Methods and approaches to improving the design of flexible backing grinding tools

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Abstract. Grinding with flexible backing grinding tools, such as flap wheels and grinding belts, has found wide application at all stages from roughing to decorative surface finish. At the same time, the performance of traditional factory-built flap wheels and grinding belts in many respects do not meet the expectations of consumers. Among other reasons, this is due to the fact that the designs of flap wheels and grinding belts are based on traditional sandpaper. In turn, the sandpaper is made from abrasive mass which is not sorted by shape and not oriented relative to the backing plate surface. The described situation leads to the fact that a large number of grains does not participate in the cutting process, but on the contrary, have a negative impact on it, because the abrasive particles fall out of the bond, heat and deform the material to be ground without cutting it off. The approaches to improving the design of flexible backing grinding tools are discussed, the issues of their design and manufacture using the abrasive grains with controlled shape and orientation are revealed in the article. The data on the impact of the grain shape and orientation on the cutting ability of grinding belts are given.

1. Introduction
Grinding with flexible backing tools has become widespread in many industries, because it has several advantages inherent only in this type of grinding, including:

- the elasticity and the resilience of the cutting face;
- the low level of power loads;
- the ability to grind large surfaces, etc.

Flap wheels and grinding belts often allow workpieces to be ground when the use of dimensionally stable tools is inefficient or technically challenging to implement. Flexible backing grinding tools have more favorable conditions for the grain performance, as a result of which they can provide the following positive points:

- a larger number of the grains participate in the process of cutting at the same time;
- the time of interaction between a single abrasive grain and the surface to be ground increases;
- shock loads reduce when the grains cut into the surface to be ground;
- the temperature in the cutting zone reduces, etc.
The above factors have a total positive impact on the performance and quality of grinding with flap wheels and grinding belts [1-5]. A feature of grinding with such tools are favorable conditions for the use of the cutting properties of abrasive grains, which are self-adjusting in height and evenly distribute the load among themselves. In addition, the grains have some mobility relative to each other, which provides better chip removal and reduces glazing.

However, as noted above, the use of standard flap wheels and grinding belts demonstrates their performance because they are produced from abrasive grains of uncontrolled shape and unoriented relative to the backing plate surface [2].

In practice, the performance of flexible backing grinding tools is increased in the following ways:

- Changing designs of flexible backing grinding tools [4];
- Selecting the optimal cutting conditions [5];
- Using an overlapping tooth design [6-8];
- Using lubricant coolant;
- Cleaning the sandpaper.

Let us consider in more detail the known methods of improving the performance of flap wheels and grinding belts.

**Changing the designs of flexible backing grinding tools.**

Designs of flexible backing grinding tools can be improved by improving the stress-strain properties of the backing plate surface, bond, grinding grains, etc.

To increase the adhesion between the bond and the grinding grains, the latter are coated with special compounds (iron oxides, etc.). This contributes to increasing tool life.

Studies show that the shape of the grinding grain has a great impact on the performance of flap wheels and grinding belts. The use of round grains, i.e. close to the shape of the sphere allows increasing resistance, and the use of grains of elongated forms - cutting ability.

To improve the properties of the bond, as well as to expand its technological capabilities, various additives are introduced into it.

Traditionally, flexible backing grinding tools consist of a sandpaper.

In the process of manufacturing sandpapers, grinding grains are applied to the backing plate using various methods: mechanical, electrostatic and suspension.

The first method consists in applying a uniform layer of abrasive grains to the backing plate. In this case, the grains are pressed into the adhesive layer with a special roller, and the non-adhered grinding grains are removed by a hammer device. The result of such an application is clearly illustrated in figure 1.

**Figure 1.** The scheme of the sandpaper manufactured by mechanical method.

With the electrostatic method (figure 2), the grinding grains are fixed with their largest axis perpendicular to the backing plate surface covered with glue. This method provides the sandpaper greater cutting ability than the previous one.

Small micropowders are applied by suspension method. For this, a suspension consisting of a binder, a solvent and a micropowder is produced. Then the suspension is applied to the backing plate.
using a baryta-coating machine by means of a machine shaft, after which it is leveled with hair brushes.

**Figure 2.** The scheme of the sandpaper manufactured by electrostatic method.

**Selection of optimal cutting conditions.**
Selection of the conditions of flap and belt grinding depends on the size, shape, and stress-strain properties of the workpiece to be ground. The grinding process of a particular part provides for accuracy, cleanliness of the surface to be ground and performance.

The main grinding conditions include: the tool performance itself, its rotational speed, the grinding depth (pressure, tension), the shape and stiffness of the contacting element, the longitudinal feed, the coolant.

**The use of overlapping tooth design.**
The performance of flap wheels and grinding belts can also be enhanced using climb grinding operation scheme. In comparison with the up grinding scheme, climb grinding provides:

- grinding accuracy improvement;
- increase in metal removal;
- reduction of cutting forces;
- some reduction in roughness;
- decrease in sandpaper wear.

The study of the mechanism of the grinding grain operation under climb grinding shows that it cuts into the material being ground from the side of a thick part of the chip with a further transition to its thin part. Grinding grains easily dig into material. Under counter grinding, the grains cannot immediately cut into the material, they first resiliently and plastically deform the material, experiencing great friction, and only after that separate the chips; the operating conditions of the grain being the most difficult. Grain slips and wears out quickly. The slippage of the grinding grain worsens the surface roughness parameter, increases the heat generation in the cutting zone and causes burns on the surface to be ground. The durability of the tool is reduced.

**Coolant application.**
The use of coolant during grinding and polishing improves the performance and durability of flap wheels and grinding belts, as well as the quality of the surface to be ground. Coolant is used to cool the parts and lubricate the grinding tool. At the same time, the cutting process is improved, the sandpaper glazing is eliminated, the heat release is reduced, etc.

When grinding, water, water-based liquids, mineral oils, light fats, soluble oil emulsions with additives of sulfur, chlorine and other materials that perform lubricating, cooling, washing and protective and anticorrosion action are used as coolants.

**Sandpaper cleaning.**
Cleaning the working surface of flap wheels and grinding belts helps to increase the grinding process performance, reduce the temperature in the cutting zone and improve the quality of the ground surface.
When analyzing the above methods for improving the performance of flexible backing grinding tools, it can be concluded that the improvement of the design of tools is the most promising way to improve their operational properties. This follows from the fact that the tool performance is a key factor that has an important impact on the grinding process. Other factors have a local impact and play a secondary role. Thus, it is preferable to improve the flexible backing grinding tool performance at the initial stage by the development of more advanced designs.

2. Methods and researches

The analysis of the operation of flexible backing grinding tool shows that grinding grains play a key role in their performance, since they are involved in the cutting process. Therefore, improving the performance of grains or their more rational use is an efficient method of improving the quality of flap wheels and grinding belts.

Meanwhile, it is known that grains are far from fully using their potential. The reasons for the insufficient cutting ability of the grains are varied, for example:

- the low strength;
- the insufficient adhesion to a bond;
- the presence of defects;
- the propensity to colorize, etc.

The main reason for the low performance of tools is the arbitrary shape of the grinding grains used in them. Analysis of the literature on this issue shows that the control of the form and the rational use of grinding grains can significantly improve their performance.

Therefore, control of the shape of the grinding grains in the manufacture of tools, along with their focused orientation, is a promising solution to improve the performance of flap wheels and grinding belts.

In the course of research, the flap wheel was designed and manufactured, for which RF patent No. 2240224 was granted (see figure 3). The wheel consists of flaps made of abrasive grains, classified according to the shape and oriented in a certain way relative to the surface of the flap.

![Figure 3. Flap wheel design.](image-url)
The figure shows the following positions: 1 – the metal washer (wheel housing); 2 – the flap; 3 - the part of the flap surface with non-abrasive layer; 4 - the part of the flap surface with abrasive grains; 5 - cloth backing; 6 - the base layer of the binder; 7 – the top layer of the binder; 8 – the controlled-shape abrasive grains oriented using the electrostatic method.

3. Results and discussion
In the course of the improvement of designs of flexible backing grinding tools based on the systematic approach to the orientation of abrasive grains and their geometric shape, the following tasks were fully solved:

- vibration (patent for invention of the Russian Federation No. 2248851) and electrostatic (patent for invention of the Russian Federation No. 2223603) separators used to divide the standard abrasive mass into 3 fractions with isometric, intermediate and lamellar grains were designed and manufactured;
- the calculation of the shape factor of grains of various fractions was made using the special software;
- the new flexible tools was designed;
- the original technology for the manufacture of new tools is developed;
- the equipment for the manufacture of new tools - a compact electrostatic abrasive application line and heat chamber - was designed and manufactured;
- the methods for assessing the performance of flexible backing grinding tools are developed;
- the tests of tools prototypes were carried out to determine the following indicators: cutting ability, wear, cutting forces, temperature in the cutting zone and surface roughness;
- the mathematical models showing the impact of the grinding grain shape factor on the performance of flexible tools are developed;
- practical recommendations for the application of new designs of flexible tools are formulated.

As an example, the dependence of the impact of the shape and the orientation of grinding grains, as well as the grinding time on the cutting ability of grinding belts are shown in figure 4.

![Figure 4](image-url)

**Figure 4.** Change in cutting ability ($Q$) of standard grinding belt and grinding belts with various shapes ($K$) and orientations ($\gamma$) of grinding grains when machining steel S 235 during time ($t$).

From the graphs and diagrams it is seen that:
• the cutting ability of the grinding belts with orientation angle $\gamma = 75^\circ$ is higher throughout the experiment;
• the cutting capacity of the grinding belts with isometric grains ($K_f \approx 2.27$) is the lowest, and that of the grinding belts with lamellar grains ($K_f \approx 2.27$) oriented at an angle $\gamma = 75^\circ$ is the highest;
• the cutting capacity of the experimental belts with lamellar grains ($K_f \approx 2.27$) is higher than the cutting ability of the standard belts (GOST) by 30÷40%, and the cutting ability of the belts with isometric grains ($K_f \approx 1.14$) is lower by 25÷30%. The experimental belts made of the intermediate shape grains ($K_f \approx 1.56$) showed almost the same cutting ability as that of the standard belts.

The conducted studies convincingly prove that the cutting capacity of the belts can be significantly increased through the use of plate-shaped grains ($K_f \approx 2.27$), oriented relative to the backing plate at an angle $\gamma = 75^\circ$.

4. Conclusions
Practical recommendations aimed at the rational use of new tool designs were formulated on the basis of the conducted comprehensive studies:

• for roughing operations, it is preferable to use flap wheels and grinding belts made of grains with the highest $K_f$ values (i.e., lamellar and plate-shaped);
• for finish work, the most appropriate are flap wheels and grinding belts with low $K_f$ values (i.e., isometric shape grains).

Experimental samples of flexible tools were successfully tested, both in laboratory and in industrial environments, where they proved their advantages in comparison with standard tools.

Thus, a focused approach to the choice of the shape and the orientation of grinding grains at the stage of manufacturing flexible tools provides a more complete use of their potential.

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