Study of performance criteria of experimental tumbling bodies

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Abstract. Tumbling is a surface plastic deformation of loose workpieces due to their collision with a working tool in an enclosed volume when they are moved due to the rotation of the working body. Special tumbling bodies are used as a working tool for the implementation of this operation. Tumbling process performance criteria depend on many factors. Along with the type of tumbling, the adopted cutting conditions and the equipment used, the design and dimensions of tumbling bodies, as well as the materials from which these bodies are made, have a significant impact on the final result of polishing the workpieces. New designs of tumbling bodies are created with the aim of increasing the process performance, as well as improving the surface quality of workpieces. The issues related to the development and study of performance criteria of experimental tumbling bodies are reflected in the article.

1. Introduction

As already noted above, the performance criteria of tumbling bodies depend on the properties of the materials from which they are made, namely: abrasive grade, grain size, shape of grinding grains and type of bond.

The shape and geometry of a tumbling body directly affects the cutting ability. For example, bodies with sharp edges, such as a prism or a pyramid, have a higher cutting ability than bodies having fewer cutting edges, such as a sphere or a cone. The characteristics of a tumbling body and abrasive grains affect the filleting rate of the cutting edges. The higher the speed, the faster the cutting edges lose their cutting ability [1-3, 6, 9].

The wear resistance of a tumbling body depends on the properties of the abrasive grains and the bond. During the process of tumbling, abrasive grains are abraded, thereby some of the material is lost and the cutting ability is deteriorated. Abrasive grains can be destroyed under the action of impacts and excessive contact stresses, as well as unglue of the bond due to excess forces arising in the machining zone. The roughness of the treated surface depends on the gritness [4-8].

To produce a tumbling body with the required performance criteria, it is necessary to select the optimal geometric shape, grain size, type of abrasive and bond, which will provide the machining process with maximum efficiency.

To study the influence of the design features of tumbling bodies on their main performance criteria, three types of bodies in the shape of a cone were made – solid one, one with a cavity and one with a metal core. The design and geometric dimensions of the cones are shown in figure 1.
14AM20 was chosen as an abrasive for all experimental tumbling bodies, and a modified epoxy resin was used as a bond.

![Diagram of tumbling bodies](image1)

**Figure 1.** Experimental tumbling bodies in the form of: a) solid cone; b) hollow cone; c) hollow cone with a metal core.

2. **Methods and researches**

To study the performance criteria of experimental tumbling bodies, the tumbling installation (figure 2) with a barrel having a horizontal axis of rotation was designed and manufactured.

![Diagram of tumbling installation](image2)

**Figure 2.** Tumbling installation layout.

The barrel 1 receives rotation from the engine 3. The gearbox is placed in the engine housing, providing the ability to adjust the engine rpm speed. The toggle switch 2 is provided to start the engine. Since the engine is fixed to the motor axis, two rollers 4 are used for the purpose of additional support.

The studies were carried out according to the following original methodology:

- The required ratio of workpieces and tumbling bodies: 1:6 – for rust and 1:12 – for paint.
- The barrel rotation frequency (n): 45 rpm.
- Machining time (t): 10 hours.
- Type of workpiece: 30x30x30 mm (length x width x height) size S235 steel corner.
“Image Pro Insight” software platform making it possible to measure and analyze images was used for analyzing the area of material removed from the workpiece. The algorithm of measuring the area of the removed material is as follows:

- rust or paint is applied to the part to be machined;
- the part is being machined;
- the part is photographed;
- the photos are analyzed using the “Image Pro Insight” program.

The purpose of the experiments was to study the following parameters:

- specific wear of tumbling bodies, \( q \) (the ratio of the mass of tumbling bodies after machining for 1 hour to the mass of tumbling bodies before machining);
- machined area, \( S \) (ratio of surface area after machining to the original surface area).

To assess the wear of experimental tumbling bodies, KS-1000 scales, the accuracy of which reaches 0.01 grams, was used.

3. Results and discussion
At the first stage of the research, workpieces coated with rust were machined. Every hour, the part was photographed, and from figure 3 it is clearly seen how the rust area on its surface changes when machined with standard tumbling bodies.

![Figure 3](image3.png)

**Figure 3.** Change in the surface area of a workpiece machined by standard tumbling bodies:

a) in 1 hour; b) in 5 hours; c) in 10 hours.

As a result of image analysis in the “Image Pro Insight program”, the following graph was plotted (figure 4).

![Figure 4](image4.png)

**Figure 4.** The area removed with standard bodies.
The images for hollow tumbling bodies (figure 5), as well as hollow bodies with a metal core (figure 6) were obtained in a similar way.

Figure 5. Change in the surface area of a workpiece machined by hollow tumbling bodies: a) in 1 hour; b) in 5 hours; c) in 10 hours.

Figure 6. Change in the surface area of a workpiece machined by hollow tumbling bodies with a metal core: a) in 1 hour; b) in 5 hours; c) in 10 hours.

Based on the results of three experiments, a comparative graph of the area removed is plotted (figure 7).

Figure 7. Comparative graph of the area removed.

The results of wear of tumbling bodies of a standard design (solid cone), hollow tumbling bodies, as well as hollow bodies with a metal core when machining rusty workpieces are shown in table 1.
The data in the table illustrate the loss of mass of tumbling bodies for 10 hours of machining.

Table 1. Wear of experimental tumbling bodies when machining rusty surfaces.

| Machining time, h | Standard | Hollow | Hollow with a core |
|------------------|----------|--------|-------------------|
| 0                | 132.66   | 132.14 | 127.62            |
| 1                | 129.83   | 131.35 | 125.65            |
| 2                | 128.6    | 130.91 | 124.77            |
| 3                | 127.86   | 129.95 | 124.42            |
| 4                | 126.73   | 129.5  | 123.91            |
| 5                | 126.65   | 128.9  | 123.78            |
| 6                | 126.29   | 128.63 | 123.54            |
| 7                | 126.12   | 128.39 | 122.96            |
| 8                | 125.59   | 128.15 | 122.67            |
| 9                | 124.55   | 127.78 | 122.32            |
| 10               | 124.24   | 127.49 | 122.1             |

The analysis of the obtained statistical data suggests that standard bodies in the form of a solid cone are subject to the greatest wear and bodies in the form of a hollow cone have the least wear.

At the second stage of the research, workpieces coated with paint were machined.

In this case, the degree of blasting of all four sides of the machined corner (1 and 2 – the inner surfaces, 1 and 2 – the outer surfaces) was studied separately using all varieties of experimental tumbling bodies.

Based on the results of machining parts using standard (figure 8), hollow (figure 9), hollow with a ball (figure 10) tumbling bodies, graphs were plotted showing the distribution of the area removed over all surfaces of the workpiece.

Figure 8. Distribution of the area removed with standard tumbling bodies.

Figure 9. Distribution of the area removed with hollow tumbling bodies.
Figure 10. Distribution of the area removed with hollow tumbling bodies with a metal core.

Table 2 shows the results of wear of tumbling bodies of a standard design (solid cone), hollow tumbling bodies, and also hollow bodies with a metal core when machining workpieces coated with paint.

Table 2. Deterioration of experimental tumbling bodies when machining painted surfaces.

| Machining time, h | Standard | Hollow | Hollow with a core |
|------------------|----------|--------|-------------------|
| 0                | 132.66   | 132.14 | 127.62            |
| 1                | 129.83   | 131.35 | 125.65            |
| 2                | 128.6    | 130.91 | 124.77            |
| 3                | 127.86   | 129.95 | 124.42            |
| 4                | 126.73   | 129.5  | 123.91            |
| 5                | 126.65   | 128.9  | 123.78            |
| 6                | 126.29   | 128.63 | 123.54            |
| 7                | 126.12   | 128.39 | 122.96            |
| 8                | 125.59   | 128.15 | 122.67            |
| 9                | 124.55   | 127.78 | 122.32            |
| 10               | 124.24   | 127.49 | 122.1             |

The data obtained as a result of a series of experiments on tumbling painted workpieces correlate with previously obtained results when machining rusty workpieces and confirm that standard bodies in the form of a single cone are subject to the greatest wear and hollow cone bodies typically have the smallest wear.

4. Conclusions
Further research in the field of development of new design concepts for tumbling bodies can provide an intensification of the tumbling process on the one hand, as well as an improvement in the surface quality of the machined workpieces on the other hand.

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