THE EFFECT OF BURNISHING PARAMETERS ON STEEL FATIGUE STRENGTH

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ABSTRACT
The possibilities of sliding burnishing with cylindrical elements made of diamond composite with ceramic bonding phase are presented in this paper. The influence of some parameters of sliding burnishing on fatigue strength of 40 HM steel is also included.

KEYWORDS: sliding burnishing, diamond composite, surface layer, fatigue strength.

1. INTRODUCTION
All various types of machining, but now more frequently superficial plastic working by burnishing are applied in the technology of machines and devices [3].

Burnishing is superficial plastic working which can be performed at machining centre as finishing. In this process created chips, sparks or dusts, redundant cooling liquids which are necessary in the case of application of machining, e.g. during abrasive machining are not presented.

Burnishing is then ecological machining having considerable prospects of development as a method of shaping defined and operation-useful properties of surface layer of machine elements. [4].

This process is applied in machine-building and aircraft industries in machining of various sorts of materials – from hardened steel through mild steel to nonferrous alloys – of such machine elements as e.g. shafts of compressors of turbines, rings of rolling bearings.

It is also used as operation preparing elements for galvanic- and heat-chemical treatment and for machining of galvanic coats [2].

Burnishing of machine elements can be applied for the following purposes:

• possibility of obtaining surface of very small roughness and big radii of rounding of vertexes and cuts,
• creation of durable internal compressive stresses in surface layer of cold work, and the increase of hardness,
• the increase of resistance to operation results such as abrasion, superficial fatigue, corrosion,
• the decrease of costs of production of machines,
• making the product more ecological.

In practice all mentioned purposes can be achieved at the same time, but in a different degree.

The following kinds of burnishing were developed:

• rolling burnishing (with rollers, balls, steel rolls made of steel or of ceramics and sintered carbides),
• oscillatory burnishing (sliding or rolling),
• electromechanical burnishing (with current of low voltage and high intensity flowing through the system 'object - tool'),
• dynamic burnishing (centrifugal and stream ball peening ),
• sliding burnishing (with spherical elements made of natural and artificial diamonds) [5].

Parts of spherical shape are the most often applied (described in literature) elements for sliding burnishing.

There are the following their disadvantages:

• difficulty in setting the vertex precisely in the axis of the burnished element,
• necessity to replace the working element of the tool after losing the required shape (radius of rounding),
• lower durability in comparison to other types of burnishing elements.

Cylindrical elements sliding burnishing with a cylindrical is presented in fig.1) do not have these defects, and their merits are:
the area of their contact with the object can be changed with wear of working surface,
• they do not require precise setting at the machine tool,
• they enable more precise machining, because they show lesser susceptibility to vibrations during burnishing.

Fig. 1. Diagram of distortions of roughness during sliding burnishing with a cylindrical element: a) cross-section; b) longitudinal section of burnishing zone

2. DIAMOND COMPOSITE WITH CERAMIC BONDING PHASE

Tools materials for burnishing have to be characterized by series of properties ensuring their long operation.

There are the following most important properties of the tools:
• hardness – tool should not require frequent regeneration or replacement,
• shock-resistance,
• preservation of constant properties in wide range of temperatures,
• high thermal conductivity,
• chemical resistance excluding the possibility of chemical reaction with the machined material,
• low coefficient of sliding friction.

Working ends of burnishing tools can be made from natural single-crystal diamonds or synthetic diamonds in the form of composite containing diamond dust and binder.

Tools made from single-crystal diamonds are not much comfortable in use – due to strong anisotropy of crystals of the diamond they require precise setting of the tool during machining. They wear not only by abrasion but also by chipping, which unfavorably influences the quality of the machined surface.

The diamond composite tools have the similar properties, are more comfortable in use and cheaper. These tools wear only by abrasion (abrasion occurs in working area).

At present, materials of the following trade names are the diamond composites applied for SB (sliding burnishing)
• ballas (ABS).
• carbonado (ASPK),
• AKTM,
• Syndax-3.

Quite high (2,5 – 4 higher), in comparison to natural diamond coefficient of sliding friction (important for SB) and relatively big quantity (about 10% of weight) of metallic (Ni and Cr), which causes high porosity of surface and worse frictional properties are the main defect of these materials (especially ballas and carbonado).

Materials AKTM and Syndax-3 contain matrix of diamond particles (85 – 90% of weight) between which there are particles of filler – silicon carbide.

Stresses in material arising during hardening of silicon (increase of silicon’s volume by about 10%), which leads to growth of cracks after sintering and causes brittleness of such type of shaping elements are the serious disadvantages of these materials [6].

The use of composite material which properties will comprise features of phases creating grains of diamond constituting the phase of high hardness, and the bonding phase ensuring fracture toughness and shock-resistance is the way leading to the possibility of using the full properties of diamond and simultaneously reducing its features unfavorable for properties of the tool’s operation.

The following types of bonding phases are applied for manufacturing diamond composites:
• metallic bonding phase,
• non-metallic bonding phase,
• phase bonding carbide-making metal – metal.

The method of high-pressure sintering in the conditions of static loads is one of the ways of manufacturing diamond composites.

For the purposes of industrial production presses which enable sintering at the
pressure in the range 5-9 GPa and
temperature 1500 – 2300 K are applied.
High-pressure devices consist of hydraulic
press and special chambers making sintering
possible (Fig. 2,3) [1].

Fig. 2 Chamber for high-pressure sintering
with spherical anvils of Bridgman’s type:
1- die (A – carbide anvil, B – binding
rings), 2 – pyrophyllite shield , 3 – packing
ring of pyrophyllite, 4 - reactionary insert,
5 - punch, 6 – plates of the press [1]

Fig. 3 Reactionary insert for sintering in
the chamber of Bridgman’s type: 1 –
contact plate of molybdenum, 2 – foil of Ta
or Zr,3 – graphite heater, 4 – sintered
material, 5 – separator of Mo, 6 -
pyrophyllite shield, 7 – graphite separator,
8 – pyrophyllite roller, 9 – molybdenic
element improving distribution of
temperatures [1].

For realization of the process of burnishing
with cylindrical composite elements shaping
elements of diamond composite with ceramic
bonding phase containing Ti and Si in the
form of Ti₃SiC₂ were manufactured. Shaping
elements were made in IOS in Cracow in the
chamber of high-pressure sintering with
spherical anvils of Bridgman’s type.

The process of sintering is characterized by
the following parameters:
• pressure of sintering – 8GPa ± 0.2
GPa,
• sintering point - 2073 K ± 50 K,
• time of sintering – 25 seconds.
Selected physical and mechanical properties
of diamond composite of Ti₃SiC₂ are
presented in Table 1.

Application of titanic-siliceous carbide allowed
to obtain composite of very good parameters,
i.e. resistance to high temperature, chemical
resistance, high rigidity at simultaneous
plasticity, very high abrasion and low
coefficient of friction at metals.
This composite does not contain graphite,
which favorably influences its mechanical
properties.

Table 1. Selected physical and
mechanical properties of diamond
composite of Ti₃SiC₂[6]

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Hardness HV1 (GPa)</th>
<th>Young’s Modulus (GPa)</th>
<th>Rₚカフェ</th>
<th>Rₐ</th>
<th>Rz</th>
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<tbody>
<tr>
<td>3.06</td>
<td>38</td>
<td>487</td>
<td>253</td>
<td>0.05</td>
<td>0.69</td>
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</table>

Practical realization of the tool consisted
on making the holder in which one can mount
sinters made previously (Fig. 4). The tool has
simple structure and can be fastened at
engine lathes, it also allows regulation of
clamp force of the device to the machined
object in the range from 5 to  500 N.

Fig.4 Chuck for sliding burnishing with
cylindrical elements: 1 – burnishing
element, 2 – clamp plate, 3 – screw,
4 – replaceable end , 5 – fastening sleeve,
6 – screw , 7 – base pin, 8 – spring,
9 – body, 10 – stop, 11 – adjusting screw,
12 – extensometer bridge

3. EXPERIMENTAL
The main target of the performed investigations was to evaluate the effect of various burnishing parameters on the steel fatigue strength ($\sigma_{FS}$).

The studies were conducted on steel 40HM of hardness 32 HRC – Ø 27 mm. The base pretreatment included turning and grinding.

Roughness before burnishing was $Ra=0.80$ µm. The process of burnishing was performed with three cylindrical elements of diameters $r=4,6,8$ mm.

The hasten pendular bending fatigue tests were carried out using an electrodynamics vibrator with resonance frequency of the samples adopting the boundary number of cycles of $2 \cdot 10^6$.

The used technique, that consisted in cutting samples out of special shaped cylinders, was described in [7] in details.

The fatigue strength was calculated using stepped method on the basis of results of experiments on 16-sampled batches [8].

The fatigue experiments results are shown on Fig. 5,6,7.

### Table 1

<table>
<thead>
<tr>
<th>Force [N]</th>
<th>r=4mm $\sigma_{FS}$ [MPa]</th>
<th>r=6mm $\sigma_{FS}$ [MPa]</th>
<th>r=8mm $\sigma_{FS}$ [MPa]</th>
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<tr>
<td>0</td>
<td>395</td>
<td>395</td>
<td>395</td>
</tr>
<tr>
<td>50</td>
<td>399</td>
<td>401</td>
<td>397</td>
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<td>75</td>
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<td>420</td>
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<tr>
<td>275</td>
<td>385</td>
<td>390</td>
<td>375</td>
</tr>
</tbody>
</table>

Fig 5. Influence of burnishing force on the value of $\sigma_{FS}$, feed - $p=0.066$ mm/r, velocity- $v=500$ rotation/min.

### Table 2

<table>
<thead>
<tr>
<th>Feed mm/r</th>
<th>r=4mm $\sigma_{FS}$ [MPa]</th>
<th>r=6mm $\sigma_{FS}$ [MPa]</th>
<th>r=8mm $\sigma_{FS}$ [MPa]</th>
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<tr>
<td>0,03</td>
<td>461</td>
<td>451</td>
<td>452</td>
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<td>0,038</td>
<td>472</td>
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<td>449</td>
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<td>0,048</td>
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<tr>
<td>0,066</td>
<td>491</td>
<td>440</td>
<td>417</td>
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<tr>
<td>0,083</td>
<td>490</td>
<td>436</td>
<td>420</td>
</tr>
<tr>
<td>0,11</td>
<td>470</td>
<td>423</td>
<td>414</td>
</tr>
</tbody>
</table>

Fig 6. Influence of feed on the value of $\sigma_{FS}$, burnishing force - $F=225$[N], velocity - $v=500$ rotation/min.
4. CONCLUSION

The technology of sliding burnishing with cylindrical elements of diamond composite can be used in very simple and uncomplicated way for smoothing machining of various types of materials. Application of the new diamond sinter with ceramic binding phase in the form of titanic-siliceous carbide as the tool material for sliding burnishing will allow eliminating hitherto existing defects of the applied composites. Application of a cylindrical element as the tool in the place of applied spherical elements has several merits. A cylindrical element is easier to manufacture and easier to grind, which reduces the costs of its production, when the contact zone ‘tool-machined object’ will wear, we can easily change its position through turn of the tool or change of its height in relation to the machined object. After exhausting the possibilities of turn of the tool we can easily grind it – in this way we will extend its life several or several dozen times. After carried out machining we can draw the following conclusions. The highest fatigue strength we managed to obtain was $\sigma_{FS} = 495$ [MPa] for parameters $p=0,066$ mm/rotation, $v=500$ rotations/min, force $F=225[N]$ and radius of the cylinder was 4mm.

For the rest of cylindrical elements (6 and 8 mm) $\sigma_{FS}$ was from range 385 [MPa] to 440 [MPa], for the highest force 275 [N] we can observe decrease (to 375 MPa) the fatigue strength below value before burnishing (395 MPa).

For the feed and burnishing speed parameters difference are not so visible except for 4 mm element. The results of the realized fatigue experiments showed the distinctly advantageous effect of diamond burnishing with cylindrical elements on the improvement of the fatigue strength of the steel 40HM.

REFERENCES


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