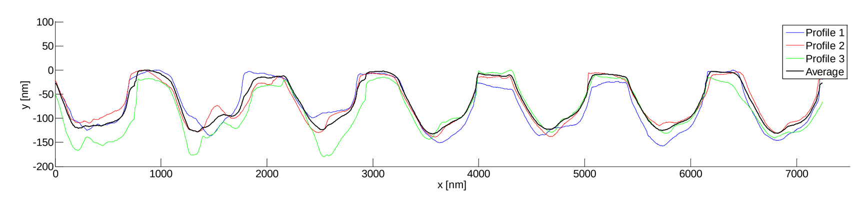

Fig. 8: AFM profiles from the 3 profiles shown in Fig. 5.

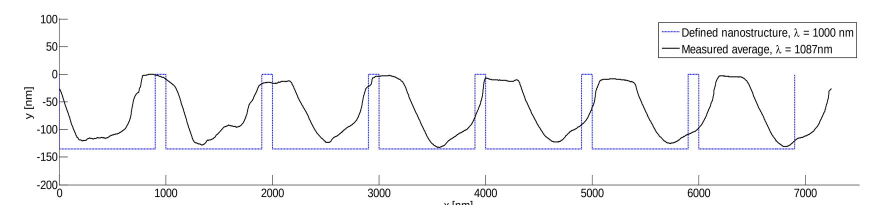

Fig. 9: Comparison of the measured AFM profile with the defined nanostructure

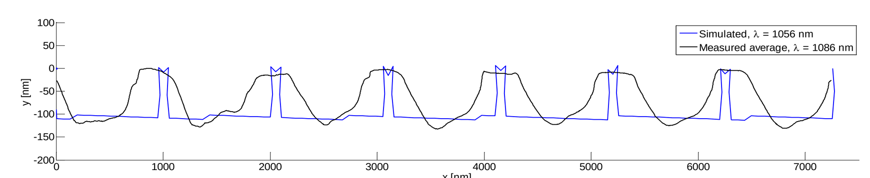

Fig. 10: Comparison of the measured AFM profile with the simulated shape of the nanostructures stamp.

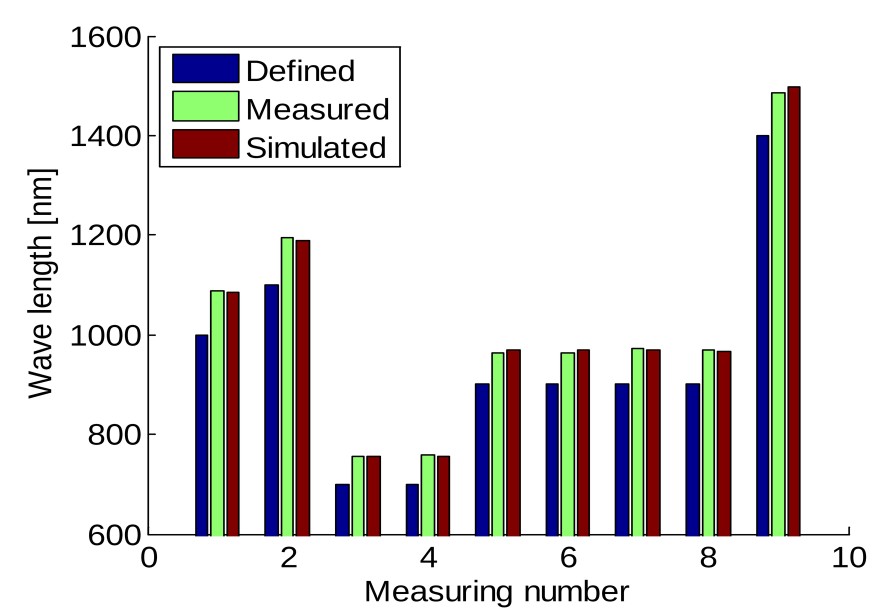

Fig. 11: Wavelengths measured at 9 different places on the specimen, compared with the values from the numerical model.

Conclusions

The model was used for simulating nanoimprint of a nanostructure giving a color effect on a double-curved concave steel substrate used for injection moulding (Fig. 3). The strain field (relative deformation) was both extracted from the simulations (Fig. 6 and Fig. 7) and measured on the deformed flexible stamp (Fig. 5) Both experiment and simulation showed a mismatch between the predefined and the actual nanostructures as a result of stretching of the flexible stamp. The model was shown to predict the stretch of the nanostructures with a maximum error of 0.5% (see Fig. 11), indicating that the model is able to capture the overall physics of this manufacturing process. The model did however not give any explanation of the more rounded corners of the measured nanostructures (see Fig. 8 - 10), which suggests that this behavior is not a result of the imprinting process itself, but maybe arises from the subsequent etching and injection moulding manufacturing steps.

Further information

More information about modelling the deformation of flexible stamps can be found in the authors paper [5]. Information on the project of applying functional nanostructures on injection moulded plastic parts can be found on the plast4future website: http://www.plast4future.eu/

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Acknowledgments

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