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Numerical investigation of the effects of process parameters on forming load and failure in hot nosing process

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Abstract. Nosing process is generally used to reduce the diameter of the open end of the circular thin-walled tubes. Friction coefficient and workpiece temperature are two important process parameters that should be investigated to understand the process in detail. In addition, forming length and nosing ratio need to be considered to carry out a successful process. If these parameters are not determined correctly, workpiece damage like buckling is inevitable. The purpose of this study is to investigate the effects of the process parameters on the forming load and failure of the workpiece in the hot nosing process.

Introduction

The nosing process is a commonly favored method among metal-forming manufacturers for acquiring cost-effective final products with the desired microstructure. Furthermore, owing to its effectiveness in achieving the final product thickness and forming surface, it is considered as a futuristic forming technique, as the production steps do not require any subsequent machining stage. In addition, the process is typically employed for reducing the diameter and increasing the thickness of a circular thin-walled shell through the application of press loads. Depending on the specific requirements, the nosing process can be applied to both cold and hot-temperature workpieces [1,2].

Gouveia et al.[3], emphasized the significance of achieving higher nosing ratios and reducing forming loads through modifications of the contour, radius of the tube, initial gap height, and lubrication conditions . Manabe and Nishimura [4], highlighted the importance of designing the nosing die-forming surface in a circular curved manner to minimize nosing load, achieve maximum nosing ratio, and ensure uniform surface pressure. Tang and Kobayashi [5], conducted a study employing a coupled analysis of deformation and heat transfer. They utilized AISI1045 with a rigid-plastic material idealization, adapting the theory of visco-plasticity. The correlation between experimental results and numerical simulation was in good agreement regarding to maximum force during nosing, thickness distribution, deformed shapes and temperature distribution.

Additionally, it is crucial to address the issue of buckling under axial load during nosing. To mitigate this, it is recommended, as suggested by [6], that preheating be implemented at a rapid rate to prevent the propagation of high temperatures into the cold region of the shell.

The friction coefficient and workpiece preheating length are two important process parameters that should be investigated for a comprehensive understanding of the process. Incorrect determination of these parameters can lead to workpiece damage, such as buckling, becoming unavoidable. The aim of this study is to investigate the influence of process parameters, which are friction coefficient and workpiece preheating length, on both the forming load and the occurrence of workpiece failure within the context of the hot nosing process. Moreover, a two-stage nosing forming approach was studied to prevent workpiece buckling failure and concurrently reduce

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forming load. A coupled displacement-temperature finite element analysis (FEA) was conducted to investigate the parameters explained.

Methodology

For this study, a workpiece with a diameter of 300 mm, a thickness of 8 mm, and a length of 1300 mm was selected shown as in Figure 1.

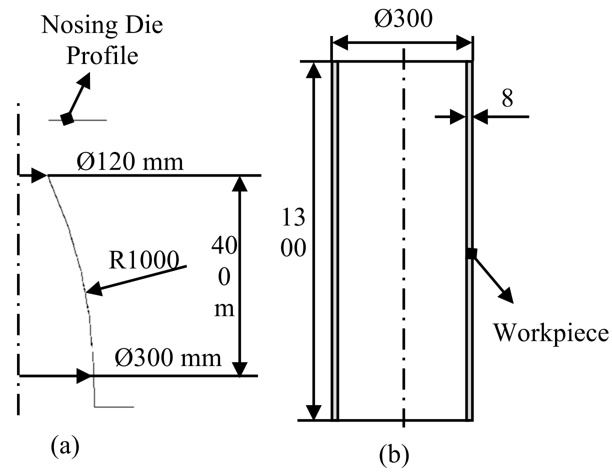

Fig. 1. a) Basic dimensions of the die, b) Basic dimensions of the workpiece

Material. In this study, the material was selected as 42CrMo4 (1.7225) for the workpiece, and material properties varying with strain rate (SR) were utilized in the analyses. Strain rate dependent material data, shown in Figure 2, was prepared with JMatPro [7].

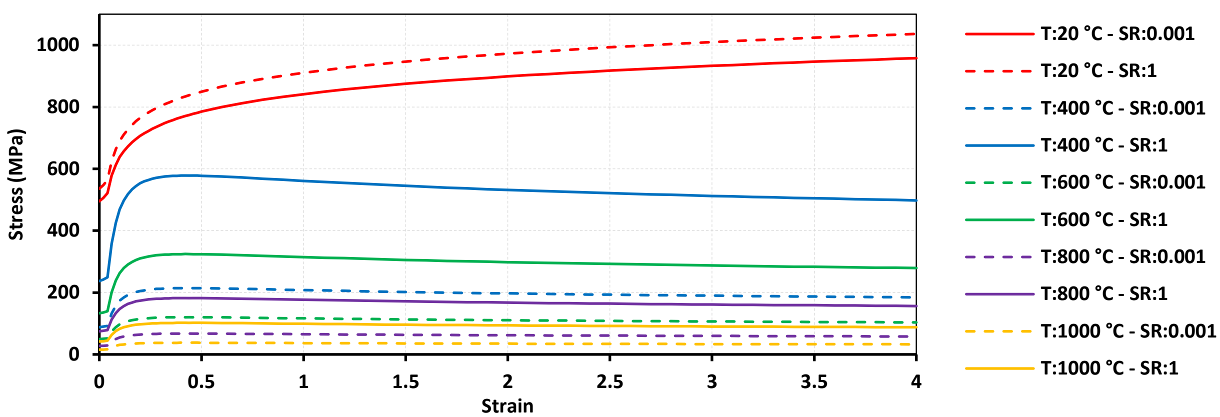

Fig. 2. Stress-strain flow curve depending on strain rate of 42CrMo4 (1.7225) material

Finite Element Method. In order to evaluate effects of the friction coefficient between the upper die – the workpiece, as well as the preheating length of the workpiece, on the process, a finite element analysis study was conducted. Finite element model was introduced in this section, followed by a discussion of the obtained analysis findings.

Throughout the study, the models were modeled in an axisymmetric environment and analyzed using a coupled approached involving deformation and heat transfer in ABAQUS/Explicit. The relevant surfaces of both the upper and the lower die, which were selected to be rigid, were included in the finite element model. The workpiece was modeled as deformable. CAX3RT element type was used to mesh workpiece, as the use of axisymmetric reduced-order solid elements provides much less computational time. This element type includes 4-node thermally coupled axisymmetric quadrilateral, bilinear displacement and temperature, reduced integration and hourglass control. After performing a mesh convergence study, the element size was determined as 0.8 mm for each workpiece. The analysis utilized a total of 5456 elements and 6147 nodes.

In the analysis model, the lower die, modeled as analytically rigid, was fixed. The velocity of 100 mm/s was defined for the upper die, which was modeled to move vertically. The temperature of the cold region of the workpiece and rigid dies were set to 20 °C, whereas the hot region of the workpiece was defined with a temperature of 900 °C. The heating process in the preheating region is made with induction heating method. The preheating length of the workpiece, determined to be full (400mm) and half (200mm) of the nosing length, is illustrated in Figure 3.

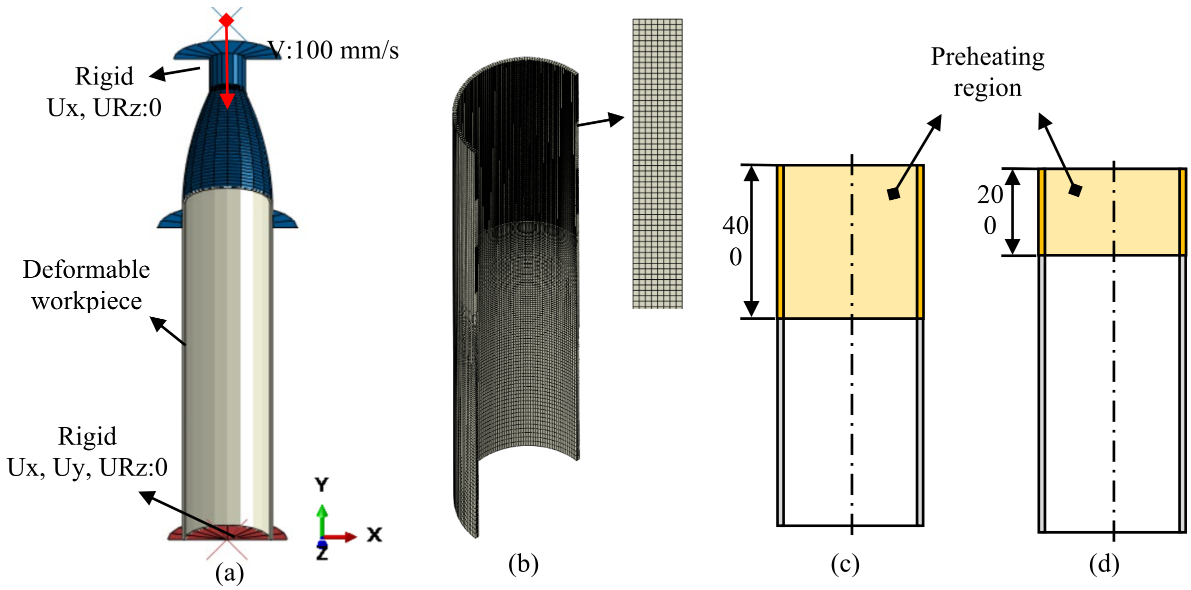

Fig. 3.Boundary conditions descriptions of hot nosing process, b) Workpiece mesh model, c) Full preheating region, d) Half preheating region.

The contact interaction between die and workpiece was defined using the general contact definition in ABAQUS /Explicit. The analysis duration was set to 3.8 seconds, and the step included variable mass scaling factor to maintain a constant stable time increment of 2e-06. Mass scaling is a method employed to accelerate computations by augmenting the mass of the workpiece. After the solving stage of the analysis, it was checked that mass scale factor (EMSF indicator in ABAQUS) was sufficiently low to prevent any impact on the solution. A thorough examination of artificial strain and kinetic energy parameters was conducted to ascertain that inertial forces did not exert influence on the overall solution.

Results and Discussion
Effect of the Preheat Length on the Process. Determining the preheat length in the hot nosing process is crucial to prevent premature failures. If the preheat length is longer than necessary, the workpiece may buckle in the hot region that has not been formed yet. The analysis results, in which the length of heating region was excessive, are given in Figure 4. Buckling failure is evident in the hot region that has not yet entered the die, as illustrated in Figure 4. The hot region outside the die was unable to withstand the instantaneous process load, leading to buckling.

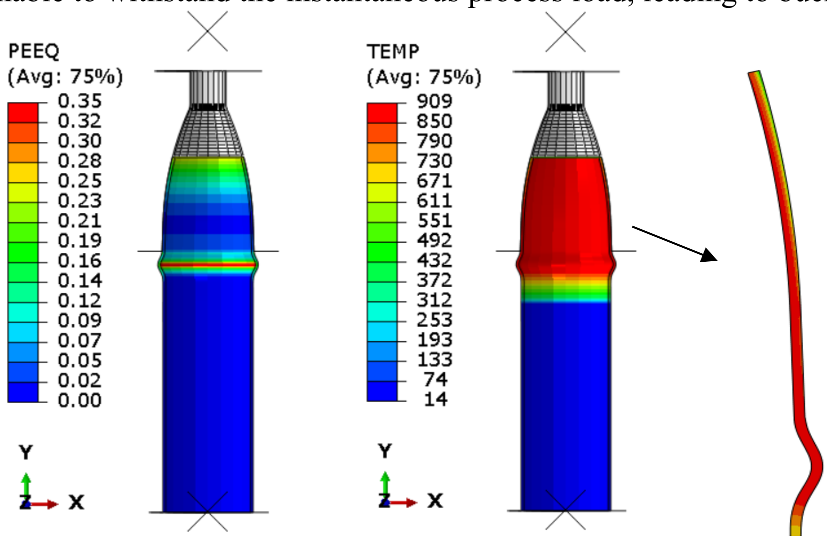

Fig. 4. Strain and temperature distribution of the model with preheating along the nosing length

If the preheat length is shortened to half of the original length, the process can be executed successfully. An illustration of a successful process with a short preheat length is presented in Figure 5. In this case, the entire hot region entered the die rapidly due to its shortened length. Consequently, a significant portion of the process load was borne by the cold region. As a result, no premature buckling failure is observed in this case, thanks to the high buckling resistance of the cold section.

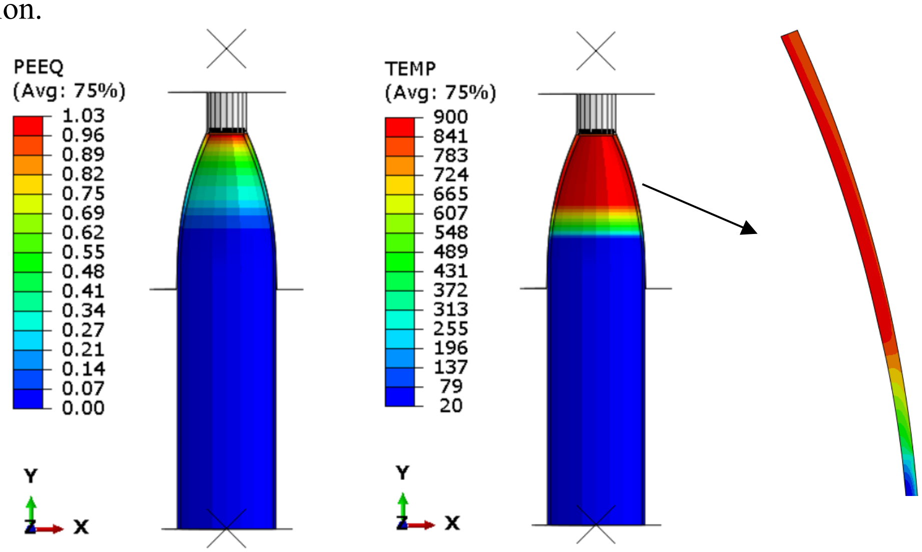

Fig. 5. Strain and temperature distribution of the model with preheating along half of the nosing length

The process loads for long and short preheated workpieces are presented in Figure 6. Preheating the long portion of the workpiece resulted in buckling failure at 65 tons, whereas the workpiece with a shorter preheating region can withstand 250 tons of process loads.

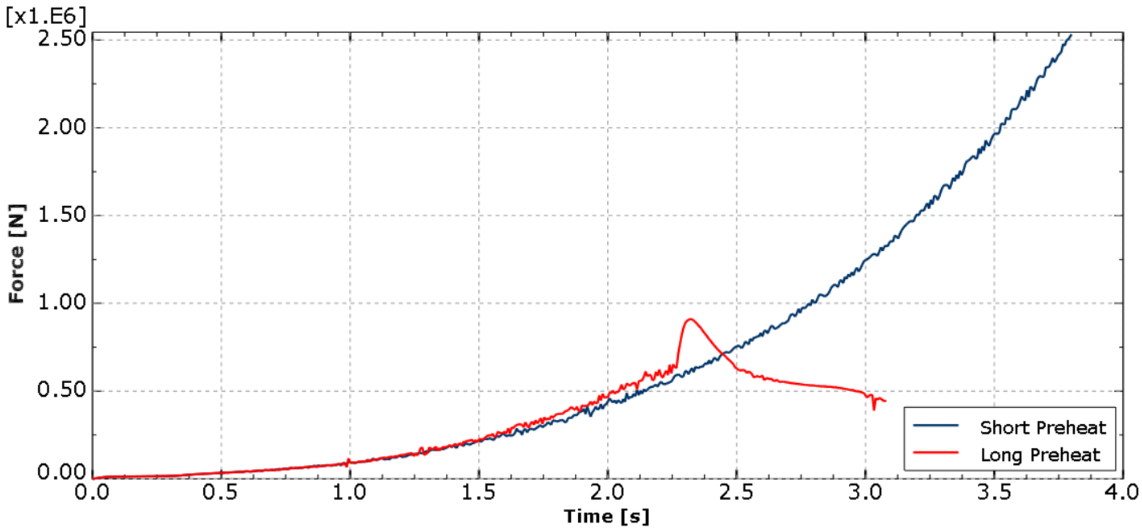

Fig. 6. The effect of preheat length on forming load

Effect of the Friction Coefficient on the Process. In addition to tip thickness, forming load is dependent on the friction between workpiece and die. Therefore, it is important to examine the impact of the friction factor on the process.

As depicted in Figure 7, there were no evident failures in the processes with low friction coefficients (m=0.05 and m=0.1), but a buckling failure occurred at a high friction coefficient (m=0.2). The observation of a buckling failure in the process with high friction coefficient is attributed to the high forming load. When the forming load exceeded the buckling load capacity of the workpiece, the failure occurred in the cold section of the workpiece.

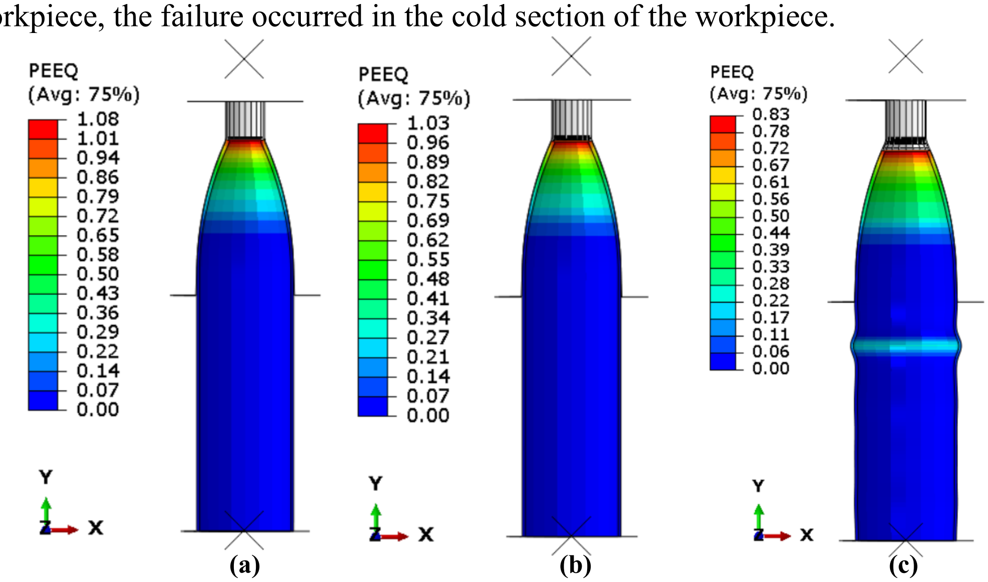

Fig. 7. Equivalent plastic strain according to friction coefficient, a) m: 0.05, b) m: 0.1, c) m: 0.2

The process loads for the different friction coefficients are presented in Figure 8. It can be seen from the figure that increasing the friction coefficient required a higher nosing forming load. Even if the increase in process load has an effect on the cooling of the workpiece during its contact with the nosing die, the cooling amount was accepted as the same for each friction condition and the cooling situation was not examined in detail within the scope of this study. The forming load was 270 tons in the process with high friction coefficient (0.2), while it was 220 tons in the process with low friction coefficient (0.05, 0.1). The high forming load obtained in the process with a high friction coefficient provides an explanation for the buckling failure observed in this process.

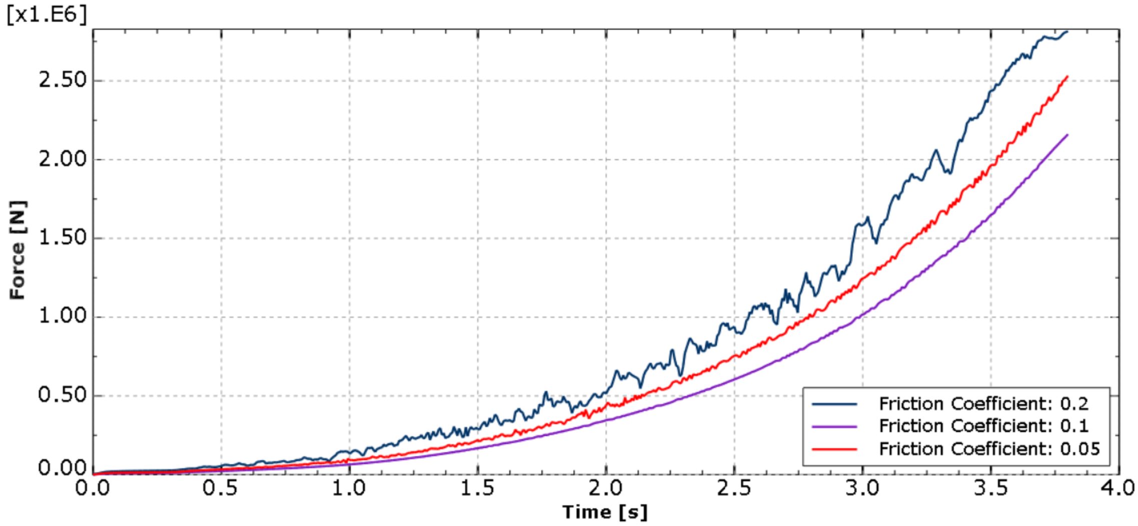

Fig. 8. The effect of friction coefficient on forming load

In terms of obtaining final product thickness, friction coefficient is a significant parameter in the process. As given in Figure 9, increasing the friction coefficient leads to the wall thickness increases.

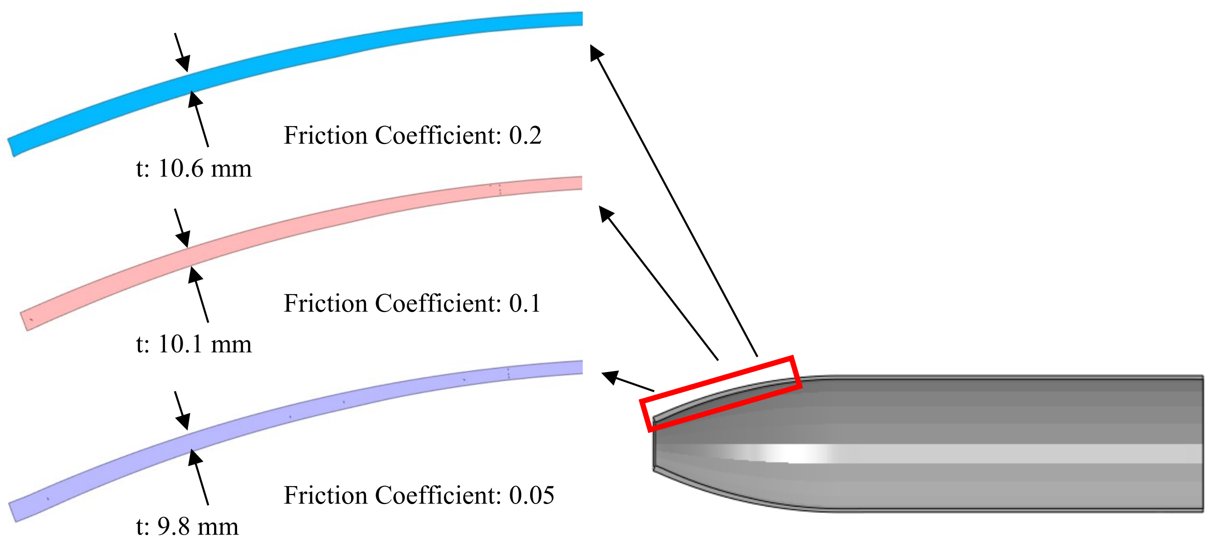

Fig. 9. The effect of friction coefficient on workpiece wall thickness increase

Two-Stage Forming Approach. For minimizing the forming load with a high friction coefficient, preferring the two-stage forming method is a productive way to decrease process loading. Investigating the friction coefficient of 0.2 in the scope of this study was handled again to see with two-stage forming approach. In both the first and the second stages of the process, workpiece formed successfully without buckling damage as shown in Figure 10.

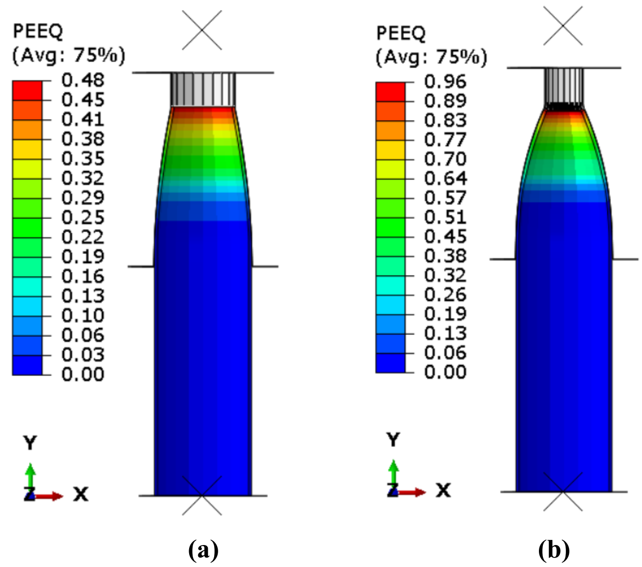

Fig. 10. Equivalent plastic strain of workpiece in the two-stage forming, a) First stage, b) Second stage

The process loads are given in Figure 11 to explain the effect of two-stage forming. Whereas the nosing process load using single-stage forming approach exceeds 275 ton, the load is under 240 ton in the two-stage forming approach. It is demonstrated that two or multi-stage forming method is the best way of minimizing process loads even if the friction coefficient is over 0.2.

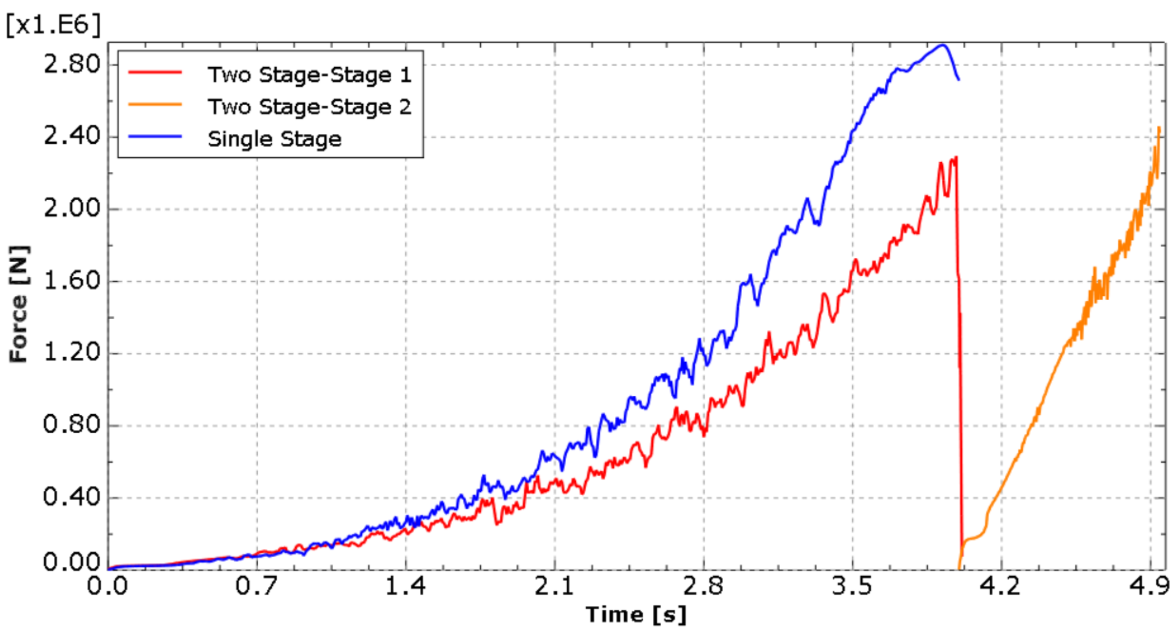

Fig. 11. The process loads in the two-stage forming

Summary

Investigating the influence of process parameters, which are friction coefficient and workpiece preheating length, and single or two-stage pressing on both the forming load and the occurrence of workpiece failure within the context of the hot nosing process were conducted. The obtained results can be summarized as follows:

- In the circumstance that the length of the heating region was excessive, the hot region outside the die was unable to withstand the instantaneous process load, leading to buckling. If the preheat length is shortened to half of the original length, the process can be executed successfully. As a result, no premature buckling failure is observed in this case, thanks to the high buckling resistance of the cold section.
- There were no evident failures in the processes with low friction coefficients, but a buckling failure occurred at a high friction coefficient. The observation of a buckling failure in the process with high friction coefficient is attributed to the high forming load. When the forming load exceeded the buckling load capacity of the workpiece, the failure occurred in the cold section of the workpiece.
- Increasing the friction coefficient leads to the wall thickness increases.
- The two-stage forming approach demonstrates that the two or multi-stage forming method is the best way of minimizing process loads even if the friction coefficient is constant.

Acknowledgement
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References

[1] Lu, Y. H. (2005). Study of preform and loading rate in the tube nosing process by spherical die. Computer methods in applied mechanics and engineering, 194(25-26), 2839-2858. https://doi.org/10.1016/j.cma.2004.07.032

[2] Chang, C. C., Pan, S. K., & Yu, K. T. (2019). Forming limit in the nosing process of micro copper cups. Key Engineering Materials, 794, 121-126. https://doi.org/10.4028/www.scientific.net/KEM.794.121

[3] Gouveia, B. P. P., Alves, M. L., Rosa, P. A. R., & Martins, P. A. F. (2006). Compression beading and nosing of thin-walled tubes using a die: experimental and theoretical investigation. international Journal of Mechanics and Materials in Design, 3, 7-16. https://doi.org/10.1007/s10999-006-9009-8

[4] Manabe, K. I., & Nishimura, H. (1984). Nosing of thin-walled tubes by circular curved dies. Journal of mechanical working technology, 10(3), 287-298. https://doi.org/10.1016/0378-3804(84)90044-5

[5] Tang, M. C., & Kobayashi, S. (1982). An Investigation of the Shell Nosing Process by the Finite-Element Method. Part 2: Nosing at Elevated Temperatures (Hot Nosing). https://doi.org/10.1115/1.3185835

[6] Carlson, R. K., (1944). "An Experimental Investigation of the Nosing Shells." Forging of Steel Shells, ASME Trans., p.45.

[7] Saunders, N., Guo, U. K. Z., Li, X., Miodownik, A. P., & Schillé, J. P. (2003). Using JMatPro to model materials properties and behavior. Jom, 55(12), 60-65. https://doi.org/10.1007/s11837-003-0013-2