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Experimental study of turn-milling process using special friction mill made of steel Hardox

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Abstract
The modern national economy of Kazakhstan Republic is characterized by the rapid progress of aviation, rocket, electronic, atomic and mining equipment, power, chemical and mining machinery. This led to a sharp increase in consumption of new types of materials with special physical and mechanical properties, with high corrosion and heat resistance, which processing by the traditional mechanical methods was associated with certain difficulties. These materials are generally difficult to treat and cutting tool wear is very high. One way of saving expensive tool material is the application of new technologies, one of which is a combined method of parts processing of body of rotation by turn-milling. One of the main differences of the developed method is the use of special friction mill that is not from the tool material instead of standard mills. Results of the study of this method have shown the possibility and efficiency of machining of the rotation body type parts by turn-milling using mill made of steel HARDOX as a cutting tool.
It is revealed that after processing by turn-milling under various cutting conditions and combinations of cutting tool and workpiece movement, the surface hardness values obtained before and after treatment are not significantly different, which affects successfully on performing of the following operations. The authors suggest that the main effect of the investigated cutting method is the occurrence of the current layer in sufficiently plastic state, perhaps even close to the melting state under certain temperature conditions.
Key Words: TURN-MILLING, FLOW CHIPS, CHIP FORMATION, CURRENT LAYER, FRICTION MILL, SUBCONTACT LAYER, TEMPERATURE, SURFACE ROUGHNESS, HARDNESS, FEED MOTION

Scientific and technological progress in mechanical engineering necessitates the use of new materials with special properties. Typically, these materials have higher strength characteristics, high heat resistance and corrosion resistance. When processing parts made of such materials, tool wear is intense. There are close links between the intensity of tool wear and the surface layer quality parameters of the parts processed by cutting [1].

The most significant metalworking reserves, which have not been mastered yet, are disclosed from the relationship of cutting methods establishing the transition from one method to another as change of kinematics and technological characteristic. This relationship allows us to improve the classic and develop entirely new complex methods [2]. The turn-milling is a kind of turning with multiblade revolving pick. Insignificant differences lie in the use of standard mills and rotation axes location of workpiece and tool [2, 3].

The research results of the titanium alloy processing by turn-milling are given in [4]. As processed material, the round rolled product made of titanium alloy VT 1-0 was used. The end mill was taken as tool. BK8 was cutting part material. The treatment was carried out at the counter and passing scheme of tool advance without using of LCTF (lubricant cooling technological facility). It was found that the surface quality differs slightly when the processing of titanium alloy with a cutting speed of 15 m/min at the counter and passing scheme of the tool advance. With increasing cutting speed when counter scheme of the tool advance, the surface quality is reduced by the chip pickup on the surface processed. When passing turn-milling the surface quality is improved and there is a reliable removal of chips from the cutting zone. Also, the chip samples have been researched when the counter scheme of the tool advance, which have been strongly deformed and, with an increase in cutting speed, this deformation magnifies. When passing processing scheme the chips obtained have less deformed condition [5, 6]. At the department of "Technological equipment, mechanical engineering and standardization" the following grant topic is performed: “Development of a special machine constructions enabling a pulsed cooling feed and replacement of cutting tool made of hard alloy on the tool made of structural steel when thermal friction cutting of metal workpieces”(contract No723-2015). As a part of this topic, a series of experimental studies of the combined turn-milling method using special cutting tool (friction mill) have been carried out. One of the main differences of the developed method is the use of special friction mill, which is not made of the tool material, instead of standard mills. The basis for the research and development of this process were the results obtained by the authors in the development of resource-saving ways of thermal friction processing at low speeds [7, 8]

Experimental tests were carried out in a special unit mounted on lathe. Samples (round rolled pro- ducts) prepared for processing were made of the following materials: steel 30KhGSA and steel 3. Friction mill was made of steel HARDOX 400. Also, the standard angular cutter made of material P18 was used for processing.

Figure 1 shows a picture of the special friction mill.Experimental studies were carried out in three stages.

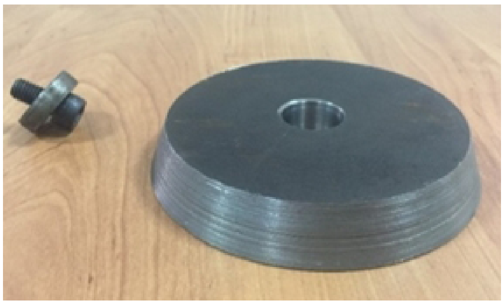
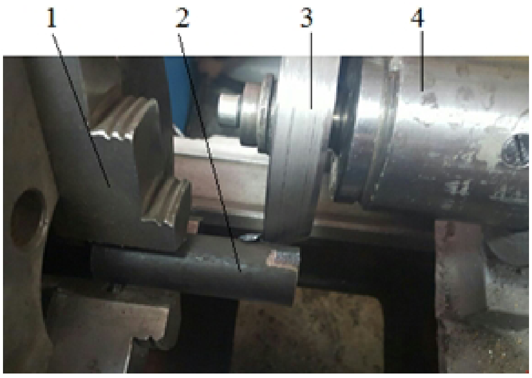


Figure 1. Special friction mill

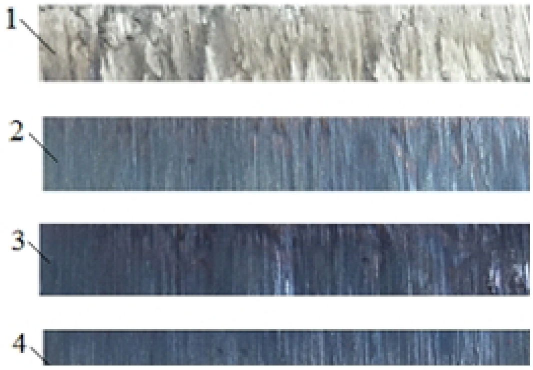


1. three-jawed chuck; 2. workpiece made of steel 30KhGSA; 3. friction mill made of steel HARDOX 400; 4. special unit spindle

Figure 2. The processing of steel 30KhGSA

At the first stage, the special friction mill is connected with rotary motion and feed motion, wherein the workpiece is fixed. At the second stage, the friction special mill and workpiece are simultaneously interconnected with rotation movement, wherein the tool additionally comprises a feed motion. At the third stage, angular cutter made of P18 was used as a cutting tool. Tool and workpiece at the same time were connected with rotation movement, and the tool further has a feed motion.

Figure 3 shows the surface of the processed steel 30KhGSA and types of chips obtained when different tool feeds.



a)

b)

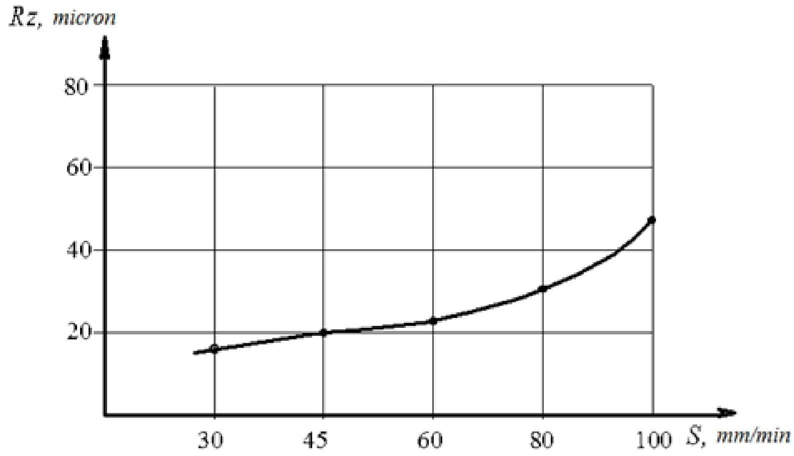
c)

a - processed surface at a magnification of 20 times; b - processed workpiece; c - types of chips obtained when different tool feeds;
1 - S = 100 mm/min; 2 - S = 80 mm/min; 3 - S = 60 mm/min; 4 - S = 45 mm/min;
5 - S = 30 mm/min; t = 1.5 mm; n_{sr} = 2000 rev/min; v_u = = 250 m/min

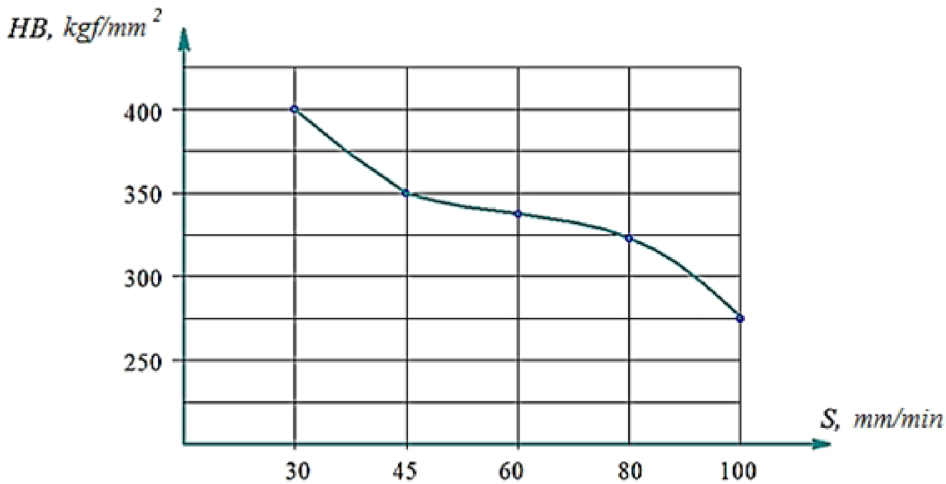
Figure 3. The processed surfaces of steel 30KhGSA and chips types

When processing steel 30KhGSA the flow shearing chips were formed (Fig. 3, *c*). The chip surface contacting with the cutting edge of the tool was smooth, and the opposite side was rough. After completion of the tests, when inspecting the cutting part of the friction mill the signs of wear, scratches, and the presence of burnt areas and scale pickup were not observed. This can be explained by the fact that when the high temperature (θ>600°) chip layer softens, becomes very ductile and acquires certain mobility. So-called active layer is appeared [9,10] and it can be assumed that there is a chip sliding relative to the current stagnant layer that protects the surface of the friction mill from wear. It can be concluded that the main effect of the test cutting method is the occurrence of the current layer in sufficient plastic state, possibly even close to the melting state under certain temperature conditions. The appearance of this layer reduces the friction on the workpiece-tool surface, and consequently, reduces wear and improves surface quality. Further scientific conclusions can be drawn from a study of the chip section in deformed state.

Figure 4 shows the feed charts impact on the roughness and hardness of the cutting surface during processing of steel 30KhGSA.



a)



b)

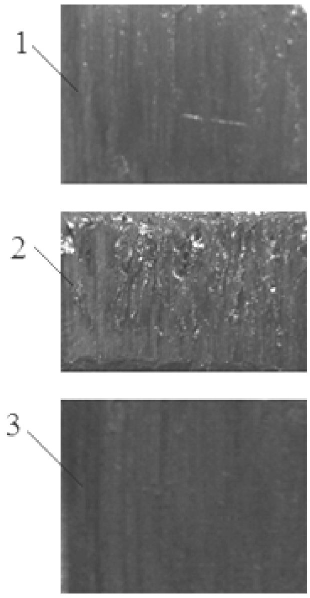
a – chart of feed impact on roughness; b – chart of feed impact on hardness t = 1.5 mm; n_{sr} = 2000 r/min; v_u = 250 m/min

Figure 4. Feed impact charts on the roughness and hardness of the cutting surface

While conducting tests, feed values ranged *S* = 30 ÷ ÷ 100 mm/min. Measurement of surface roughness was carried out using a device (profilometer) TR 100. Measurement of hardness of the treated surface was carried out using a dynamic device TDM-2. The results of experimental studies have shown that the feed impact on the roughness of the cutting surface is monotonic, i. e. with the feeding increase the surface quality deteriorates. The increase feeding has a monotonous impact on the hardness of the cutting surface. According to the chart (Fig. 4b), it can be seen that the hardness value decreases when feeding increase.

Conducted initial experimental studies indicate the possibility of mechanical processing by the proposed method of turn-milling using the tool made of steel HARDOX 400.

Figure 5 shows the processed workpiece made of steel 3 and types of chips obtained.



b)

a)

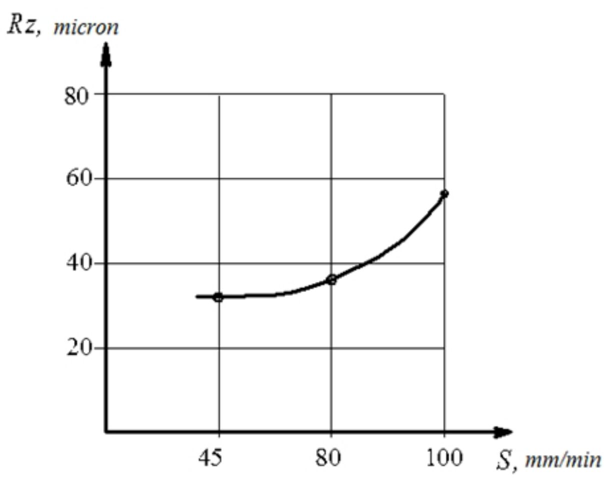
c)

a - processed surface at a magnification of 20 times; b - processed workpiece; c - the types of chips obtained when processing with various feeds

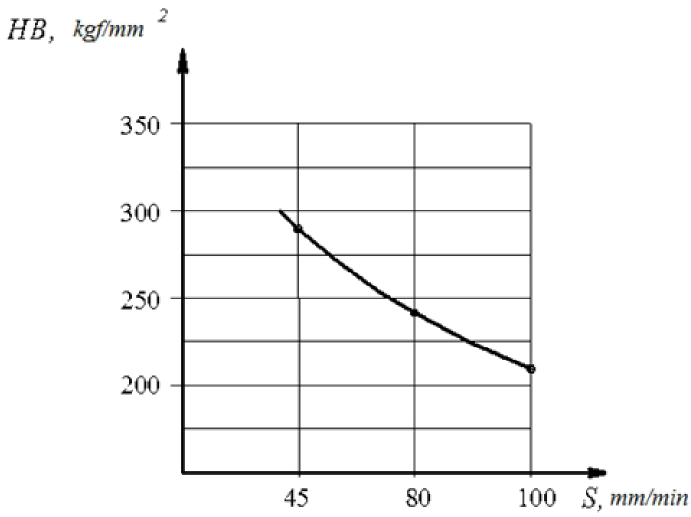
1 - S = 100 mm/min; t = 1.0 mm; 2 - S = 80 mm/min; t = 2.0 mm; 3 - S = 45 mm/min; t = 4.0 mm; n_{sr} = 2000 r/min; v_u = 250 m/min

Figure 5. The processed surfaces of steel 3 and chips types

During the processing of steel 3 at various feedings, a sharp change in the character of chip formation process is observed. A temperature has a great influence on chip formation process. This temperature occurs in tool-workpiece subcontact layer that provides high ductility of the shear layer. Increasing the feed facilitates the chip formation and output. Fig. 6 shows the feed charts impact on roughness and hardness of the cutting surface when processing the steel 3.



a)



b)

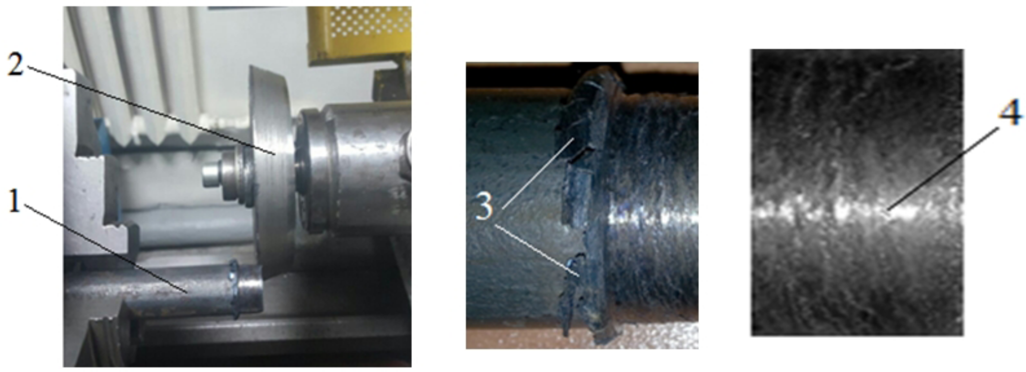
a – the chart of feed impact on roughness; b – the chart of feed impact on hardness
t = 1.0 mm; n_{sr} = 2000 r/min; v_u = 250 m/min

Figure 6. Feed impact charts on the roughness and hardness of the cutting surface

The results obtained show (Fig. 6 *a*), that when feed increasing the microroughnesses height rises and the hardness decreases (Fig. 6 *b*). In both cases, it is observed that the feed increasing has a monotonous impact.

The experiments on study the possibility of processing by turn-milling were carried out when simultaneous rotating of workpiece and tool.

Figure 7 shows the processing of steel 30KhGSA when simultaneous rotation of workpiece and tool.



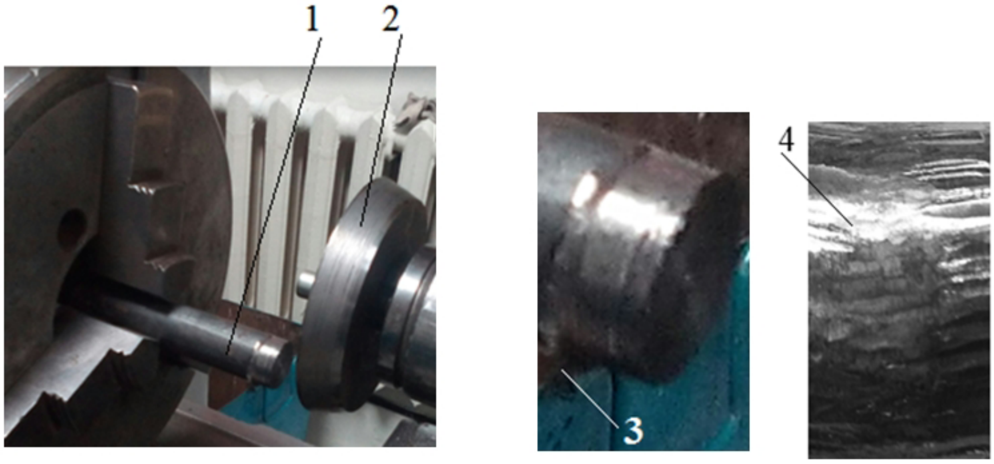
a) b) c)

a – processing; b - processed workpiece; c - machined surface roughness
S = 45 mm/min; t = 1.5 mm; n_{sr} = 2000 r/min; v_u = 250 m/min
1-workpiece; 2 – friction mill made of steel HARDOX 400; 3- chips;
4- processed surface at a magnification of 20 times;

Figure 7. The processing of steel 30KhGSA in case simultaneous rotation of workpiece and tool

The experiment on the processing of workpiece made of steel 30KhGSA was conducted when simultaneous rotating of workpiece and tool. The workpiece with following dimensions was processed: ø30mm, *l* = 25 mm. The treatment process has roughing character and the chips output is not observed during the cutting process. The surface hardness was measured before and after processing that was HB217 before treatment and HB220 after treatment respectively. The surface roughness corresponded to R_z 40.

Figure 8 shows the processing of steel 3 when simultaneous rotating of workpiece and tool.



a) b) c)

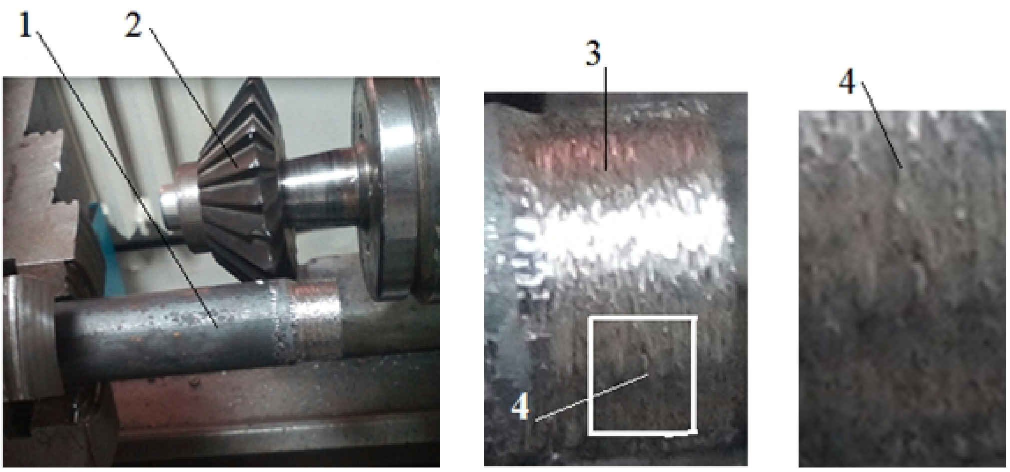
a – processing; b - processed workpiece; c - machined surface roughness
S = 60 mm/min; t = 1.0 mm; n_{sr} = 2000 r/min; v_u = 250 m/min
1 - workpiece; 2 - friction mill made of steel HARDOX 400; 3 - chips;
4 - machined surface at a magnification of 20 times

Figure 8. The processing of steel 3 on case of simultaneous rotation of workpiece and tool

Processing of steel 3 when simultaneous rotating of workpiece and tool has been performed under the same cutting conditions as when the processing of steel 30KhGSA. The workpiece ø26mm was selected for processing, length of treated surface was l = 32 mm. The surface roughness corresponded to R_z60. The hardness of the surface was HB131 before the processing and HB148 – after processing. After treatment, surface hardness increased slightly.

To investigate the turn-milling, method the standard angular cutter was used.

Figure 9 shows processing of steel 3 by angular cutter when simultaneous rotation of workpiece and tool.



a) b) c)

a – processing; b - processed workpiece; c - machined surface roughness
S = 40 mm/min; t = 1.5 mm; n_{sr} = 2000 r/min; v_u = 250 m/min
1- workpiece; 2- angular cutter; 3- machined surface; 4- machined surface at a magnification of 20 times

Figure 9. The processing of steel 3 by angular cutter when simultaneous rotating of workpiece and tool

During processing of steel 3 by angular cutter in case of simultaneous rotation of workpiece and tool, the previously selected modes of cutting were not changed. The workpiece with following dimensions ø30mm, l = 28 mm was subjected to processing. During the processing, there was crushing of chips and their removal from the treatment zone. These chips were severely deformed. Surface hardness was measured before and after treatment that was HB131 before and HB137 after the processing respectively. The surface roughness corresponded to R_z 80.

The aim was to obtain experimental data showing the possibility of mechanical processing by turn-milling using the mill made of steel HARDOX as cutting tool, as well as to get general information regarding chip formation process, the surface quality forming and feed impact on the quality indicators.

The results show the possibility of processing by the proposed method. It is necessary to conduct further experimental studies for more extensive study of the processes occurring in the course of treatment and technological capabilities of turn-milling.

Conclusion

1. The possibility of mechanical processing of parts such as body of rotation by turn-milling using a mill made of steel HARDOX as a cutting tool has been shown.

2. It has been found that the feed impact on the roughness and hardness of the cutting surface is monotonic, i. e. with feed increasing the surface quality deteriorates, and the hardness of the surface is reduced.

3. It has been revealed that after processing by turn-milling when simultaneous rotating of workpiece and tool the surface hardness value before and after treatment differs slightly, which successfully affects the performance of the following operations.

4. The results obtained when processing of steel 3 by standard angular cutter when simultaneous rotation of workpiece and tool confirm the conclusions of [4], namely that for the implementation of high-quality grinding of chips, a number of tool rotations n_t should be greater than the number of part rotations n_p.

5. We can assume that the main cutting effect of the investigated method is the occurrence under certain temperature conditions of the current layer in sufficient plastic state, probably even close to the melting state. The appearance of this layer reduces the friction on the workpiece-tool surface, and consequently, reduces wear and improves surface quality. However, to obtain reliable results, further scientific researches of the chip section in deformed state are needed.

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