Influencing of the Pile-up and the Sink-in by the Coefficient of Friction in the Nanoindentation Test

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Introduction

The nanoindentaiton test is often used for measuring of the surface's material parameters which cannot be measured by conventional macro tests. During the nanoindentation, a diamond indenter of known geometry is pressed into the specimen. When the indenter is pressed into the material, the surface of the relatively hard materials bends inwards under the indeter. This behavior is called sink-in (Fig. 1A). If tested material is relatively soft, the plastic deformation causes that the material flows upwards along the sides of the indenter's faces. This is called pile-up effect (Fig. 1B). The friction between the indenter and the specimen could have and influence on the indentation curves and sink-in or pile-up effect. This effect was firstly observed on the nanoindentation of the bone tissue [1] which has the pile-up behavior.

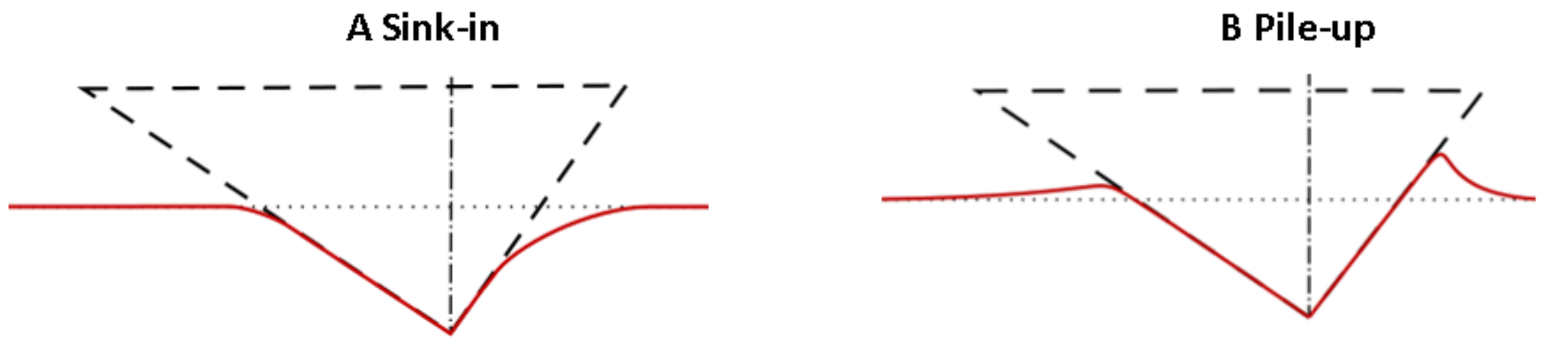

Fig. 1: Sink-in and pile-up effect

Finite element model

The specimen was assumed like cylindrical body loaded by the Berkovich indenter. The indenter was blunted with the radius 400 nm [2]. Only one sixth of the specimen and indenter was modelled due to the symmetry.

Two materials were used for the specimen. The first one was fused silica with Young's modulus E_{fs} = 72 GPa and Poisson's ratio μ_{st} = 0.17 [2]. Plasticity was modelled with ideal elasto-plastic model of material with yield stress 6 GPa. The sink-in behavior was observed for fused silica. The second material was X5CrNiCuNb16-4 steel with E_{st} = 210 GPa and μ_{st} = 0.33. The plasticity was modelled with the multilinear model, which was fitted to the data from the tension test (Fig.2). The indenter was from diamond with E_{dia} = 1 147 GPa and μ_{dia} = 0.07 [2].

The speciemen was loaded by the displacement of the upper area of thy indenter by 1 340 nm and then unloaded. The displacement perpendicular to the planes of symmetry was fixed same as the displacement perpendicular to the lower area of the specimen.

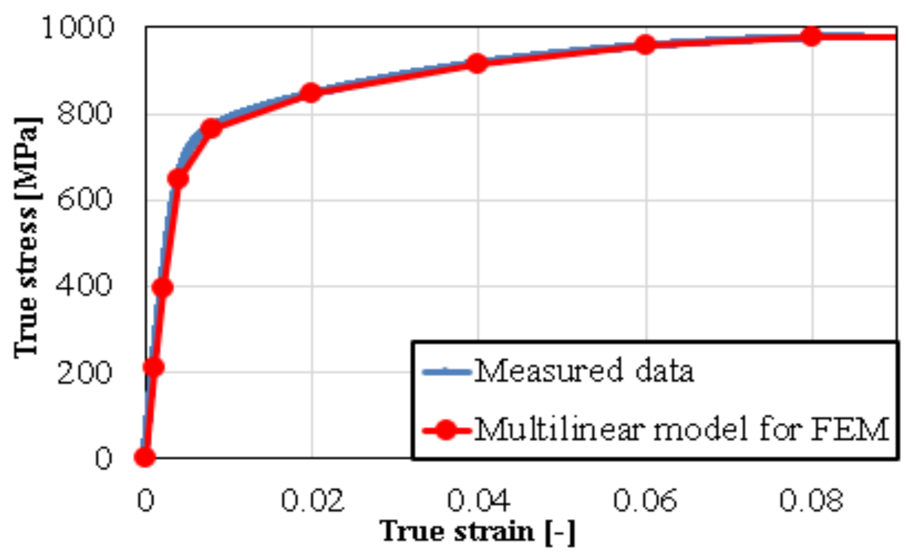

Fig. 2: Model of material (steel)

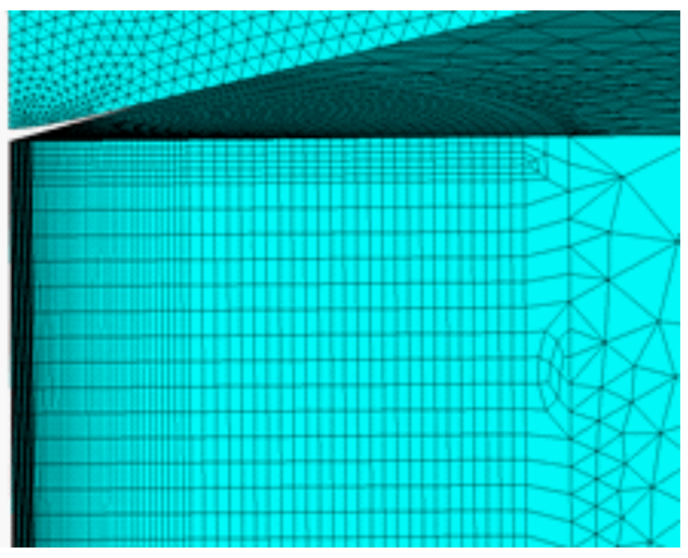

Fig. 3: Mesh in the contact region

The mesh of the specimen was made from the linear SOLID 185 elements. Due to the curvature of the indenter tip, the quadratic SOLID 186 elements were used. Contact region from CONTA 174 and TARGE 170 elements was made between the indenter and the specimen. The coefficient of friction between the bodies was changed between 0.01 (nearly no friciton) and 0.3 and height of pile-up or depth of the sink is was calculated.

Results

The main goal was to obtain the dependency between sink-in or pile-up on the friction. The sink-in was nearly independent on the finction (Fig. 4), while the pile-up was strongly dependent until the coefficient of friction 0.15. For higher values it was independent too.

The calculated indentation curves for steel showed that the coefficient of friction had nearly no impact on them (Fig. 5). There waas only very small difference in the unloading parts which was related to the change of the contact area.

The calculated indentation curves had the expected shape but there was a difference between the calculated and measured maximal value of the force. The difference could be caused by the geometrical imperfections of the indenter,. Another reason could be the imperfection of the model of material caused by the very high strains which were under the tip of the indenter. The employment of more complex model of material will be done in future work.

Conclusion

The impact of the friction on the results fo the FEM calculations has been assessed and the indentation curves of the fused silica and steel with the different values fo the coefficient of friction were calculated. The results showed that the sink-in is nearly independent on the coeffcient of friction, while the pile-up is dependent on the friction. In the contrast, the indentation curves are independent on friction in both cases. The calculated indentation curves showed lower values of the force probably due to the inaccuracies in the model of material and geometry of the indenter. The impact of the inaccuracies in the indenter geometry and tilt will be assesseed in future work.

References

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[2] Kovář, J., Fuis, V., and Tomáštík, J. (2020). Influencing the indentation curves by the bluntness of the Berkovich indenter at the FEM modelling. Acta Polytechnica CTU Proceedings, 27, 131-135.

Acknowledgement

This study was realized with the support by the grant FSI-S-20-6164 and with the institutional support RVO: 61388998.

This work has been supported by the project No. FV 19 - 07 funded by The Ministry of Education, Youth and Sports (MEYS,MŠMT in Czech) institutional support.

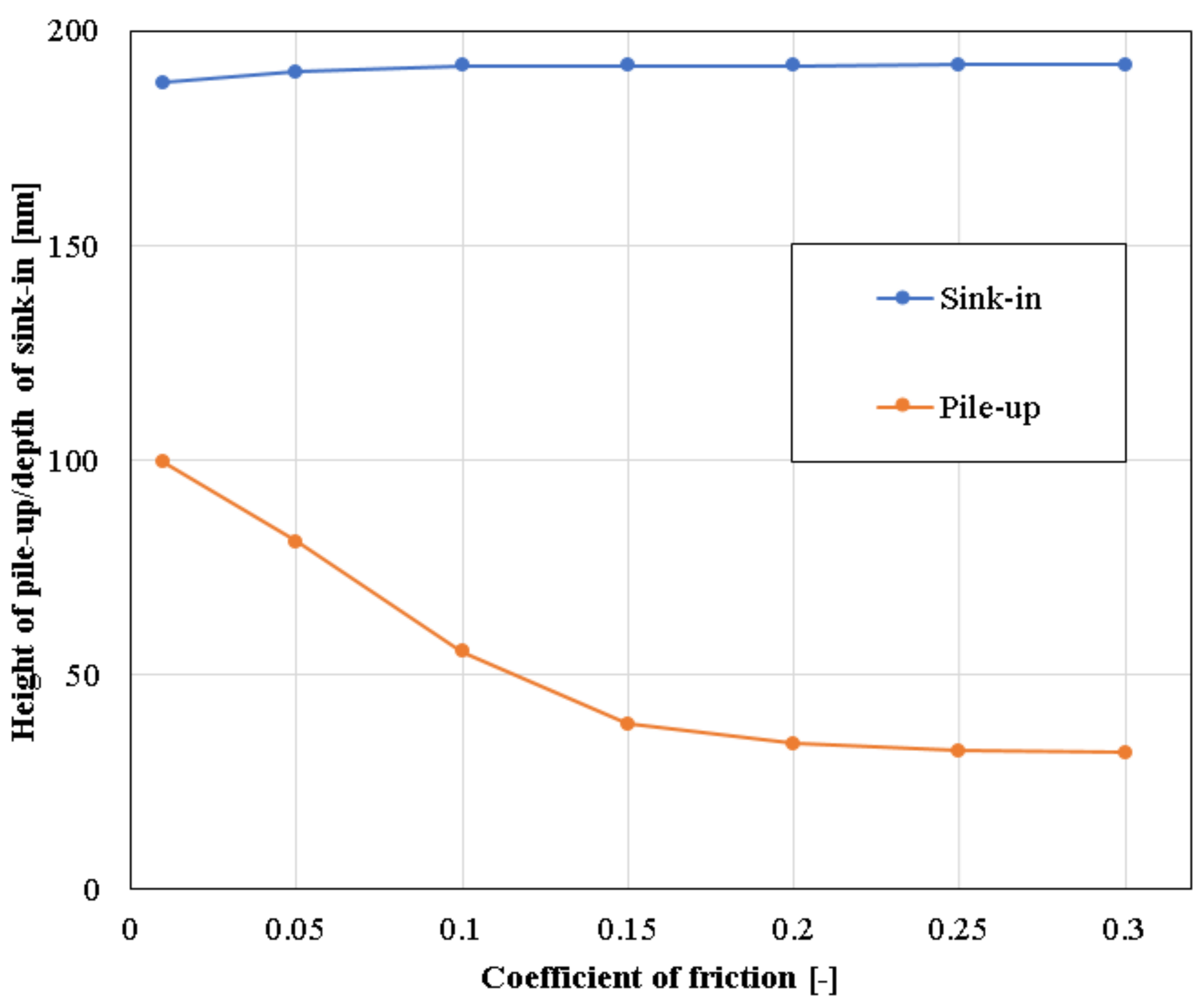

Fig. 4: The depencency of the height of the pile-up on the coefficient of friction (steel) and the depth of the sink-in on the coefficient of friction (fused silica)

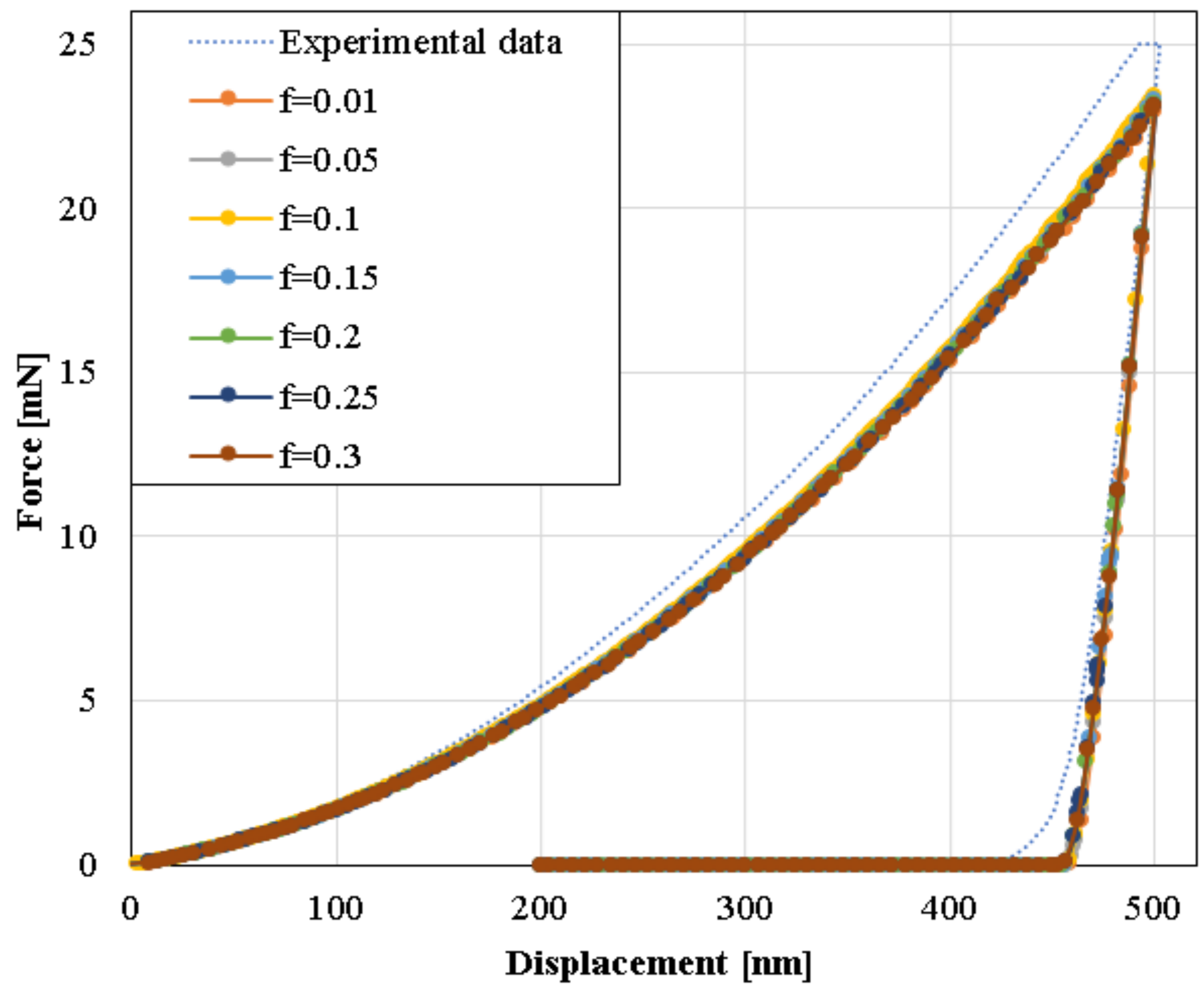

Fig. 5: Indentation curves for different values of the coefficient of friction (f)