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THE SLIDE BROACHING BURNISHING AND THE INFLUENCE OF DEFORMATION ON ROUGHNESS OF 314L STAINLESS STEEL SLEEVES

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Abstract: The paper is intended to inform the reader of the effectiveness of the technological burnishing process utilizing a three burnishing broach mandrel for the inner finishing of cylinder surfaces. The burnishing tools were constructed out of 40HM steel, and the burnishing broach tool was secured in a Hydraulic Press MX-340G. The mechanism of slide burnishing broaching consists of prepared burnishing mandrel pushers with diameters Ø17 mm. The sleeves were designed to achieve a reduction ratio in burnishing of 0.3 mm to 0.5 mm. Here, slide burnishing was conducted in two passes, (down and then up). The burnishing was performed at a constant rate of feed and with the same force for all samples. In the thesis, classifications and characteristics of burnishing with conditions of process parameters and the used instrumentation are presented.

Keywords: burnishing broaching, finishing, hard machinable materials, austenitic steel.

1. INTRODUCTION

In previous years, the trend has been to create more durable, functional and precise component tooling machines. Such machinery has to incorporate better manufacture techniques and innovativeness, albeit at concurrent decreased manufacture cost. In order to meet the requirements, continuous improvement is necessary. Here, the surface layer of such toolshas decisive impact on product reliability and quality standard. For this purpose, smoothness-strengthening processing, otherwise known as finishing processing, is applied. This generates dimensional accuracy, and raises the hardness of the surface layer, ensures surface smoothness, minimizes compressive stresses and creates surfaces without abrasive impurities. These effects, in turn have positive impact on fatique strength.

Burnishing is a mechanical method of finishing primarily for metal and their alloys. Burnishing removes the local plastic strain that is formed in the superficial layer through hard kinetic action, and it creates a quality finish. This kind of processing is made possible with the aid of burnishing elements such as mandrels, rollers and abrasive spheres. The burnishing phenomenon is realized without heating up the tool and the object [Kukiełka 1994; Starosta and Dyl 2008].

The greatest progress in field of burnishing treatment came about in the '30s and the '40s of the 20th century, although already in 1916, elastic strain testing and remedial treatment was standard procedure [Przybylski 1987].

The development of burnishing tools and burnishing methods in the '60s of 20th century allowed for smoothness working processing, in addition to dimensional processing. Burnishing tools became unified, and it was made possible to incorporate burnishing technology on lathes, milling machines, drills and numerically controlled treatment machinery. Generally, ball bearing and diamond elements are applied in the burnishing process. This enables hardened steel treatment and hardened surface creation through nitriding, carburizing and electrolytic coating [Dyl 2014; 2017]. Burnishing is applied in cylinder and slide bearing production, enhancing hardness and minimizing friction. The development of the burnishing process was concentrated on dealing with hard machinable materials processing, including hardened steel, composite, ceramics, alloyed coating and composite coating. Improvements in the burnishing process made rapid progress due the use of modern devices and tools, and insight into processing procedures [Blicharski 2004].

Taking into account the variety of shape tools and the variety of applied solutions, there are 20 standardized processing methods. Burnishing applied as processing involves enhancing surface quality, dimensional-smoothness and surface strengthening. The crucial constraint during burnishing is the hardness of the processed material. This should not be equal to or harder than the hardness burnishing device. Material of unit elongation value less than 6% is considered to be hard machinable materials. Thus, material of unit elongation larger than 6% is burnishable, but the decisive difficulty is to achieve low roughness [Tubielewicz 2000]. In series production, materials of hardness higher than 45 HRC are not treatable using traditional burnishing steel elements. These materials can, however, be treated via the slide method with the use of diamond burnishing elements [Korzyński 2007]. Some constraints are also caused by the system in which the machine tool is working, because such should be characterized by high stiffness [Przybylski 1987].

The main advantage of chipless forming burnishing compared to classical machining method is the possibility of receiving a surface with low roughness, larger rounding top radius and notches.

After applying the burnishing process to surfaces, it is possible to obtain large coefficients of reflection, high surface loading, surface layers with increase abrasion resistance, fatigue-mitigation and minimal surface corrosion. Upon applying the burnishing procedure, metal fibres maintain internal continuity, formation scorch is eliminated, thermal deformation, or decarbonizing are minimized. The surface after burnishing is distinguished by low coefficient friction and also good lubricant adhesion.

The process is connected with developing production technology and has a lot of advantages, including high stability, high capability of processing, possibility of burnishing followed by additional machining, instrument application at different machine tool stations. Burnishing is a safe type of treatment, because the process is realized at low temperatures and lacks chip creation, sparking and the use of dangerous fluids. There are however, several disadvantages to utilizing the burnishing process. Among these are problematic choices in specific processing parameters, necessity for careful burnishing processing, the difficulty of use in treating thin-walled sleeves.

The intensive development of burnishing technology has contributed to the creation of modern constructional materials with complex physical, mechanical and chemical properties. The use of these materials is associated with the need to elaborate new technologies for their production, and to improve existing methods.

Hard machinable materials are commonly used in different industrial branches, such as in the automotive and aircraft industries, tooling or die-casting, due to increasing requirements that are imposed on the materials, along with increased demand for hardness and a desire to decrease the weight of machine parts.

2. THE SLIDE BROACHING BURNISHING PROCESS

Slide burnishing is the act of pressing with appropriate force to the machined surface, a smooth burnishing element. This displaces the machined surface by way of producing sliding friction, while remediating plastic strain roughness.

The burnishing elements for this type of machining are hard and have low coefficients of sliding friction. The smoothing sliding procedure is use in hole machining, shaft, surface and shape planing of material characterized by high hardness. Slide burnishing enables the strengthening and smooth burnishing of hard machinable materials. Slide burnishing is also less harmful for natural environment than other abrasive machining methods.

Slide burnishing is a kind of cold finishing. The process depends on using a permanent smoothing element at constant burnishing force, in order to press down onto the machined surface. This type of processing guarantees smoothness and the accuracy of the forming surface. By way of the applied slide friction, the surface of the processed material is consolidated. The advantage of this machining is the ability to deal with high rounding radius notches and vertexes of irregularity, also to machine materials with minor angles of inclination.

Slide burnishing increases operation resistance, primarily through enhanced abrasion resistance and surface fatigue [Polowski et al. 2011].

Figure 1 shows the scheme of the slide burnishing process.

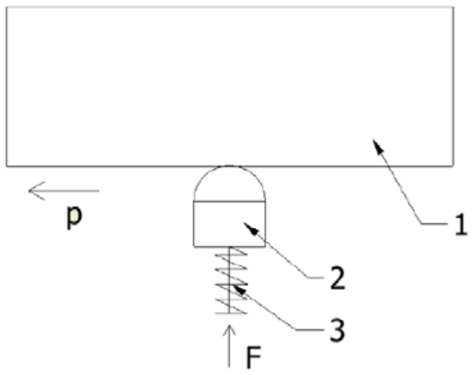

Fig. 1. The scheme of the slide burnishing process; 1 – workpiece, 2 – burnishing element, 3 – compression spring, F – burnishing force, p – burnishing feed [Przybylski 1987; Korzyński 2007]

Stiff clamp or springy working heads are applied during slide burnishing. The stiff clamp is applied in processing small surfaces so as to minimize mistakes in shaping and also for machining discontinuous surface. Slide burnishing with springy clamp is applied to enhance the properties of the object's homogeneous surface layer.

For burnishing with this type of clamp, the machine tool must be capable of highly accurate machining. Disadvantages in utilizing springy clamps are inaccurate machining, low capability and clamp depth, as well as complicated small hole machining.

2.1. The slide broaching burnishing methods

Slide burnishing can be undertaken in the form of a burnishing mandrel. This type of tool can be used in rotational or non-rotational burnishing of complex forms, and its workspace can be spherical or have some other shape. Slide broaching burnishing methods due to the mechanics of the process can be divided into: static, where the burnishing force is held constant; and dynamic, wherein the burnishing force variates over time.

Static burnishing can be applied simultaneously or directly after machine processing [Fattouh 1989]. The static burnishing methods are carried out as sliding pressure (in which sliding friction is appled) or as turning pressure (in which rolling friction is applied). The clamp force in the static method is stiff or resilient.

Burnishing is efficient and easy to apply in slide redrawing. It is used for machining holes in soft and middle hardness materials. Slide redrawing is a type of processing where sliders act on the burnishing element by way of application of a pushing character. The slide push broach mostly has a ball form – that is it is a ball bearing or circular mandrel. Push broaches are used for creating holes of short depth up to 100 mm diameter. Therein, the largest dimensioned machine elements have to be greater than expected by 0.05 mm.

Figure 2 shows the scheme of the slide burnishing broaching process.

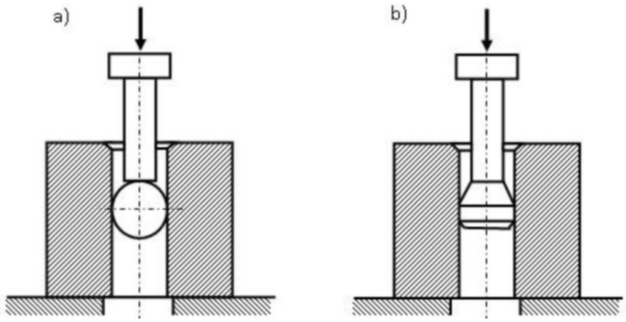

Fig. 2. The scheme of the slide burnishing broaching process: a) ball bearing, b) mandrel [Przybylski 1987]

The treatment gives the opportunity to consolidate the hardness of the surface layer, increase hole accuracy, reduce surface roughness and initiate internal stress compression. The tools applied in this method are simple in construction and give the possiblity of processing holes with misaligned axis, while remaining productive. The processing force is applied in a straight-forward system of tool-object and is statically direct to the burnishing surface. Slide burnishing broaching is used for processing steel, cast iron, bronze and brass. The pull broaching sub-method induces increased smoothness, dimensional accuracy and strain hardening of the workable surface layer. It guarantees a specific geometry and that surface structure elements will work in situations of friction. Moreover, it increases fatigue strength [Dyl 2014; 2017; Dyl et al. 2019]. In this processing technology, roughness is conditioned by the thickness of the processed wall cylinder or sleeve [Kukiełka 1994].

2.2. Instruments for slide broaching burnishing

Tip tools for sliding processing are made of materials with low sliding friction coefficient, high hardness and resistance to compression and wear [Korzyński 2007]. The burnishers are most often made of diamond (either natural monocrystalline diamonds and synthetic diamonds), which enables processing the hardest steel and non-ferrous metals alloys. The burnisher will have in the shape a ball, cylinder or cone with appropriate rounding radius.

During slide burnishing, a toolholder is used to enable performance processing on conventional machine tools, mostly the turning lathe. In the course of sliding burnishing, the device is held in a springy clamp. The tool has a working tip made of diamond composite, and the diamond element has a spherical-shaped cap with known radius determined by the hardness of the processed material. In machine tools, the holder is usually clamped in a tool post, slide or a capstan-head. The burnishing force is controlled by way of a support adjusting screw within the range of 0 to 250 N [Zaleski, Skoczylas and Bławucki 2017; Zaleski 2018]. It should be noted that the requirements for the used tool materials are increasing [Zębala 2011], as new products are manufactured from hard machinable materials, such as nickel alloys, titanium alloys, special ceramics, stainless steel, etc.

2.3. Conditions of slide burnishing

The choice of conditions is important in processing. The stress pattern encountered is connected with the energy state of the object's surface, as slide burnishing raises the surface layer condition, hence elastic and plastic strain appears. The rounding radius of the burnishing element also influences the size of contact with the processing surface. Moreover, the feed value should be selected so that the rate of feed is less than the contact length, and leaves a tool indentation so that the machined metal fills the dimple in the machined element.

The next significant aspect is settling the numbers of stress cycles that the machined surface goes through. Furthermore, as the surface hardness increases, roughness must be lessened. In the course of slide burnishing, machine oil lubrication is applied, as doing this decreases the friction between the burnisher and the machined surface, and improves tool slip.

2.4. Properties after burnishing

The burnishing processing has a beneficial effect on the surface layer, particularly on fatigue strength. High fatigue resistance is necessary in case of elements working in variable loads, such as wobble and other symmetric pendulum loads.
In the course of processing, surface stresses increase with the increase of the applied external stress. When surface layer stresss are compressive, the stresses are dealt with by organizing asymmetric processing cycles.

After slide burnishing, a surface with low roughness and large rounding radius is obtained. This can increase the fatigue strength hardness of both low and high alloy steels. The value of increase fatigue strength depends on the value of technological parameters and the burnishing method [Przybylski 1987]. Slide burnishing, however, has an adverse impact on anticorrosive properties. Still, hardness growth occurs along with the decreased surface roughness that is obtained during the slide burnishing. This also improves the tribological wear resistance of frictional pairs, as by machining friction nodes found in hard and low hardness steels, we obtain more favourable tribological properties.

2.5. Characteristic of steel AISI 314l

Super alloys are hard machinable materials characterized by high mechanical strength with simultaneous resistance to surface degradation under the influence of a chemically active environment at high temperatures [Ziółko 1995].

The austenitic steel AISI 314L is a heat-resistant steel with similar chemical composition to AISI 309 grade, and, on comparison to it, it has higher resistance to oxidation due to the higher contents of chromium and nickel [Blicharski 2003]. The highly alloyed chromium-nickel-silicon steel is characterized by high tenacity and good mechanical properties. It has high resistance to simultaneous oxidation and high temperature loads, it is heat-resisting up to temperature 1150°C and is high-temperature creep resisting to 690°C.

AISI 314L steel contains chromium (24.0–26.0%), nickel (19.0–22.0%), manganese (up to 2%), silicon (1.5–2.5%), phosphorus (up to 0.045%), sulfur (0.03%) and carbon (up to 0.2%). It is perfectly suited for use in environments of gases containing oxygen and nitrogen, however, it does not demonstrate corrosion resistant properties for sulfur compounds. When used in situations where gases of high concentrations are encountered, heat resistance is reduced to 900°C [Przybyłowicz 2007]. The material has many advantages, including high yield strength, low coefficient of thermal expansion and hardness up to 223 HB. Steel AISI 314L is used to manufacture parts of devices used for gas pyrolysis and methane conversion, as well as for parts subject to high loads working at high temperatures, i.e. hooks, elements used in ovens, elements of tanks in the oil and petrochemical industry.

3. STUDY METHODOLOGY

3.1. Test material

Experimental research was carried out for the slide burnishing of sleeves prepared from an AISI 314L (1.4841) steel shaft. The external diameter of all sleeves was 45 mm and the height was 25 mm. However, after burnishing, the internal diameters were 17 mm and the diameters differed by 0.3 mm and 0.5 mm. Of note, the internal diameter of the sleeve should be 0.3 mm smaller than the diameter of burnishing element. The burnishing broaching elements were made of 40HM (1.7225) steel hardened at a temperature of about 850°C, the material was cooled in oil.

3.2. Measurement methods

The paper presents a design of mandrel pushers for machining sleeves made of hard machinable materials for the Maqstock MX-340G universal hydraulic press in the Laboratory of Plastic Working Department of Marine Materials and Renovation Technology. One of the requirements made during the project was to match the mandrel pushers under a clamping blanking die, so that the diameter of the burnishing mandrel is within the diameter range of the MX-340G hydraulic press die [*Prasa hydrauliczna uniwersalna MX-340* 2020].

Burnishing with a mandrel took place in two passes (Fig. 3), and the process was conducted in the vertical direction – moving down, then up, where the sleeve had to be secured before displacement.

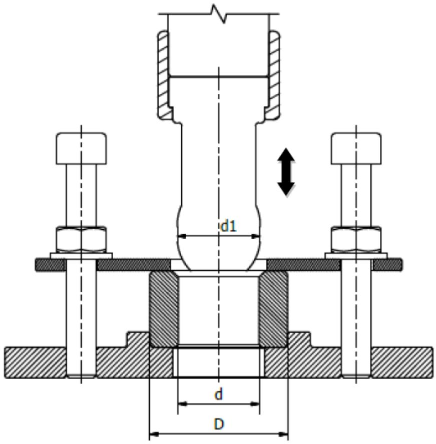

Fig. 3. The schema of slide broaching burnishing

4. RESEARCH RESULTS

In the next stage, we examined the relation between roughness and deformation of the sleeves surface through slide burnishing broaching. Figures 4 and 5 show the roughness of the profiles after the burnishing broaching process for sleeves Ø16.5 mm and Ø16.7 mm. The values shown in Figures 4 and 5 are characterized by a lower average arithmetic profile after processing. The value difference before and after the processing was nineteen times lower for Ø16.5 mm (Ra = 1.91 µm) and for Ø16.7 mm – twelve times smaller (Ra = 1.78 µm).

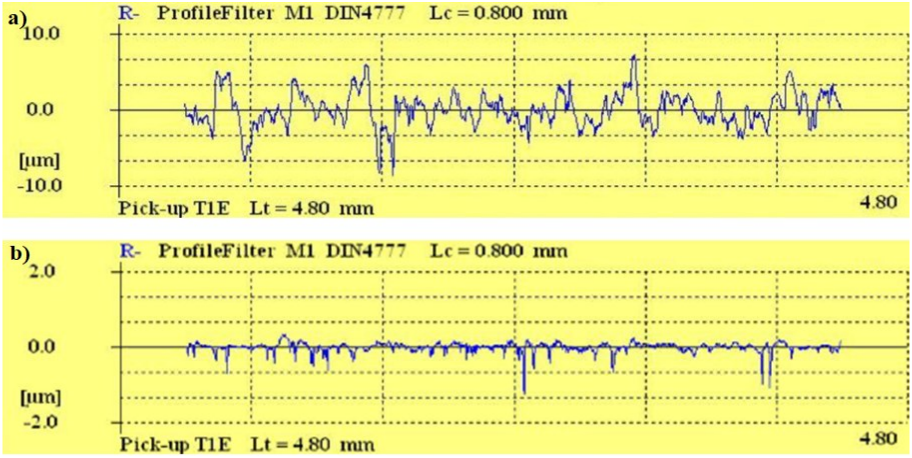

Fig. 4. Profile roughness for the Ø16.5 mm sleeve a) before processing – Ra = 1.91 µm, b) after burnishing broaching processing – Ra = 0.1 µm

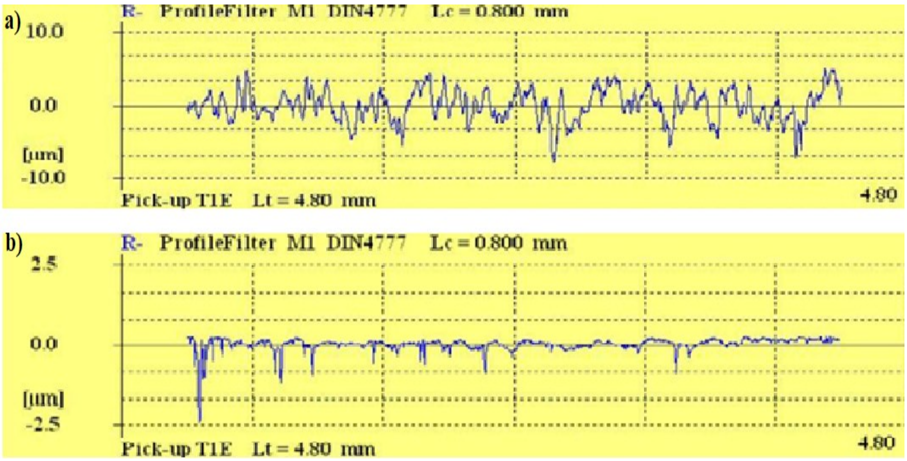

Fig. 5. Profile roughness for the Ø16.7 mm sleeve a) before processing – Ra = 1.78 µm, b) after burnishing broaching processing – Ra = 0.14 µm

Figure 4b and Figure 5b show the arithmetic mean deviation profile after slide burnishing broaching for a relative deformation factor ε_{nc} = 1.8 –3.03%. Herein, the Abbott-Firestone curve parameters take the smallest value ε_{nc} = 1.8% for Ø16.7 mm.

After the slide burnishing broaching process, the roughness of the inner surface of the sleeves Ø16.5 mm and Ø16.7 mm was measured. For this purpose, three measurements of surface roughness were made.

Table 1 shows examples of surface roughness parameters for the two steel sleeves. In the data contained, it can be estimated that the average arithmetic roughness profile for Ø16.5 mm is Ra = 0,10 μm and for Ø16.7 mm is Ra = 0,14 μm. Both of these are of low value, and can be considered favorable after burnishing. The Abbott-Firestone curve values for Ø16.5 mm (Rpk = 0.14 μm, Rk = 0.32 μm, Rvk = 0.25 μm) and for Ø16.7 mm (Rpk = 0.13 μm, Rk = 0.34 μm, Rvk = 0.45 μm), characterize the correct surface roughness.

Table 1. The parameters of surface roughness for the steel sleeve holes after the burnishing broaching process

Sleeve dimension [mm]	No. of the samples	Rt [μm]	Rmax [μm]	Rz [μm]	Ra [μm]	Rp [μm]	RSm [mm]	Rk [μm]	Rpk [μm]	Rvk [μm]	Mr1 [%]	Mr2 [%]	Rmr01 [μm]
Ø16.7	1	2.75	2.69	1.20	0.13	0.34	0.070	0.33	0.09	0.42	6.7	83.1	0.28
	2	2.45	2.45	1.28	0.12	0.36	0.036	0.23	0.10	0.45	10.1	80.7	0.33
	3	1.80	1.80	0.95	0.17	0.86	0.052	0.47	0.20	0.48	10.4	77.8	0.82
Ø16.5	1	2.12	2.12	1.07	0.14	1.50	0.069	0.47	0.24	0.27	10.6	86.4	1.29
	2	1.58	1.45	1.09	0.08	0.34	0.038	0.22	0.10	0.24	7.7	86.7	0.32
	3	1.26	1.18	0.85	0.08	0.28	0.061	0.26	0.08	0.24	5.5	87.5	0.25

According to 10 measured highest profiles, the lowest mean value of surface roughness Ra was obtained during measurements of the Ø16.5 mm sleeve, this being 0.10 μm. In case of the roughness parameter Rz, if the diameter of the burnishing element is smaller, then the lowest roughness height is achieved. The best surface quality according to this parameter was obtained for Ø16.5 mm sleeves and was equal to Rz = 1.00 μm (Fig. 6).

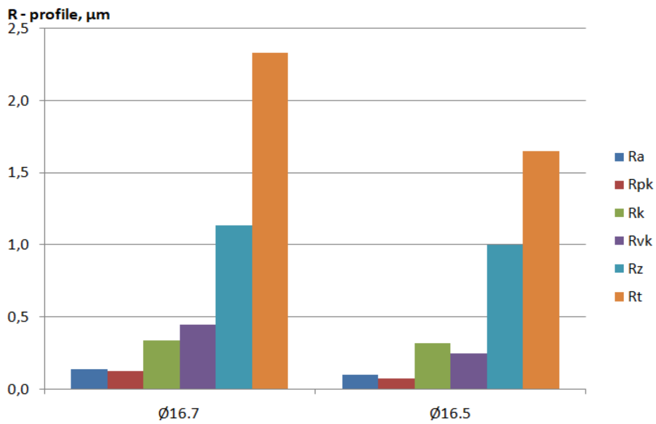

Fig. 6. The profile roughness after the burnishing broaching process for sleeve Ø16.7 mm and Ø16.5 mm

Based on the results of measurements of surface roughness parameters, after burnishing broaching, it can be stated that as the relative deformation coefficient increases, the surface roughness decreases.

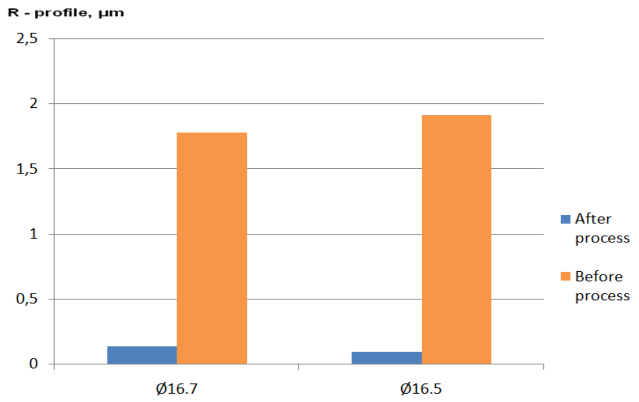

Fig. 7. Diagram of surface roughness Ra of the sleeve before and after burnishing NPT17

Figure 7 shows the results of the surface roughness Ra measurements of the sleeves after slide burnishing broaching with a burnishing tool with an outer diameter of Ø17 mm (NPT17). For the sleeve with the initial diameter of Ø16.5 mm, we obtained a better surface quality of Ra = 0.1 µm. For the Ø16.7 mm sleeve, a surface roughness of Ra = 0.14 µm was obtained - despite a lower Ra parameter by 0.13 µm before processing.

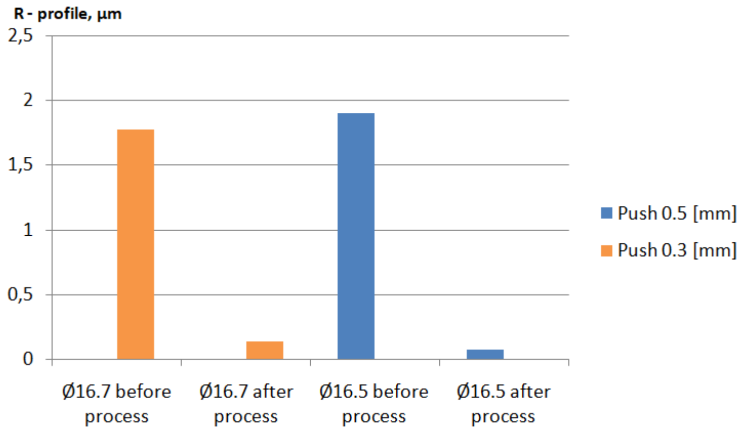

Fig. 8. Diagram of surface roughness Ra with 0.3 mm push for sleeve Ø16.7 mm and with 0.5 mm push for sleeve Ø16.5 mm

The surface roughness parameter Ra = 0.14 µm was obtained for slide burnishing broaching push with 0.3 mm for sleeve Ø16.7 mm. For a push 0.5 mm for sleeve Ø16.5 mm, surface quality is Ra = 0.10 µm, despite the worst surface quality before processing.

Figure 9 shows that the Abbott curve of the material share may indicate the specific properties of the surface layer. The obtained results of the Rpk parameter characterizing the top part of the surface have a low value, which indicates good wear resistance. Small values of the Rk parameter and large differences between Mr2 and Mr1 are characterized by good surface load capacity and resistance to high stress conditions.

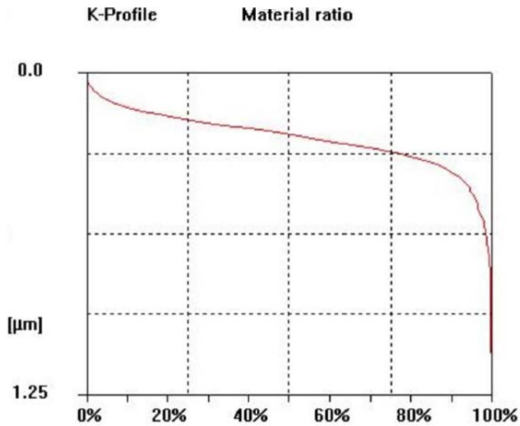

Fig. 9. Material curve for measuring the sleeve Ø16.5 mm

Material curves such as that above indicate good surface layer properties, which in the case of samples can affect leaktightness and surface parallelism.

The roughness reduction indexes carried out decrease with the increasing internal diameter of the burnished sleeve. The highest value of K_{Ra} index was obtained during burnishing of the diameter of Ø16.5 mm, which was K_{Ra} = 19.07.

5. CONCLUSIONS

The length of the life cycle of machine parts depends on the use of appropriate construction materials, and on the concept and the quality of the surface layer. In this paper, the main goal was to determine the impact of finishing processing on quality of the surface layer. One of the methods of mechanical finishing that allows obtaining a particularly advantageous surface layer is burnishing machining.

The metallurgical, machine, chemical, food, oil and shipbuilding industry, machine components require durability and reliability despite being exposed to variable loads. Slide burnishing broaching significantly influences the technological quality of sleeves created from hard machinable materials.

The appropriate choice of processing parameter for hard machinable materials rests upon the term of potential stress pattern, strain and temperature. Our research measured surface roughness of sleeves manufactured out of AISI 314l superhard steel allow before and after burnishing processing. The sliding burnishing technique generated more than acceptable surface roughness. The technique, so far is rarely used in the industry due to the lack of versatility in use and due to the production cost of the tool.

Burnishing parameters could have had an influence on the obtained results, because all sleeves were burnished with the same feed and with constant burnishing force. The rounding of the burnishing tool could also have been very important.

Our results indicated that as the internal diameter of the tested samples increase, the quality of the surfaces obtained decreases, the reason for this may be the same feed value and constant burnishing force. The resulting material curves testify, however, to good performance of the surface layer, which in the case of the received samples may decide about tightness and the parallelism of the surface.

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