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NUMERICAL ANALYSIS OF SLEEVE CLAMPING PROCESS

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Abstract

This paper deals with the results of numerical analysis of sleeve clamping for example on steel cables by means of rotary groove segments. The areas of application of cables and strings are discussed and the way of making on them endings is presented. Numerical analysis of the process was made basing on finite element method (FEM), using commercial software DEFORM-3D. Geometrical models applied in calculations and impression shape's influence on the product quality were discussed. The obtained results of the numerical analysis were used during designing a machine for the process practical realization.

Key words: clamping, groove rolling, FEM

1. INTRODUCTION

Cables and strings are widely applied in industry. They are used mainly in aviation and automotive industry for driving of various types of steering mechanisms, which require high reliability. Another area of cables application is crane machines and towing machines used in transport, and which are at risk of dynamic load. A different character have cables used in building industry, where they are usually used as guy ropes supporting masts or bearing elements, on which all constructions are mounted (Kowalczyk & Steininger, 1963). The choice of the appropriate section of the cable or string and material, from which these products are made, depends on way of loading and on place of their work. In engineering calculations the following factors are considered: static and dynamic durability, elongation, crawling, work conditions etc. No matter what the application is, a large influence on reliability and work safety has the way the string is ended, as the ending should guarantee obtaining durability comparable to cable durability (EN 13411-3). One of the most reliable methods of cables endings manufacturing is the way applied so far in yachting and based on the cable ending splicing. This demanding and time consuming method has been replaced by clamping on cables a sleeve with various endings. This solution is at present widely used in machine and automotive industry. The process of sleeve clamping on cables is realized mainly by means of special pads placed on presses, which exert pressure on them and lead to ending deformation and its clamping on the cable. This is a very simple method, and the obtained connection has good mechanical characteristics however, it requires considerable press pressures in the case of larger diameters of clamped sleeves. Additionally, in the place of pads splitting, cross section ovalization appears and flash hard to remove is present, which, due to aesthetic reasons is not accepted by receivers.

Considering industrial expectations, at the Department of Computer Modelling and Metal Forming at Lublin University of Technology a new way of sleeve clamping on steel cables was worked out, which is based on elongated rolling between two

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groove segments. The proposed method is very simple and universal, and the obtained connection has high aesthetic and durability. Additionally, kinematics of tools which rotate allows for realization of the clamping process at relatively small driving power.

This paper presents the results of numerical analysis of clamping process of steel sleeves by means of cylindrical groove segments, made by application of finite element method.

2. GEOMETRICAL MODEL OF SLEEVE CLAMPING PROCESS

Numerical analysis of the sleeve clamping process was made with the application of commercial software DEFORM 3D basing on FEM. Due to a complex character of material flow, calculations were made in conditions of three dimensional state of strain. In simulations the following aspects were analyzed – geometrical parameters of the obtained forgings, kinematics of metal flow, force parameters of the process, and distributions of strains in sections of the formed products were determined. An example of the sleeve clamping process geometrical model is shown in figure 1a – the process beginning and figure 1b – the end of the process.

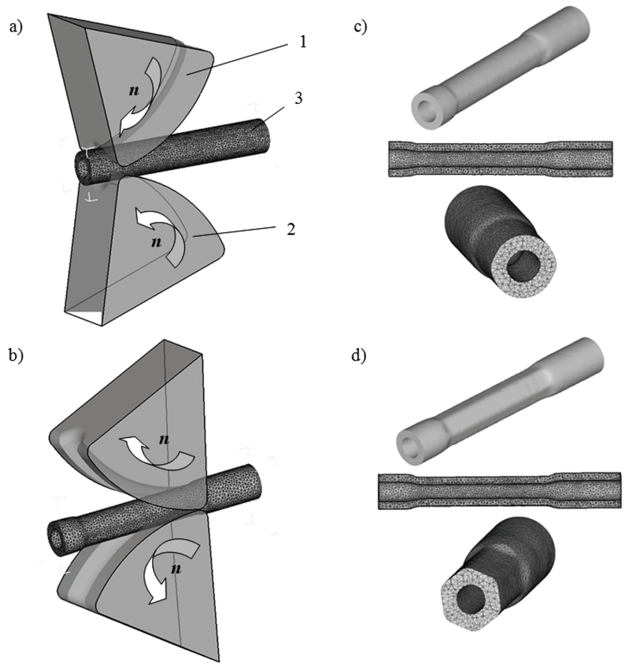

Fig. 1. Geometrical model of the sleeve clamping process by means of rotary groove segments: a) the process beginning; b) the process end; c) an example of the sleeve clamped in circular impression and d) hexagonal, description in the text.

The models consist of two cylindrical tool segments (1 and 2), rotating in the opposite directions with the constant velocity n = 2 rot/min. At the segments surfaces, grooves are made, which shape, after tools assembling, corresponds with the cross section of the clamped sleeve. A steel sleeve (3) type 0H17N12M2 according to PN (316 acc. AISI) (Dobrzański, 2005) with external diameter d = 18 mm and internal d_o = 10.5 mm and length l = 100 mm, modeled by means of tetragonal elements, was used as a billet. The billet was divided into 60000 elements of initial size 0.70 mm. During calculations a constant remeshing option was used. Due to difficulties with modelling of a steel cable inserted into the sleeve (Juraszek, 2005), in calculations this element was omitted and it was assumed that reduction of the internal diameter of the steel sleeve at the level 3 - 4 mm would be adequate to obtain proper rigid connection. During choosing the degree of diameters reduction, measurements of traditionally clamped endings on steel lines were considered. The shape of groove impressions on the segments were chosen in such a way that it was possible to analyze the sleeve clamping process, in which the final cross section was the ring of external diameter d = 16 mm (figure 1c) and hexagon of characteristic dimension s = 14.8 mm (figure 1d). In calculations, it was assumed that clamping took place at the environment, material and tools temperature T = 20°C. It was also assumed that friction factor at sleeve-tool surface of contact was m = 0.15 (constant friction model). A characteristic feature of the sleeve clamping process between two rotating segments is the fact that the process starts at a certain distance from the semi-finished product head. Because of that, there is no risk of slide at the beginning of clamping, which allows for application of very smooth working surfaces of the impressions. It is also possible to guarantee obtaining products of high aesthetic and high quality of external surface.

Figure 2 presents progression of shape and strain distributions during sleeve clamping in the circular impression (figure 2a) and hexagonal (figure 2b). A characteristic feature of the process is local plasticizing of metal in roll gap, due to which metal flows axially to the sleeve axis, reducing its external and internal diameters. However, the observed elongation is relatively small, which allows to assume that the sleeve material will be squeezed into external braid composing a certain connection. The local flowing of metal in the process of sleeve clamping requires relatively smaller forces than in comparison with the process realized traditionally, in which product clamping takes place on the whole length.

The obtained shape of cross section at clamping by means of groove segments of circular shape (figure 3a) shows a small ovalization, which does not influence the connection durability. This ovalization can be removed by repeated rolling of the sleeve turned of 90^o in comparison with the first phase. During the sleeve squeezing by segments, on which grooves were cut in the shape of hexagon, deformation of the product cross section was not observed (figure 3b). Metal forming of the sleeve on the cable in the shape of hexagon is especially favorable in the case, when the clamped semi-finished product ends with screwed mandrel. This makes the further strings assembling easier due to the possibility of holding the clamped ending by means of a key.

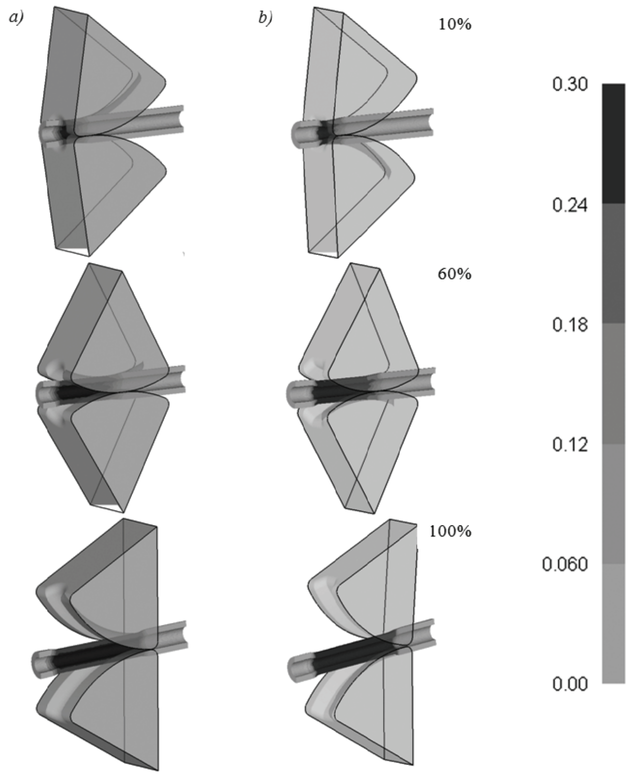

Fig. 2. *Strains distribution determined by FEM in the steel bush clamping process by means of groove segments of impression shape: a) circular; b) hexagonal, depending on the process phase.*

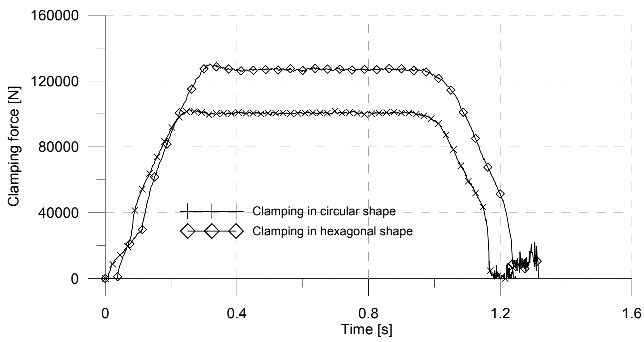

Fig. 4. *Diagram of axial forces determined by FEM during simulation of the steel sleeve clamping in circular and hexagonal impression.*

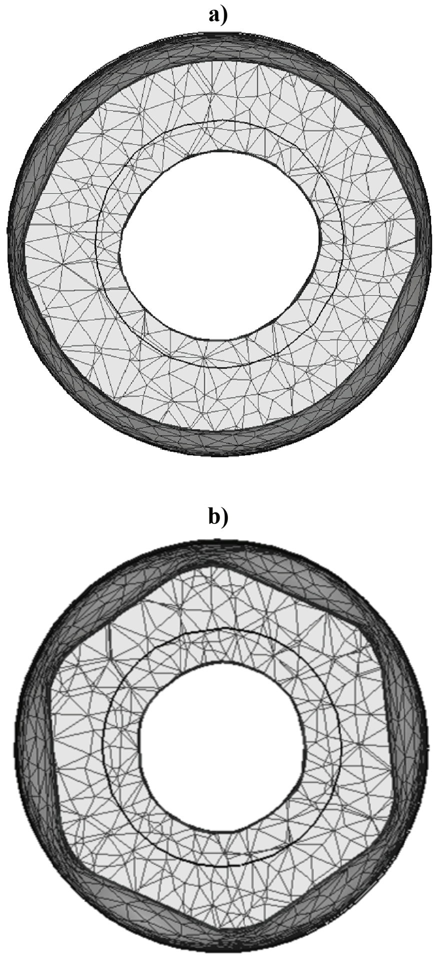

Fig. 3. *Shape of cross section of the bush clamped by rotary groove segments: a) in circular impression; b) in hexagonal impression, determined during numerical simulations.*

Diagrams of axial forces (sleeve clamping) - figure 4 and rolling moments noticed on segments – figure 5 during FEM analysis provide important information.

At the initial stage of the clamping process the axial force grows fast, which is connected with tools inserting at maximal value of reduction ratio. Next, the constant course of the force is observed, which corresponds with the assumed rolling process. At the final stage of the clamping, the clamping force rapidly lowers to zero, which is the result of gradual diminishing of reduction ratio. It should be, however, noticed that during sleeve clamping in the circular section the force is above 20% lower in comparison with the forced observed during rolling in hexagonal impression. It is caused by larger plastic strain during rolling on hexagon. A similar character has rolling moments distributions (figure 6), present at groove segments. After a quick increase connected with gradual increasing of reduction ratio to maximal value, stabilization of moments values at relatively constant level takes place. At this stage the proper sleeve clamping is present. At the initial stage of the process a gradual decrease of reduction ratio appears and it is connected with quick reduction of rolling moments to zero. As it was expected, during the sleeve clamping in the hexagonal impression, the moment value is larger of about 30%. This confirms the earlier assumption that metal in that case undergoes larger deformation.

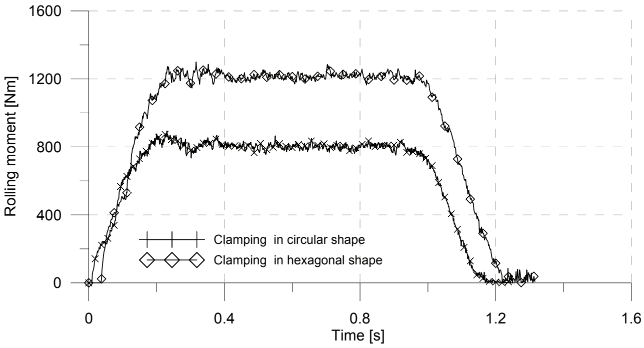

Fig. 5. Diagram of rolling moments determined by FEM during simulation of the steel sleeve clamping in circular and hexagonal impressions

The noticed distributions of forces and moments allow to presume that the sleeve clamping process in both cases is stable. The observed maximal axial force during clamping in hexagonal impression reaches 140 kN, which is the value considerably smaller in comparison with the traditional process realized between flat pads on the press, in which clamping force has the value up to 600 kN.

3. CONCLUSIONS

On the basis of conducted numerical research, the possibility of the sleeve clamping, eg. on steel cables by means of groove pads was determined. In the result of numerical analysis the shape of tools segments allowing for even clamping of the sleeve according to the guidelines of one of the manufacturers was worked out. Obtained by means of FEM forming parameters were used for designing a prototype working stand for this process practical realization. The research planned to be realized by means of this stand will be used for a practical verification of theoretical calculations.

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NUMERYCZNA ANALIZA PROCESU ZACISKANIA TULEI

Streszczenie

W opracowaniu przedstawiono wyniki analizy numerycznej procesu zaciskania tulei między innymi na linach stalowych przy pomocy obrotowych segmentów bruzdowych. Omówiono obszary zastosowań wyrobów typu liny i cięgna oraz przedstawiono sposoby wykonywania na nich zakończeń. Analizę numeryczną procesu przeprowadzono w oparciu o metodę elementów skończonych (MES), wykorzystując komercyjny pakiet oprogramowania DEFORM - 3D. Omówiono modele geometryczne zastosowane w obliczeniach oraz wpływ kształtu wykroju na jakość wyrobu. Uzyskane wyniki analizy numerycznej wykorzystano w projekcie przyrządu do praktycznej realizacji tego procesu.

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