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Parameter's Optimization of Surface Plastic Deformation Corrosion-resistant Steel by Computer Simulation

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The knurling of corrosion-resistant steel 95X18 (the nearest analog is AISI 440B, AISI 440C, AISI A756, DIN-1.4125, SUS440C, Z100CD17) simulation with finite element method is investigated in the paper. Diagram stresses, strains and displacement are calculated by using CAE system SolidWorks. Dependence of strengthening area on processing tools geometry and loaded force are investigated. We proposed the algorithm of knurling parameters optimization by using a computer simulation. The correlation between simulation and experimental data was found.

Keywords: corrosion-resistant steel, martensitic steel, finite element method, computer simulation, surface plastic deformation.

1. Introduction

Surface plastic deformation is often applied proceeding operation. Using this method allows to solve some technological problems such as decreasing roughness, hardening surface layer, forming required relief [1]. As a result of surface plastic deformation microstructure and physical properties of surface layer can be changed, hardness, strength, wear resistance increased , useful stress field appeared. The are many different modifications of surface plastic deformation such as knurling, bead-blasting treatment, caulking, ironing. The technologist chooses the way of strengthening in accordance of a particular problem to be solved.

Knurling is useful for treatment of plane, internal and external cylindrical surfaces, curving part [2]. Surface quality depend on material, size and shape of a treated detail. Hardness, locked-up stresses increase with a loaded force. Depth of cold working layer change from 0.01 to 1 mm with dependence on proceeding parameters. The determination of treatment parameters is a main technological problem. Constructor should perform mutually contradictory requirements – to provide the necessary depth of the strengthening layer and save the the geometry of machined surfaces. Particularly acute problem appears when using a knurling as a finishing operation in the processing of steels with high hardness.

Corrosion-resistant martensitic steel 95X18 (C – 0.9-1%, Si up to 0.8%, Mn up to 0.8%, Ni up to 0.6%, S up to 0.025%, P up to 0.03%, Cr – 17-19%, Ti up to 0.2%, Cu up to 0.3%) is widely used in industry for the production of axles, shafts, ball and roller bearings and other parts, to which of high hardness and wear resistance are required. The nearest analog is AISI 440B, AISI 440C, AISI A756, DIN-1.4125, SUS440C, Z100CD17. In the production of sleeves used in the aircraft industry using steel after heat treatment, having the following mechanical properties: ultimate tensile strength 770, yield strength 420 MPa, Young modulus 204 GPa, HRC=54-59. The high hardness of the material requires a significant load on the tool, and makes it difficult to determine the optimal parameters of knurling experimentally. The scope experimental investigations can be greatly reduced by simulation the processing in one of the CAE-systems. This approach has been used successfully by many research teams [3–6].

2. Problem Statement

The simulation of interaction of knurling tool and surface contain geometrical models creation, finite elements mesh creation, definition of loaded force and restriction, calculation stresses, strains and displacement. There is large number of software for automation; these processes are both commercial (ANSYS, LS-DYNA) and freeware (SALOME, CodeAster). We have used SolidWorks from Dassault System.

Knurling roller was a cylinder with a rounded face. Diameter of rounding was equivalent to the thickness of cylinder and coincided with the real size sample. For simulation roller was represented by half of its volume. Since really loaded force provides hardening layer with depth about 1mm, proceeding sleeve simulated its segment with depth 2 mm, length 10 mm (lengthwise rolling direction), width 6 mm (crosswise rolling direction).

The material of machining rollers significantly harder than the material of the workpiece (hard alloys are used to produce). Stresses, displacements and deformations in roller do not represent a interest. The roller in the calculations can be considered as a perfectly rigid body. As a result of this for roller description we had used the mesh with big mesh spacing. For the workpiece, on the contrary, a mesh with a small spacing had been created.

The load was simulated by force put on the top face (Fig. 1). Have considered both uniformly distributed force and force apply to central area. Modelling showed no any significant differences in both methods. Bottom face of proceeding sleeve for accordance with physical experiment was assumed to be rigid. We should note that under these conditions, the simulation of knurling was actually replaced by indentation process. The simulation of any dynamic processes require the use of large computing power and a lot of time. The replacing allowed instead of dynamic loading consider static loading. This approach represents a reasonable compromise between the accuracy of calculations and simulation time.

The main aim of the research was to determine the optimal parameters for knurling details made of steel 95X18. To achieve this goal varied processing parameters (loaded force, thickness and diameter of the roller) were changed and the change in

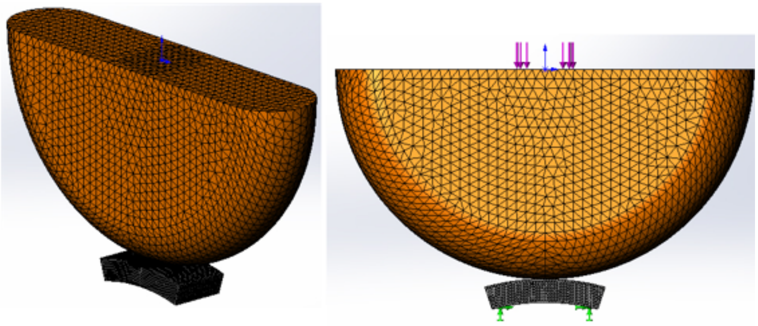

Figure 1 The geometry of the model

distribution of stresses, displacements and strains in the sample was studied.

Also studied the relevance of computer simulation results, with the results of physical experiments on knurling the sleeves of steel 95X18 by rollers of hard alloy BK8 (WC 92 %, Co 8%, nearest analog is DIN- HG30) was studied.

The processing technology is shown in Fig. 2. For the processing rollers with different thickness had been used. Load force was controlled by the dynamometer installed in the toolholder.

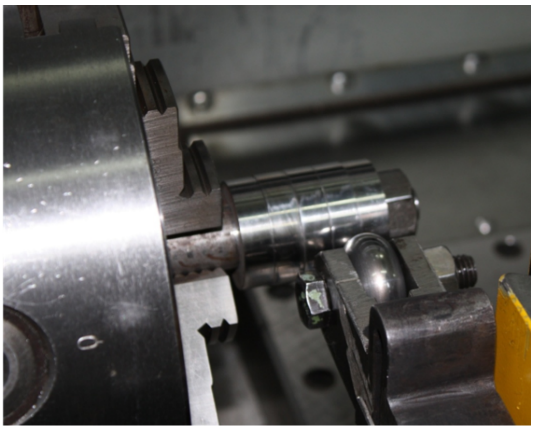

Figure 2 The processing technology

3. Results of Experiments

As a result of computer calculations distribution of stresses, strains and displacement in sleeve were obtained. Also the dependence of the strengthening area as function of geometrical shape of the machining tool and loaded force was calculated.

The typical diagram distribution of stresses is presented on Fig. 3. The value of stresses for load force 1000 N was calculated.

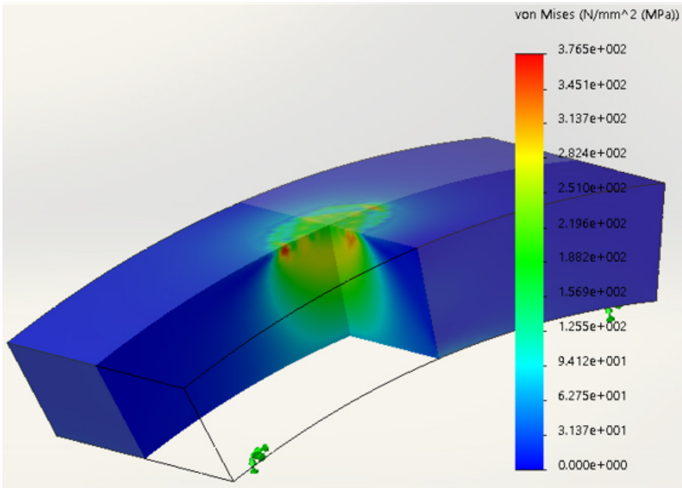

Figure 3 The stresses distribution

Stresses in surface layer do not exceed value of yield strength $\sigma_{0.2} = 420\,\text{MPa}$. In this area displacements are elastic and reversible. Strengthening area allocated in in a deeper layer. We suggest from symmetry what crossection of this area is ellipsoid with semiaxises a – lengthwise rolling direction and b – crosswise rolling direction.

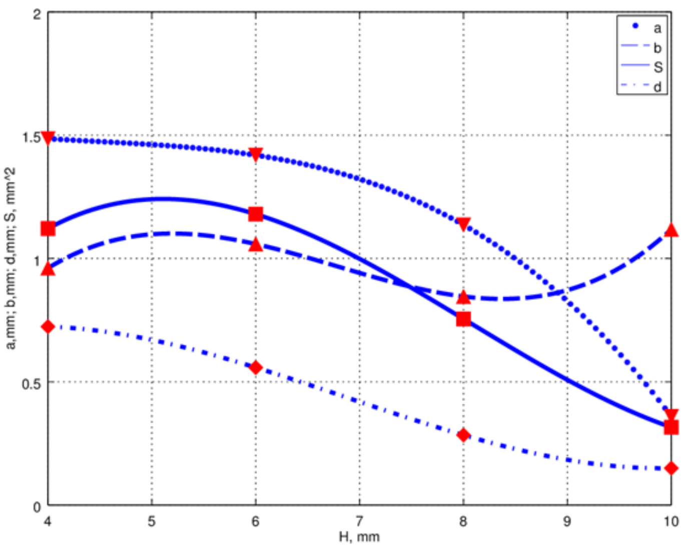

Figure 4 The strengthening area size. a – lengthwise rolling direction, b – crosswise rolling direction, S – flat area, d – depth

Analysing the data array we have determined these parameters and the strengthening area size. Since the calculation by finite element method usually contains some bugs related with a mesh, the area with deviation up to one percent from value of yield strength was investigated. The dependence of depth of strengthening calculated similarly. The dependence these units on roller thickness is submitted on Fig. 4. The interpolation with GNU Octave by Hermitian polynomial have been performed.

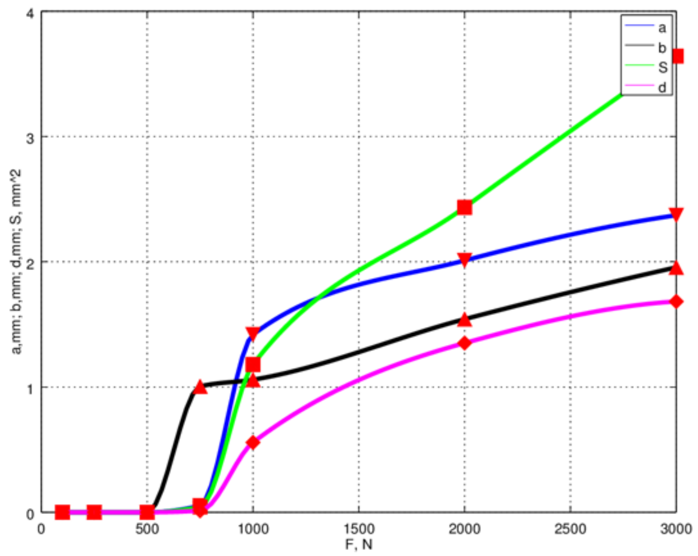

Figure 5 The strengthening area size. a – lengthwise rolling direction, b – crosswise rolling direction, S – flat area, d – depth

The dependence of the size of strengthening area, Fig. 5, strain and displacement, Fig. 6 as a function of loaded force for rollers with thickness 6 mm was studied.

4. Discussion

The dependences submitted on Fig. 5 and Fig. 6 allows to make the conclusion about the suitability of knurling. The maximum displacement under a load of 3000 N was less than 10 mkm. We can assume that in the majority of tasks, such displacement does not cause changes in the workpiece geometry, and knurling can be used as a final operation. An additional argument is that both dependencies in the studied load range are close to linear. This behaviour suggests that the great bulk of the strain is the elastic component and it disappears when the load is removed. The residual strain will be much smaller.

The analysis of strengthened area reveals an important feature of treatment. The Fig. 5 have shown that the dependence of depth is much slow than the dependence of lengthwise and crosswise size. This shows that a significant increase in the applied force does not always lead to a significant increase in the depth of the hardened layer. At some points the stresses will be likely extended in the surface layer of the material than in its depth. A reasonable solution in this situation will not increase the load force, but the reduction of thickness of the roller.

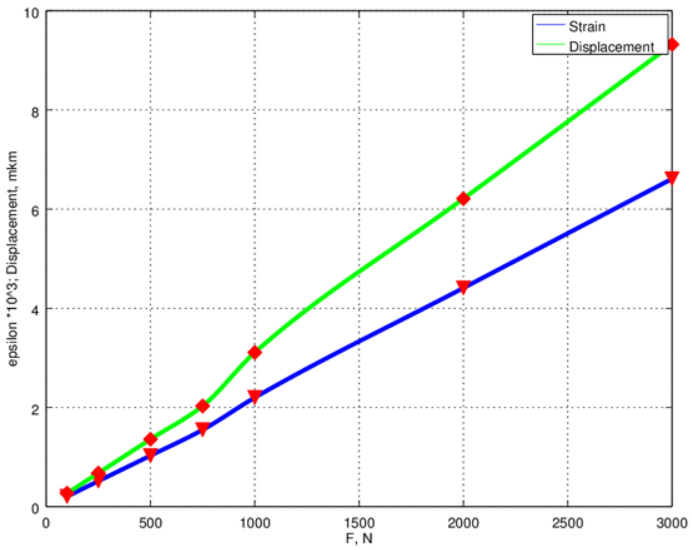

Figure 6 Strain $\varepsilon \cdot 10^3$ and displacement as a function loaded force

The results presented in Fig. 4 are quite expected. It is obvious that with the assumption constant loaded force, the increasing the of width of the roller leads to the reduction of local stresses in the material, and as a consequence, reduces the strengthening area. When the roller width of 12 mm and more stress in the material do not exceed the yield strength, deformations in this case are elastic and reversible, the hardening does not occur. Non-monotonic behaviour of the transverse size of the strengthening area is a little unusual. Initially this effect was related to bugs of the mesh of finite elements, but the calculations with changed parameters mesh confirmed the non-monotonic dependence. Perhaps non-monotonicity is associated with competing processes – increasing of roller width, which on the one hand, reduces the stresses in the material, on the other hand, increases the size of the contact area. Non-monotonicity was found in other studies. Moreover, the results of calculation of the hardened area sizes are in good correlation with the data the wear of the knurled samples published previously [7].

5. Conclusions

Using of computer simulation of knurling process significantly speeds up and simplifies the process of defining the technological parameters of treatment.

We can suggest the following sequence as a guidance:

- to determine the load range on the instrument by dependence of the maximum displacement at which there is no decay in the geometry of the workpiece;
- to select loaded forces providing the necessary depth of the strengthening in this range;
- using the graphs of lengthwise and crosswise size of the the strengthening area

to solve for a line feed, providing the necessary degree of overlap of treated areas.

This scheme allows to refuse a full-scale experiment in the finding process of processing parameters for the material of known physical and mechanical properties. Moreover, the optimized parameters can reduce the load on the processing tool and reduce the wear, to get rid of additional operations, reduce the overall processing time and the cost of the product.

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