Research of Tool Durability in Surface Plastic Deformation Processing by Burnishing of Steel Without Metalworking Fluids

S N Grigoriev 1,a, N M Bobrovskij 2,b, P A Melnikov 2,c, I N Bobrovskij 2,d

1 Moscow State Technological University Stankin
Vadkovskij per. 1, Moscow, Russian Federation
2 Togliatti State University
Belorussskaya st. 14, Togliatti, Russian Federation

E-mail: a Rector@stankin.ru, b bobrm@yandex.ru, c topavel@mail.ru,
d bobri@yandex.ru

Abstract. Modern vector of development of machining technologies aimed at the transition to environmentally safe technologies - "green" technologies. The concept of "green technology" includes a set of signs of knowledge intended for practical use ("technology"). One of the ways to improve the quality of production is the use of surface plastic deformation (SPD) processing methods. The advantage of the SPD is a capability to combine effects of finishing and strengthening treatment. The SPD processing can replace operations: fine turning, grinding or polishing. The SPD is a forceful contact impact of indentor on workpiece’s surface in condition of their relative motion. It is difficult to implement the core technology of the SPD (burnishing, roller burnishing, etc.) while maintaining core technological advantages without the use of lubricating and cooling technology (metalworking fluids, MWF). The "green" SPD technology was developed by the authors for dry processing and has not such shortcomings. When processing with SPD without use of MWF requirements for tool’s durability is most significant, especially in the conditions of mass production. It is important to determine the period of durability of tool at the design stage of the technological process with the purpose of wastage preventing. This paper represents the results of durability research of natural and synthetic diamonds (polycrystalline diamond - ASPK) as well as precision of polycrystalline superabrasive tools made of dense boron nitride (DBN) during SPD processing without application of MWF.

1. Introduction

The most important factor in making decisions about the advisability of the appointment of material as a tool for the SPD is a durability, as well as the optimal processing conditions.
Accelerated determination of tool’s durability in burnishing processing was carried out closely to plant conditions. Previously, the authors investigated the tool durability for wide burnishing steel 45 samples of high-duty cast iron [1, 2] and this study addresses the processing of chromium-manganese steel 17HG (C: 0.16-0.21%; S: 0.015-0.030%; P: <0.035%; Mn: 0.90-1.10%; Cr: 0.70-0.90%; Si: 0.17-0.37%; Ni: <0.30%; Cu<0.30%), austenitic grain at most 5 micron, snowflake sensitive. This steel is intended for the production of small parts with cementing sections running on friction.

As a criterion for tool wear was used a surface’s roughness tolerable limit Ra = 0.4 μm. This value is the limit of the technical requirements for surface: lip seal necks of crankshafts (Fig. 1).

2. Experiments
As a basis for experiments was used SPD machine for differential side joint housing.

Process-dependent parameters:
- work surface hardness HRC 58...62;
- basic surface roughness Ra = 0.6...0.8 μm;
- roughness after processing Ra = 0.2...0.25 μm;
- number of simultaneous working tools: 2;
- tool design parameters: radiused;
- tool radius: 2.5 mm;
- tool body roughness Ra = 0.06...0.07 μm;
- actuator 150...250 N;
- spindle rotational speed 540 rpm;
- feed motion 0.1 mm/rev (0.05 mm/rev on each tool);
- feed and force tool actuator: fluid;
- actuator system (feed and stroke): fluid;
- cycle: 32 sec;
- production level (duty factor 0.8): 90 pieces/hour

Machining conditions:
- speed (V): 67.9 m/min;

![Figure 1 – Processing scheme of crankshafts](image-url)
• feed (S): 0.1 mm/rev;
• revolutions (n): 540 rev/min;
• tool’s force (P): 175 N.

3. Object of research: tool materials
As tool materials were used: natural diamond, synthetic polycrystalline diamond (ASPK), and DBN - polycrystalline superhard materials (SHM) with high (up to 99.5%) contents of dense boron nitride (cubic - CBN and vurcit - VBN) with (particle size 10–100 μm) [3].

Table 1 – Tool material’s properties

| Tool material | Natural diamond (ND) | Synthetic polycrystalline diamond (ASPK) | Dense boron nitride (DBN) [4] |
|---------------|----------------------|------------------------------------------|-------------------------------|
| density, kg/m³·10³ | 3.47 - 3.55 | 3.5 - 4.0 | 3.411 - 3.482 |
| microhardness, MPa·10⁴ | 931.57 - 986.48 | 800 - 1000 | 900 - 950 |
| elastic module, GPa | 930 | 850 | 900 |
| ultimate compressive strength, GPa | 2.00 | 0.4 - 0.8 | - |
| thermostability, °C | 800 - 1000 | 600 - 700 | 1300 |
| crack growth resistance, MPa m(1/2) | 6.5 - 8.5 | - | - |
| Cost relation of prises,% | 200 - 300 | 100 | 150 |
4. Experiment results
First stage: synthetic polycrystalline diamond (ASPK), results presented on Fig 3. Tool durability 58 750 meters, that corresponds to, for example, 5200 pieces of differential side joint housing of LADA auto.

![Figure 3](attachment:image3.png)

**Figure 3** – Dependence of traversed path of burnisher made of ASPK on processed surface roughness in burnishing processing without metalworking fluids of differential side joint housing gland necks from chromium-manganese steel (surface hardness HRC 63)

Second stage: natural diamond. Tool durability: 70 000 meters, that corresponds to, for example, 7000 pieces of differential side joint housing of LADA auto (Fig. 4).

![Figure 4](attachment:image4.png)

**Figure 4** – Dependence of traversed path of burnisher made of natural diamond on processed surface roughness in burnishing processing without metalworking fluids of differential side joint housing gland necks from chromium-manganese steel (surface hardness HRC 63)

Third stage: dense boron nitride (DBN) [5]. Tool durability in this case: less than 28000 meters, which corresponds to, for example, 2500 pieces of differential side joint housing of LADA auto (Fig. 5). In mass production with annual program more than 350 000 pieces per year the result is not satisfactory.
5. Results and Discussion

Despite the fact that the durability of natural diamond tools for 30% bigger than synthetic polycrystalline diamond, it is economically sound to use synthetic polycrystalline diamond because its price lesser than natural diamonds for 200-300%. It should be noted that natural diamonds are more prone to chip during operation and instability.

Tools made of dense boron nitride (DBN) showed the lowest durability. Taking an ASPK for base (100%), natural diamonds has shown 120% durability, and DBN has shown 47%.

Probably with different set of machining conditions (high work surface hardness 58…62 HRC is the main reason for DBN failure) DBN could be used as material for tool working part. Purpose of this study was to try different tool materials in constant machining conditions, which corresponds to plant conditions. Tool force (150…250 N) could not be lowered enough to make DBN work longer because than smoothing function of burnishing will not work properly [6] and designed roughness after processing (0.2…0.25 μm) will not be achieved [7]. Combination of significant hardness of work surface, absence of MWF (high heat stress), and designed roughness leads to exclusion of DBN under these conditions of work [8].

It is hard to compare this results to other papers because there are no similar studies data available on DBN [9] and durability test are rare because of their cost, as shows in newest survey article on burnishing where analysis of more than 60 sources with range for 13 years [10].

6. Conclusion

1. Burnishing without using of MWF is cost effective with using of synthetic polycrystalline diamond, despite of lesser thermostability than natural diamond; cost of unit surface area machining of tools with ASPK lesser than natural diamond for 20%.

2. DBN can be used as hard turning tool material, but to use it with SPD processes tools needs to have a coating. If it is not acceptable then adjusting machining conditions could be useful.

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