Design of abrasive tool for high-rate grinding

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Abstract. The experimental studies aimed to design heavy-duty abrasive wheels for high-rate grinding are presented. The design of abrasive wheels with the working speed up to 100 m/s is based on the selection of optimized material composition and manufacture technology of the wheels.

1. Introduction
Abrasive machining on wheels with a speed up to 50 m/s is currently used in many branches of industry. It has been already proved that high speed of abrasive wheels can enhance efficiency of the treatment and reduce the force and temperature impact exerted on a treated material [1, 2]. Abrasion technologies increasingly use wheel speeds up to 100 m/s and higher.

Under high-force and high-speed abrasion, a wheel experiences high mechanical and thermal stresses that can induce rapid wear and even damage of the abrasive tool.

For this reason, one of the main constraints to application of new high-capacity technologies of material processing is the absence of an abrasive tool possessing increased rupture strength [3].

The known ways of enhancing the strength of an abrasive wheel include:
— improvement of wheel design by a reinforced nonworking surface;
— application of reinforcing elements;
— manufacture of a wheel of maximally close texture and uniform structure by hot shaping;
— optimized composition of a binder, including modifiers, to increase adhesion between the binder and inorganic components.

The aim of these studies was the design of an abrasive wheel capable to operate at high speeds up to 100 m/s and to ensure the operation safety owing to optimized mix formulation and technology of abrasive wheel manufacture.

2. Test procedure
In order to design an abrasive tool, it is required to know its strength characteristics. This is particularly important to ensure safe operation of high-speed abrasive wheels.

The dependence of the breaking speed $V_{\text{break}}$ of abrasive wheel on its strength, density and geometry is known [4]

$$V_{\text{break}} = \sqrt[\gamma]{\frac{g \cdot \sigma_T}{1 + \alpha}} \cdot \frac{3}{\gamma + 1 + \alpha^2},$$

where $g$ is the acceleration of gravity; $\sigma_T$ is the ultimate tensile strength; $\gamma$ is the density of material the wheel is made of; $\alpha$ is the shape factor of the wheel (inside diameter/outside diameter).
According to the data obtained in the tests of samples and wheels with bakelite resin binder subjected to tension, flexure and compression to determine breaking speed under rotation [5], the most significant strength characteristic of the material an abrasive wheel is made of is the flexing strength. In this case, the relation (1) can be given by

\[ V_{\text{break}} = K \frac{\sigma_f}{\sqrt[3]{(1 + \alpha + \alpha^2)}} \]  

where \( K \) is an empirical parameter; \( \sigma_f \) is the static flexing strength.

It is proved experimentally that \( K = 9.4 \) and \( K = 11.3 \) are valid for wheels without and with reinforcing elements, respectively. So, with the known \( K \), \( \sigma_f \), \( \gamma \) and \( \alpha \), it is possible to calculate the estimated breaking speed of an abrasive wheel. To determine physical properties, samples in the form of bars 150×90×20 mm were manufactured and tested.

In the static flexure tests, the destructive stress was determined using the formula

\[ \sigma_f = \frac{3FL_0}{2BH^2} \]

where \( F \) is the load at the moment of failure of a sample; \( L_0 \) is the spacing of bases; \( B \) is the width of a sample; \( H \) is the height of a sample, mm.

The flexure testing machine P-10 ensured uniform velocity of the load head and the bases (100 ± 20 mm/min) at the measurement error of ±1%. Each mix composition of samples was tested three times, and the average flexing stress was assumed as the test result.

The hardness of the samples was determined using sand blast model 910 in accord with the Russian State Standard GOST 18118.

The density \( \gamma \) was found from the dimensions and weights of the samples.

2. Test results

There were three variants of mix composition. Five samples of each mix composition were manufactured and tested after bakelization.

**Variant 1:** zirconium aluminum oxide (AO) bars with the grain size of 125, the limit content of grains \( V_G = 54\% \) of the sample volume, content of binder \( V_B = 34\% \), content of pores \( V_P = 12\% \); the mix was not conditioned.

**Variant 2:** AO bars with grain sizes 160, 125 and 100 at a ratio of 40–40–20\%, \( V_G = 58\% \), \( V_B = 32\% \), \( V_P = 10\% \); \%; the mix was not conditioned.

**Variant 3:** AO bars with grain sizes 160, 125 and 100 at a ratio of 40–40–20\%, \( V_G = 58\% \), \( V_B = 38\% \), \( V_P = 4\% \); \%; the mix was conditioned under the temperature of \( 60^\circ\text{C} \) for 8 hours.

The test results are reported in Table 1.

| Variant no. | Structure, % | Density, g/cm\(^3\) | Flexing strength, Pa |
|-------------|--------------|---------------------|---------------------|
|             | \( V_f \)    | \( V_c \)    | \( V_P \) |                   |                      |
| 1           | 54           | 34             | 12       | 2.93               | 371                  |
| 2           | 58           | 32             | 10       | 3.31               | 405                  |
| 3           | 58           | 38             | 4        | 3.59               | 448                  |

The strength of **Variant 1** bars is higher than the strength of **Variant 2** bars by 9\%, and conditioning of the mixture before shaping (**Variant 3**) increases the flexing strength by 20\%.

Also, the influence of binders and basic materials on heat stability of the abrasive–bakelite mixtures was analyzed. The heat stability was determined by estimating flexing strengths of bakelized bars before and after heat exposure (250 ± 5)\(^\circ\text{C} \) for 18 hours.

Three mixtures of the same structure samples (\( V_G = 54 \), \( V_B = 40\% \), \( V_P = 6\% \) were tested. **Variant 1:** powdered binder—pulverized bakelite (SFP-011A), unmodified; basic material—pyrite.
**Variant 2:** powdered binder—pulverized bakelite modified by polyvinyl buteral (SFP-0129A), unmodified; basic material—pyrite.

**Variant 3:** a mix of powdered basic materials of pyrite, copper power and micro-powder of silicon carbide and pulverized bakelite modified in accordance with **Variant 2**.

The test data are given in Table 2.

**Table 2. Heat stability of the tested samples.**

| Description                                      | Unit | Mixture variant |
|--------------------------------------------------|------|-----------------|
| Strength before thermal treatment                | Pa   | 430.6 428.3 457.9 |
| Strength after thermal treatment                 | Pa   | 343.4 357.1 390.1 |
| Strength variation after thermal treatment       | %    | –20.3 –16.6 –14.8 |

These data show that the maximal heat stability (i.e. minimum reduction in strength) is a feature of the samples manufactured using modified pulverized bakelite and compound basic material.

Thus, the mixture and manufacture method, which is the use of zirconium aluminum oxide with the grain size composition of 160, 125 and 100 in combination with the modified binder and the compound basic material with conditioning, ensured improved physical properties of the abrasive–bakelite tool and were taken as the model for the further research.

High-density abrasive bakelized tools were manufactured using hot shaping under low and high temperature from 60 to 100°C and from 170 to 180°C, respectively. Under low-temperature hot shaping, the organic binder was softened, the mixture became yielding and was well compacted under pressure. Under further increase in the temperature up to the high-temperature hot shaping range, particle polymerization of the binder took place (hardening) and almost nonporous material was manufactured.

The low- and high-temperature hot shaping tests used samples made of the mixture composed of AO with the grain size 160, 135 and 200 to make the active face of an abrasive wheel and the mixture composed of silicon carbide with the grain size 12N to make the nonworking face of the wheel.

The data of these tests are compiled in Table 3.

**Table 3. Physical properties of the test samples.**

| Parameter                      | Unit          | Low-temperature hot shaping | High-temperature hot shaping |
|--------------------------------|---------------|-----------------------------|-----------------------------|
|                                |               | Acting face | Nonworking face | Acting face | Nonworking face |
| Density                        | g/cm³         | 3.30        | 2.41            | 3.38        | 2.69            |
| Rupture stress under flexure   | Pa            | 760 ± 50   | 800 ± 40        | 820 ± 40   | 1070 ± 50       |
| Ultrasound speed (USS)         | m/s           | 4620 ± 20  | 4260 ± 40       | 4800 ± 30  | 5010 ± 50       |
| Cratering depth                | mm            | 0.25 ± 0.1 | 1.8 ± 0.15      | 0.20 ± 0.1 | 1.6 ± 0.15      |
| Hardness degree                | –             | EH           | EH              | EH           | EH              |
| Estimated breaking speed       | m/s           | 145 ± 5    | 174 ± 5         | 140 ± 4    | 190 ± 5         |
| Estimated strength margin      | –             | 2.1 ± 0.15 | 3.05 ± 0.15     | 2.2 ± 0.1  | 3.6 ± 0.2       |

EH—extremely hard

It is clear from Table 3 that the bars manufactured under high-temperature hot shaping possess higher density, strength, USS and hardness than the bars made using the low-temperature hot shaping technique.

**3. Conclusion**

The author has accomplished the experimental research aimed to design high-speed (100 m/s) abrasive wheels. The physical properties of an abrasive bakelized composite studied depending on mixture
composition and manufacture technology allowed optimization of the both factors, and a pilot run of abrasive wheels 25-250×50×76 38A 125 EH (extremely hard) B (bakelized) R (reinforced) 100 m/s of the standards geometry and strength has been manufactured.

Structurally, the abrasive wheels have the acting faces made of zirconium aluminum oxide and the nonworking faces made of fine-grained AO or silicon carbide, which allows enhanced strength of the wheel at the lower cost due to saving of expensive AO.

To enhance operation safety, the wheels are reinforced with the four layers of roving along the outside diameter as against the two-layer roving of series-produced abrasive wheels for operation at the speed of 50 m/s.

The samples made with the optimized mixture parameters and manufacture technique have been subjected to strength testing.

A pilot run of 10 abrasive wheels was manufactured using the high-temperature hot shaping method and: $V_G = 54$, $V_B = 44\%$, $V_F = 2\%$ to make the acting face and $V_G = 50$, $V_B = 48\%$, $V_F = 2\%$ to make the nonworking face; the mixtures before shaping were conditioned under $65 \pm 5^\circ C$ in the course of 12 hours; shaping press had a force of 250 t, the hot shaping temperature was $180 \pm 5^\circ C$, holding time under pressure was 40 min, bakelization under $185^\circ C$ took 16 hours; after bakelization, the wheels were machined with a diamond tool along the outside diameter and on faces.

To determine the actual strength margin, 2 wheels from that pilot run were subjected to rotation until rupture on test bench SBIP-350. The first wheel was ruptured at 12230 rpm (160 m/s), the second wheel—at 13030 rpm (170 m/s); thus the strength margin made 2.6–2.9.

The rest 8 wheels were set aside for the full-scale testing in order to specify their operating factors.

Finally, the designed abrasive wheels 25-250×50×76 38A 125 EH B R 100 m/s) conform with the assignment for their development. The new wheels have the size, disbalance, safety factor and operating factors in accordance with the initial specifications.

References
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