EFFECT OF THE REDUCTION RATIO ON THE STATE STRAIN OF THE STEEL TUBES AFTER BURNISHING BROACHING PROCESS

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Abstract

The paper presents numerical research of burnishing process of the steel tubes. Burnishing broaching process is a technology of surface plastic forming of machine parts. Processing tools are hard with smooth surface. Burnishing tools are balls, rolls, and dinks. Burnished can be flat surface and cylindrical shape. In cylindrical shape can be burnished outer and inner surface. The internal surfaces of the tubular elements are treated among others by burnishing broaching. Because of the type of the force can be divided into static and dynamic burnishing. Due to the kinematics can be divided into sliding and roller burnishing. Occurrence of moving parts in direct contact with the material qualifies for the group process of burnishing rolling. The sliding burnishing design element property is part of the work surface burnished permanently attached to the handle. Burnishing is used as a finishing strengthens and smoothness, can be realized on the universal machine tools and machining centers, effectively replaces the machining operations such as grinding, reaming, honing and lapping. Theoretical analysis of the burnishing carried out in numerically. For the calculations used commercial package Forge ® based on the finite element method. Computer simulations were carried out at the Institute of Plastic Forming Processes and Safety Engineering, Faculty of Production Engineering and Materials Technology, Technical University of Czestochowa. The paper presents effect of burnishing broaching process on the state strain of the steel tubes.

Keywords: surface plastic forming, burnishing broaching process, steel tubes

1. INTRODUCTION

Burnishing broaching process is a finishing machining of holes, having a number of advantages. This treatment allows to increase the dimensional accuracy of holes, the surface roughness parameters decrease, increasing the hardness of the surface layer, formation of compressive residual stresses. It is also important that the burnishing technology allows machining holes with a lack of straightness of the axis. The advantages of burnishing broaching may also be considered high performance and relatively easy technological instrumentation. The tools used for processing by the burnishing broaching special broaches plungers in variety of shapes and steel balls such as bearing. The beneficial effect of treatment holes burnishing broaching process the state of the surface layer and the accuracy of the machined holes are obtained for products made of unalloyed steel, steel alloys and stainless steel, copper alloys, and titanium alloys. Burnishing broaching process is most often used for machining of circular cross section holes with a diameter from a few tenths of millimetres to about one hundred. In the papers [1, 2] confirmed the usefulness of burnishing broaching process as a finishing hole machining sliding bearings. It is important that the burnishing technology sets were prepared special burnished elements in the form of beads used as a tool for broaching. At the yield point of the piece-part material, the surface is plastically deformed by the cold flowing of subsurface material. The result is a mirror-like finish and tough, hardened surface. The pressure required for roller burnishing depends on various factors such as tensile strength of the material, surface toughness before and after burnishing, ductility, shape of the rollers and diameters.

Developed using artificial neural networks [2] model of stress distribution in the surface layer of workpieces can be used to expand the burnishing broaching process control system, which may advantageously influence the quality of the machined elements used for the machine construction. As part of the many works defining numerical elasto - plastic model of plastic surface treatment has been made a number of theoretical analyses using the finite element method to determine the state of stress and strain at the interface of two bodies pressed against [3, 4, 5, 6, 7, 8, 9]. On the surface of the contact elements cooperating with one another to determine the status of stress and strain using a Forge ® MES [10, 11, 12]. This commercial packet Forge® is used for simulation different plastic works: rolling, forging and pressing, drawing and other simulated [3, 6, 9, 11, 12, 13, 14]. As an innovative application of the program is to use it to burnishing broaching process. Determination of the state of stress in the surface layer is a particularly important issue due to the possibility of the projections at the relevant technological parameters of the mechanical condition of machine components. Plastic forming surface modelling consists in determining the impact of the rigid tool pre-defined curvature of the deformable object, which is the Hertz model, which is a modification of the model Bussinesqa [15, 16]. It takes into account the fact that the burnishing force spread out over a contact surface of the spherical tool and the workpiece in the half elastic - plastic.

2. METHODOLOGY AND NUMERICAL RESEARCH

Numerical research was conducted for C45 steel samples. The samples were in the form of steel tubes. Internal diameters of samples from each set were made by boring in three dimensions. The largest internal diameter of a set of samples was about 0.1 mm smaller than the diameter of the tool. Two more samples from a given set of internal diameters were smaller than the ball diameter by 0.2 mm and 0.3 mm. In the **Fig. 1** is shown schema burnishing broaching process by ball. Burnishing broaching process is performed using the balls bearing steel 20CrMo4 through the hole. Computer simulations of plastic surface treatment was carried out at ambient temperature.

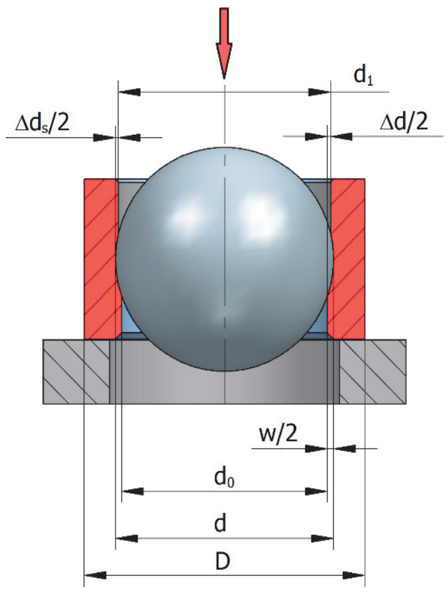

Fig. 1 The schema of burnishing broaching process, *D* - external diameter tube, *d* - outer diameter of the ball, d_0 - diameter inner tube before burnishing broaching, d_1 - diameter inner tube after burnishing broaching, *w* - reduction ratio, Δd - absolute plastic strain, Δd_s - absolute elastic strain

The friction forces been modeled on the basis of the solution Tresca and determined from the equation [10, 13]:

$$\tau = -m\left(\frac{\sigma_0}{\sqrt{3}}\right) \tag{1}$$

where: τ is the vector of unitary friction forces, MPa, σ_0 is the base flow stress, MPa, *m* is the friction factor.

The computer simulations was carried out with C45 steel. The temperature of materials was 20 °C. The external diameter *D* = 45 mm and internal d_0 = 33.02 ÷ 33.22 mm. The diameter of balls bearing was *d* = 33.32 mm. The coefficient of sliding friction of steel on steel is 0.1. The use of a computer program Forge ®, which is based on the finite element method and has built-in thermo-mechanical models, requires defining the boundary conditions. For the boundary conditions are: properties of a material, the conditions of friction, kinetic parameters and thermal properties and tools. Forge ® commercial package uses a model consisting of a finite element mesh, whose base element is a triangle. For the computer simulation, the following input data: the initial temperature is the ambient temperature, the heat exchange coefficient between the workpiece and the tool 3000 [W/Kmm^2], the heat exchange coefficient between the material and the air 100 [W/Kmm^2]. Due to limitations of the software used movable third element in the form of a thin disc sliding burnishing tubes. The use of a moveable tubes on the beads did not affect the accuracy of the calculations and only affect the calculation time by increasing the number of elements in the node which calculations are performed. Computer simulations were carried out in a three-dimensional reference system. **Table 1** shows examples of the geometrical parameters for the steel tubes after burnishing broaching process.

Table 1 Geometrical parameters and strain ratio of the tubes after burnishing broaching process

No. of samples	*D*, [mm]	d_1, [mm]	*d* [mm]	d_0, [mm]	*w*, [mm]	ε_n, [%]	Δd, [mm]	Δd_s, [mm]
4501	*45*	*33,28*	*33,32*	*33,22*	*0,1*	*0,3*	*0,06*	*0,04*
4502	*45*	*33,29*	*33,32*	*33,12*	*0,2*	*0,6*	*0,17*	*0,03*
4503	*45*	*33,29*	*33,32*	*33,02*	*0,3*	*0,9*	*0,27*	*0,03*

The relative plastic deformation for burnishing sliding is expressed by the formula:

$$\varepsilon_n = \frac{d - d_0}{d_0} \cdot 100\% \tag{2}$$

where: *d* is outer diameter of the ball, d_0 is diameter inner tube before burnishing broaching.

Of strain hardening of the material structure of the surface layer is obtained by cold plastic deformation, this improves the fatigue strength. Processing of burnishing provides the creation of a surface layer of large compressive stress, so very often is observed the increase of materials treated by burnishing fatigue resistance (surface and volume). Resistance to fatigue is one of the exploitation properties of machines, changing preferably by burnishing. Can be determined based on the relationship between the parameters and the strain and stress state in the surface layer material. It is therefore important to determine the stress and strain state in the tubular elements widely used in the metallurgical industry, machinery and shipbuilding.

The source of heat evolved in the deformation zone is the work of plastic deformation. In practice, about ten percent of this energy is converted in the area of plastic deformation in the heat. With intensive surface treatment process in the surface layer forming material at the interface with the tool of the present temporary increase in temperature, it is caused not only by the work of deformation, but also the occurrence of the friction surface of the tool with the workpiece, and the effect on the temperature in the deformation zone of the technological parameters are of the burnishing process.

An example of the temperature distribution of the relative deformation of ε_n = 0.9% and the ball diameter d = 33.32 mm, reduction ratio w = 0.3 mm, shown in **Fig. 2**.

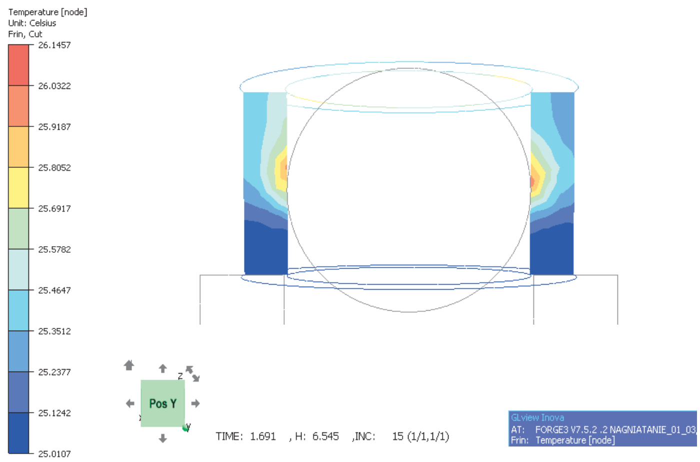

Fig. 2 The temperature distribution of the reduction ratio w = 0.3 mm for burnishing broaching process

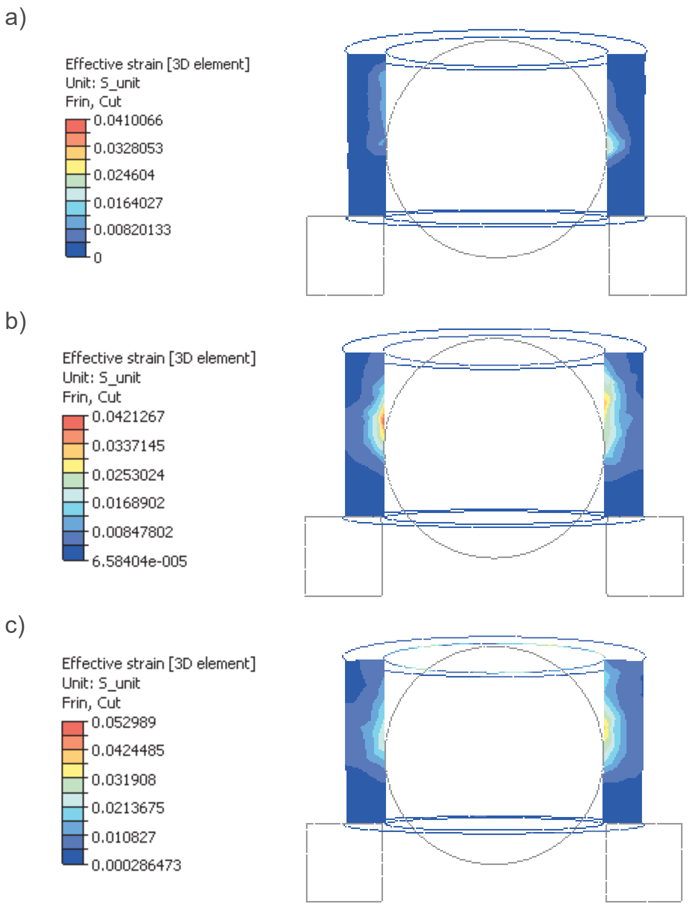

Fig. 3 The effective strain distribution of the reduction ratio a) w = 0.1 mm and b) w = 0.2 mm and c) w = 0.3 mm for burnishing broaching process

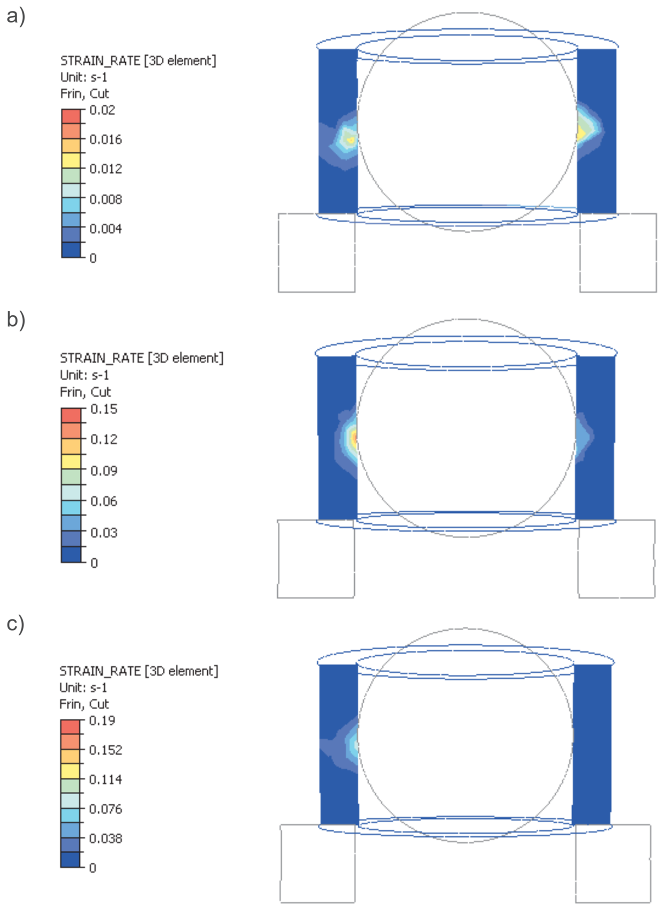

Fig. 4 The strain rate distribution of the reduction ratio a) *w* = 0.1 mm and b) *w* = 0.2 mm and c) *w* = 0.3 mm for burnishing broaching process

Fig. 3 shows the effective strain distributions substitute for computer simulation of the burnishing ball diameter d = 33.32 mm burnishing reduction ratio: in a range of from 0.1 mm to 0.3 mm. Effective strain burnishing process is dependent on the reduction ratio value of the burnishing. Based on the results listed in **Fig. 3**, we can conclude that the intensity of the deformation in the surface layer of the tubular element on the inside with a ball at the interface increases with the reduction ratio burnishing.

Fig. 4 shows the strain rate distributions substitute for computer simulation of the burnishing broaching process by ball diameter d = 33.32 mm and reduction ratio: w = 0.1 mm and w = 0.2 mm and w = 0.3 mm. With the increase of the reduction ratio, the intensity of the strain rate increases.

Distributions of effective strain and strain rate in burnishing computer simulation show the most intense nature of the surface of an elastically deformable material contact with the ball.

SUMMARY AND CONCLUSIONS

On the base of numerical analysis was determined that the reduction ratio has significantly influenced on the state strain of the inner tube holes after burnishing broaching process. An increase in the value of reduction ratio, the value of the effective strain increases. After burnishing simulations can be concluded that the most intense nature of the surface of an elastically deformable material contact with the ball is the state of effective strain and strain rate. The values of the deformation tensor gradient propagate into the material. Examined the cross-section of the sleeve can be seen that the area is characteristic of the occurrence of deformation tensors maximum value at a certain depth from the surface of the workpiece, but not more like half of the wall thickness of the tubes. After numerical analysing studies of burnishing broaching can say that can effectively specify state of strain required for planning finishing machining abrasive tube for the piece production and small lot production.

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