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THE RESEARCH INTO COMPONENTS OF FRICTION FORCE TOOL-PART DURING FRICTION HARDENING OF PLANE STEEL FACES

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Summary

It is show, in the paper, that the components of friction force in the tool wear land are increased by the increase of the value of the conditions treatment (the velocity of translation machine table, the cross-feed, depth of the tension) by friction hardening of steel. The components of friction force are compared for two kinds of tools: disc-tool with smooth surface and disc-tool with transverse grooves.

Keywords: nanocrystalline white layer, friction hardening, friction force, transverse grooves

Analiza składowych siły tarcia narzędzie-część w procesie wzmacniania powierzchni płaskich elementów stalowych

Streszczenie

W pracy przedstawiono analizę wyników pomiaru składowych siły tarcia przy umacnianiu powierzchni płaskich elementów stalowych. Wykazano, że zwiększenie wartości parametrów procesu obróbki stali (prędkości przemieszczenia stołu obrabiarki, posuwu) zwiększa składowe siły tarcia w strefie kontaktu narzędzia z powierzchnią obrabianą. Wprowadzenie do procesu narzędzi z rowkami poprzecznymi na ich części roboczej powoduje zmniejszenie wartości składowych siły tarcia w porównaniu z narzędziami o gładkiej części roboczej.

Słowa kluczowe: nanokrystaliczna warstwa biała, umacniane tarczowe, siła tarcia, poprzeczne rowki

Formulation of the problem

Provision of durability of parts, which is determined by the quality condition of the surface layer, is a topical task of mechanical engineering. The most important parameters of workpieces, i.e. operability, reliability, metal

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consumption, cost of goods sold, etc., depend on the quality of finishing. The durability of machine parts depends on the quality of parts' processing and on the condition of their surface layer, which is deliberately formed during the finishing operations of the technological process of manufacturing [1-7].

New technologies of metal surfaces finishing, which consist of creation of a nanocrystalline structure in the surface layers, are of great interest. Creation of microstructure by a controlled change of grain size in the nanometric range (less than 100 nm) is a powerful means of constructing new functional materials with unique properties and performance characteristics. Studies of nanocrystalline materials have shown that many of their properties significantly differ from those (higher tensile strength and yield strength, greater resistance to wear and fatigue fracture, etc.) of the coarse crystalline materials, which is due to their specific microstructure.

Currently, methods with the use of highly concentrated energy sources (laser, electron beam, ion-plasma and other processing), are applied to the surface finishing and hardening. These methods are characterized by the exposure of small volumes of the metal surface layer to the concentrated energy flows of high intensity at high velocities, and their subsequent fast cooling. Friction treatment belongs to these finishing methods of surface hardening. In the general case they are characterized by the formation of two qualitatively different structural zones - zone of secondary tempering (nanocrystalline white layer) and the heat-affected zone with the structure of high-speed drawing. Heating temperature of surface layers, their plastic deformation and the rate of their change during the processing significantly influence the process of formation of nanocrystalline (white) layers.

Methods of hardening of the metal surface layer with the use of highly concentrated energy sources are based on non-stationary processes of fast tempering. Physical and chemical processes that take place during the formation of the hardened layer are very complex. They are characterized by high heating rates of the surface layers, simultaneous shear deformation and subsequent cooling. Hardening, which takes place under such non-stationary conditions, significantly differs from the process under normal conditions. The heating temperature of the surface layer, stress in the contact zone of tool-part and mass transfer processes influence the formation of structural and stress state. All these processes influence the formation of quality characteristics of the hardened surface layer.

During the friction hardening the heating energy flow is formed in the contact zone of metal tool- disc and processed part during their high-speed (60-80 m/s) friction. Shear deformation of the surface layer of the processed part takes place in the contact zone of tool-part. Technological environment is supplied to the processing zone in order to improve the quality parameters of the hardened surface layer.

Friction treatment is similar to the grinding process in terms of the kinematics of the process and processing modes. Universal flat-grinding machines or cylindrical grinders with the modernization of the main drive gear unit or specially designed equipment are used for its implementation.

Friction hardening of the working surfaces of samples was performed on the modernized flat-grinding machine from *KNUTH*, *HFS 3063 VS* (Fig. 1). The engine was set with a possibility of changing the rotation frequency of the spindle.

Fig. 1. Metal-working equipment for friction hardening flat surface

A metal tool-disc is set instead of an abrasive wheel. Hardening of the surface layers of machine parts during the friction treatment is done due to the exposure of local surface volumes of metal to the intensive flows of heat energy and shear deformation. Primarily, a tool with a smooth working part is used in friction treatment. A tool with a discontinuous working part is used in order to increase the shear deformation of the metal surface layer and provide the impulse supply of heat flow to the contact zone of tool-part. Transverse grooves are cut on the tool working part. The groove width was selected based on the condition of providing full withdrawal of a tool and a part from contact.

The tool consists of a body, a variable friction (working) ring and a clamping ring. The outer diameter of the tool equaled 360 mm, the width of the working part was 6-8 mm. Variable working ring was made of steel 45 in the condition as delivered. Tool's construction provides the possibility to fit the working ring that is made of materials with different thermophysical properties. Use of different materials of the working part of the tool makes it possible to change the value of heat flow, which occurs in the contact zone of tool-part, to change the stiffness of the working part of the tool, to obtain the required quality of the treated surface.

It is necessary to know the numerical values of the friction force components that occur in the contact zone of tool-part during friction hardening in order to modernize the existing machines or develop special equipment. They are needed to perform calculations of bearings of the machine's spindle unit.

Since the friction hardening of flat surfaces is similar to flat grinding in terms of the kinematics of the process, we decompose the friction force F in the contact zone of tool-part into three components: normal F_y, acting along the radius of the tool-disc that is being hardened and perpendicular to its rotation axis; tangential F_z, acting tangentially to the working surface of the tool and parallel to the treated surface, and transverse F_x, acting parallel to the rotation axis of the tool, which is being hardened, to the direction, opposite to the feed motion (Fig. 2). Measurement of friction forces' components in the contact zone of tool-part was performed using the three-component dynamometer manufactured by the *Kistler* Company, type 9121.

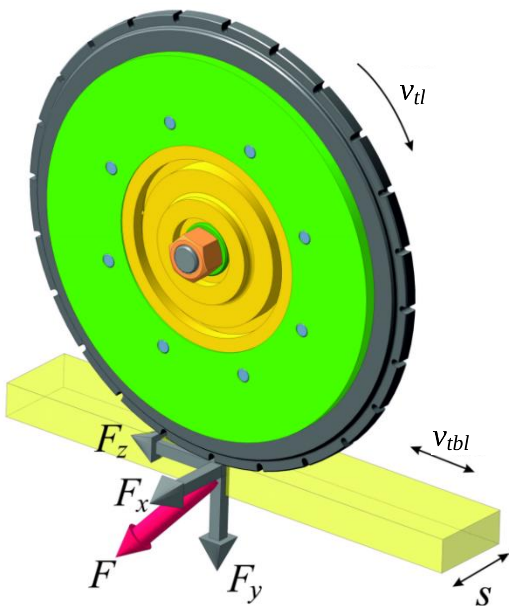


Fig. 2. The components of the friction force in the contact zone during friction hardening of flat surfaces: v_{tl} – circular speed of the tool; S – cross-feed; v_{tbl} – speed of the machine table translation

A piezoelectric system of measuring force components is used in the three-component dynamometer manufactured by the *Kistler* Company, type 9121. This system of measuring force components differs significantly from other methods. The forces, which act on the quartz crystal, are proportional to the electric charge that occurs in this case. Compression of sensing element amounts to thousandths of a millimeter. Quartz dynamometers are very rigid systems. Due to high natural frequencies they can measure even very fast processes. Quartz force piezo sensors do not require setting zero value – they are immediately ready for measurement. The advantages of piezoelectric measurement system: high rigidity and therefore high natural frequency, wide measurement range, linearity and absence of hysteresis, low "noises" (less than 1%); simplicity of operation, compactnes, unlimited working life.

A piezoelectric dynamometer is connected to the high-quality multichannel amplifier-converter, which in turn has the arranged parallel and serial interfaces for connection to a computer. A *LabView* program is used for the automation of collection and processing of data on force components on a personal computer.

The experiments have shown that friction force components F_x, F_y and F_z in the contact zone of tool-part are increasing with the increase of processing modes in the process of friction treatment of steel 41Cr4 in the hardened condition and the condition of low-temperature tempering (Fig. 3-5). The transverse component of the friction force, F_x, has the lowest value. It occurs when the tool repelled along its rotation axis. The maximum value of this component of the friction force equals about 20 N. This part of the friction force can be neglected, since its value is small.

The normal component of friction force F_x attains the highest value in the contact zone of tool-detail. The processing modes, especially the value of the vertical tension and the cross feed motion of the machine table, influence it significantly. The normal component of the friction force determines the value of pressure of the tool on the workpiece and the width of the contact zone of the tool and the wokpiece surface that is being processed. The highest value was obtained when hardening at the 6 m/min traverse speed of the machine table, at the 2.5 mm/double stroke cross feed motion and 0.3 mm vertical tension and it equals about 2000 N.

Tangential component of the friction force F_z characterizes slip resistance of the tool on the workpiece. Tangential component has little dependence on the processing mode at low values of vertical feed (0.1 mm). Vertical tension has the greatest influence on the tangential component. The coefficient of friction between the tool and the workpiece in their contact zone in the process of friction treatment was determined as a ratio between the tangential and vertical component of the friction force. The coefficient of friction is 0.05-0.08.

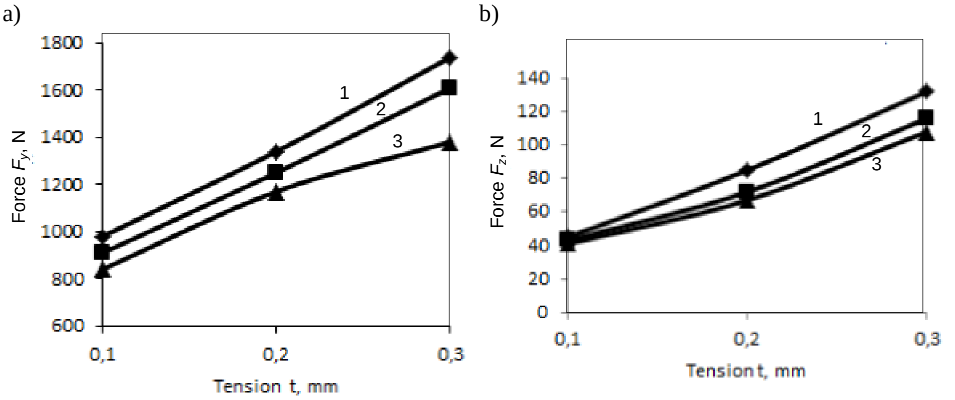


Fig. 3. The components of the friction force F_y (a) and F_z (b) in the contact zone of tool-workpiece at the frictional hardening (feed = 1.25 mm/doble stroke): 1 – v_{tl} = 50 m/s; 2 – v_{tl} = 66 m/s; 3 – v_{tl} = 80 m/s

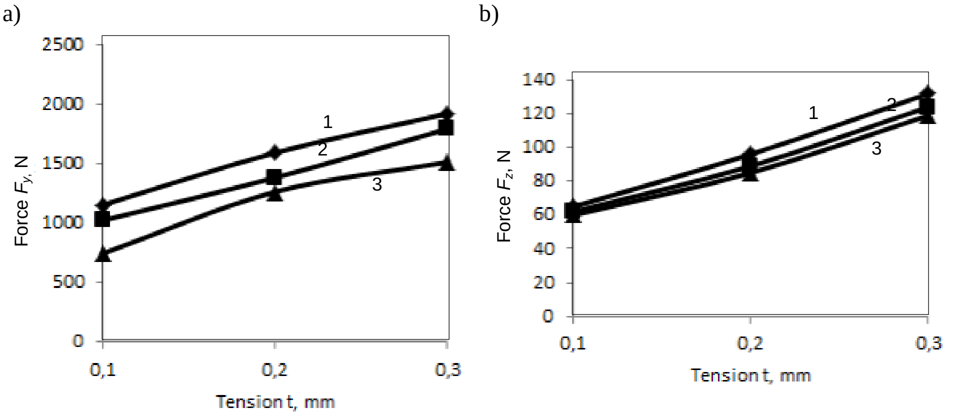
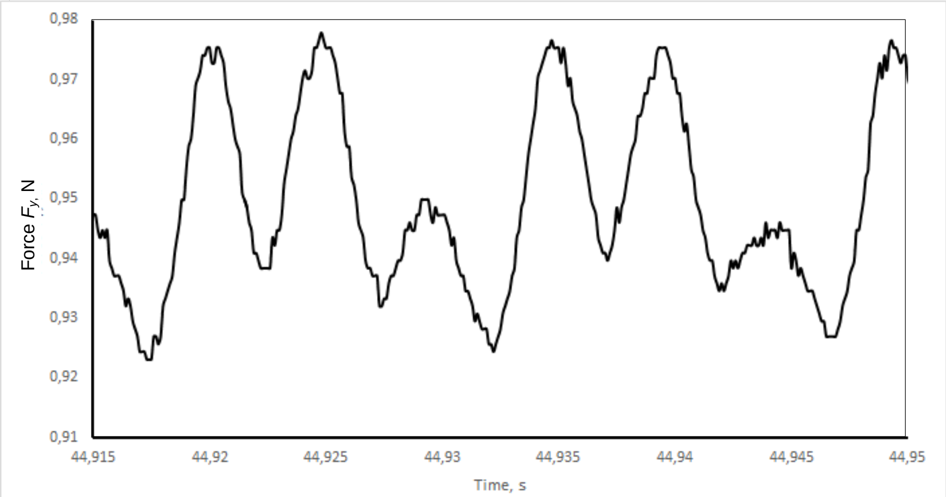


Fig. 4. The components of the friction force F_y (a) and F_z (b) in the contact zone of tool-workpiece at the frictional hardening (feed = 2.5 mm/doble stroke): 1 – v_{tl} = 50 m/s; 2 –v_{tl} = 66 m/s; 3 –v_{tl} = 80 m/s

The cross feed motion is an important parameter that influences the process of friction hardening. The normal and tangential components of the friction force increase with its increase. It is worth noting that the tool passes the same place on the workpiece 5 times when the tool width equals 10 mm and the cross feed motion of the table equals 2 mm/double stroke. Our research has shown that the best characteristics of the hardened surface and layer are obtained when the tool passes the surface at passage, which is being processed, 3-4 times.

The traverse speed of the machine table determines the time of a single contact of the tool and the workpiece. The greater the time of contact, the higher temperatures of the surface layer of the workpiece is heated to. But at the same time it should be taken into account that the surface, which is being processed, can be heated up to the melting point of the metal, what is undesirable in the process of friction hardening. At high heating temperatures, the softening of the surface layer takes place, the strength of metal decreases sharply and the tool can partially remove the hardened layer during friction.

a)



b)

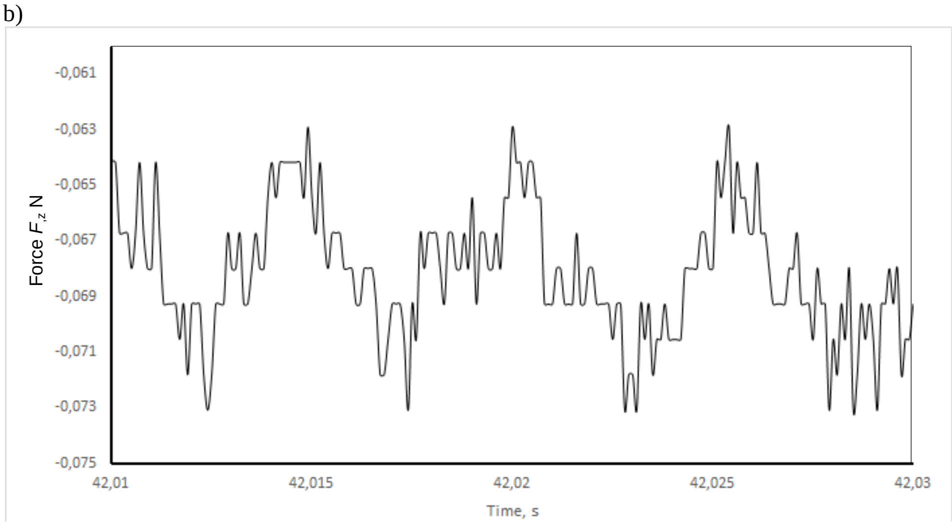


Fig. 5. Fragment of record component of the friction force F_y (a) and F_z (b) in the contact zone of tool-workpiece during friction hardening steel 41Cr4 by tool with cross slots

A change of the circumferential speed of the working part of the tool influence the value of the heat flow, which is formed in the contact zone of tool-part. The value of heat flow in the contact zone of tool-part increases with the increase of speed, and thus the density of the heat flow, which runs to the surface that is being processed, increases. As our research has shown, components of the friction force decrease with the increase of circumferential speed from 50 m/s to 80 m/s (Fig. 3 and 4).

When analyzing the obtained data on recordings of components of friction force, it can be said that all of them have a wave nature, having an equal phase. The oscillation amplitude of force components attains 0.15-0.35 of the force value and the oscillatory period equals 0.01-0.025 s (Fig. 5). Oscillations of the components of the friction force occur due to the fact that a single contact is heated to the high temperatures, the softening of the surface, which is being processed, and the decrease of the coefficient of friction takes place.

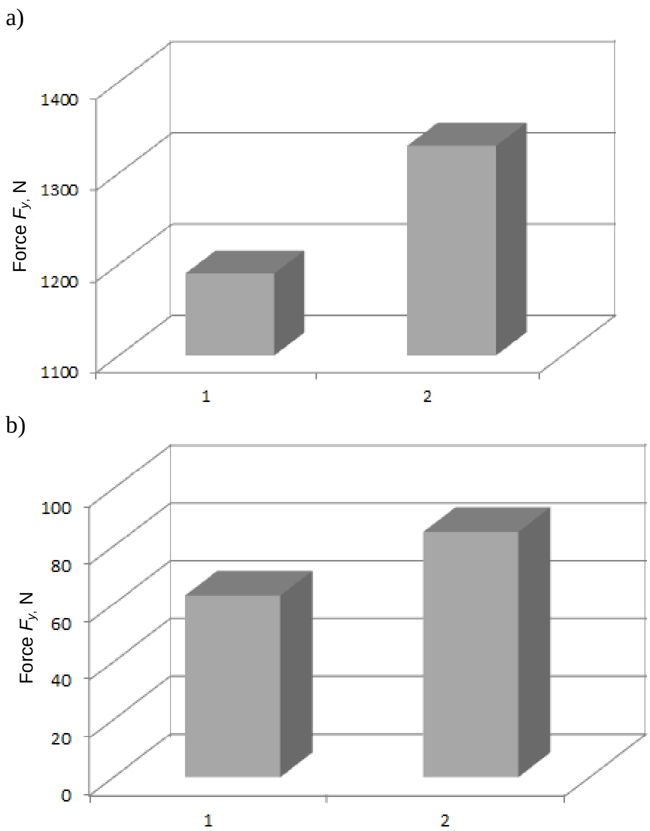


Fig. 6. The components of the friction force F_y and F_z in the contact zone of tool-workpiece at the frictional hardening by tool with a smooth surface (1) and with cross slots (2)

To compare how the form of the working surface of the tool influences the components of the friction force in the contact zone of the tool-part in the process of friction hardening: tools with a smooth working part and with the transverse grooves cut on the tool's working part were used. Studies have shown that the form of the working part significantly influences the components of the friction force (Fig. 6). The highest values of the components of the friction force are obtained when hardening with the use of the tool with a smooth working part is performed. The use of the tool with grooves leads to the decrease of the components of the friction force. At the same time it is worth noting that the hardened layer with the largest thickness and the best quality of surface are obtained in the process of friction treatment using the tool with transverse grooves.

Conclusions

1. The dependences of the components of the friction force under friction machine parts processing was analyzed.

2. Increasing the tension, cross-feed and speed of translation of machine tool components increased frictional forces in the contact zone at the tool-workpiece under frictional hardening.

3. Increasing the angular velocity of rotation of the tool reduces components of the friction force in the contact zone at the tool-workpiece under frictional hardening.

4 The tool with transverse grooves on the working part reduces the components of the friction force under frictional hardening.

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