Anti-friction epoxy coatings modified with rice husk

A R Valeeva\textsuperscript{1,}\textsuperscript{*}, A R Gimranova\textsuperscript{1}, E M Gottlieb\textsuperscript{2} and E R Galimov\textsuperscript{1}

\textsuperscript{1}Department of Materials Science, Welding and Industrial Safety, Kazan National Research Technical University A.N. Tupoleva-KAI (KNITU-KAI), Kazan, Russia
\textsuperscript{2}Department of Synthetic Rubber Technologies, Kazan National Research Technological University, Kazan, Russia

*alina.valeevaa@yandex.ru

Abstract. This paper discusses the use of epoxy coatings modified with rice husk ash in order to reduce abrasive wear of materials and increase their durability during operation. It was experimentally established that the rice husk ash used as a filler increases the wear resistance and hardness of epoxy coatings with a significant decrease in the coefficient of static friction. This effect occurs when using ash obtained by burning rice husk at various temperatures. It is associated with an increase in the density of the formed spatial network in the presence of the studied filler, due to the selective sorption of the components of the epoxy composition by a developed solid surface.

1. Introduction
Details of mechanisms (bushings, bearings, joints) operating in a wide range of temperatures, speeds and at high load quickly fail [1]. Therefore, it is relevant to create wear-resistant antifriction coatings on their surface, including those based on epoxies modified with mineral silicon-containing fillers.

It is effective to use rice husk ash with a high content of highly active amorphous silicon dioxide as fillers for wear-resistant epoxy coatings [2,3]. Due to the high concentration of silica in their composition, the use of fillers based on rice husks can significantly reduce losses during abrasive wear and improve the tribological properties of epoxy compositions [2-4].

In this regard, it is of interest to study the effect on the wear resistance and antifriction properties of epoxy coatings of ash obtained by burning rice husk at various temperature.

2. Experimental part
To obtain anti-friction compositions, an ED-20 epoxy resin (GOST 10587-84) cured with aminoalkylphenol (AF-2) (TU 2494-052-00205423-2004) was used. The hardener content was determined by the equimolar ratio of [epoxy group]: [amine]. As a filler, ash obtained at the burning temperature of rice husks 350 and 800 °C, respectively, was used.

The wear resistance of the samples was measured on an IZV-1 vertical optimometer at a specific counterbody pressure on the test surface of the sample $P = 1$ MPa, sliding speed $V_{sk} = 1$ m / s, without lubrication.
The friction coefficient characterizing antifriction properties was determined on a computer-controlled tribometer, CSM Instruments (Switzerland) automated friction machine according to the standard ball-disk test scheme (ASTM G99–959, DIN50324 and ISO 20808). The linear velocity during the test was 8.94 cm/s, the sampling frequency was 10 Hz, the temperature was 25 °C, and the humidity was 20%.

Barkol hardness was determined according to GOST 9013-59, ASTM B648-2000 and ASTM D-2583 on the «TPBa» hardness tester.

The adsorption of the epoxy resin on the surface of the rice husk ash was determined by keeping their mixture at a ratio of 9:1 at room temperature for 24 hours and then exposure in acetone under the same conditions for 6 hours, followed by filtration of the solution and determination of the mass of the solid precipitate.

Oil capacity was estimated according to GOST 21119.8.

The sol-gel assay was carried out in boiling acetone in a Soxlet apparatus for 6 hours.

3. Discussion of results
Analysis of the experimental data obtained indicates that the introduction of rice husk ash into the formulation of epoxy compositions (table 1) reduces their wear and tear. Wear resistance of epoxy materials filled with RSA is practically independent of rice husk combustion temperature.

The effect of reducing wear is due to the fact [5] that metal oxide particles used as fillers prevent the development of deformations in the polymer matrix by acting as "spikes" fastening the structural elements of the mesh polymer, which makes it difficult to slide along the shear planes. As a result, more effort is required for shear to occur, resulting from increased hardness and stiffness of the ash-filled rice husk material.

| Table 1. Wear resistance of epoxy compositions filled with rice husk ash\(^a\) |
| --- |
| \( \Pi \) | Type of filler | Wear, \( \times 10^6 \) m\(^-1\) |
| | Unfilled composition | 15.2 |
| | Rice husk ash obtained at 350 °C | 12.5 |
| | Rice husk ash obtained at 800 °C | 13 |

\(^a\) The filler content is 10 parts by weight per 100 parts by weight of ED-20.

Indeed, the test fillers increase the hardness of epoxy coatings (table 2). This effect is also slightly dependent on the burning temperature of the rice husk, as is the wear resistance.

| Table 2. Hardness of epoxy compositions filled with rice husk ash\(^a\). |
| --- |
| \( \Pi \) | Type of filler | Hardness, HBa |
| | Unfilled composition | 30,8 |
| | Rice husk ash obtained at 350 °C | 55,0 |
| | Rice husk ash obtained at 800 °C | 34,2 |

\(^a\) The filler content is 10 parts by weight per 100 parts by weight of ED-20.

The increase in wear resistance and hardness of epoxy coatings when they are filled with rice husk ash is due to the fact that RSV has a porous structure and a large surface area, which contributes to good interaction of it with the polymer matrix [6].

The processing temperature of rice husks, according to the literature [7], affects the activity and chemical composition of the obtained ash, in particular its degree of crystallinity and carbon content.

Rice husk ash, like most silicate fillers, has hydroxyl or silanol groups on the surface.

According to work [7], it is the presence of these reactive groups that increases the hardness of epoxy materials due to their influence on curing processes.
The experimental data obtained show that the test fillers significantly reduce the coefficient of statistical friction of epoxy materials (figure 1). This indicator has sufficiently low values for using epoxy compositions filled with h as antifriction coatings [8].

In the test formulations, the RW ash obtained at 800 °C provides a lower coefficient of friction of the filled compositions.

The sol-gel analysis shows that the density of the spatial grid of the epoxy composition, when filled with 10 weight hours of rice husk ash, grows. This is indicated by an increase in gel content when rice husk obtained by burning at 800 °C is used as a filler (table 3).

![Figure 1](image1.png)

**Figure 1.** The dependences of the coefficient of static friction on the time of formation of contact with the cured AF-2 epoxy polymer: 1 - unfilled composition, 2 – with 10 parts by weight of rice husk ash obtained at 350 °C, 3 – with 10 parts by weight of rice husk ash obtained at 800 °C.

Although when filling epoxy materials ZRS obtained at 350 °C, the gel content is slightly reduced, given the insolubility in acetone ash, it is also possible to draw a conclusion about the increase in the density of the network structure in this case. This may be due to the activation of the process of opening the epoxy ring [9] due to the presence of hydroxyl-containing groups on the surface of the ash.

The interaction of the epoxy polymer with silicon-containing fillers is characterized by the formation of hydrogen bonds according to the scheme (Figure 2), since the ED-20 contains a significant number of OH groups and bridging oxygen atoms [10].

![Figure 2](image2.png)

**Figure 2.** The formation of hydrogen bonds.

This also contributes to the increase in hardness and wear resistance of the coatings when filling them with rice husk ash.
Table 3. The gel content in epoxy compositions filled with rice husk ash.

| Type of filler                        | Gel content, % |
|--------------------------------------|----------------|
| Unfilled composition                 | 86.8           |
| Rice husk ash obtained at 350 °C     | 86.1           |
| Rice husk ash obtained at 800 °C     | 87.4           |

*The filler content is 10 parts by weight per 100 parts by weight of ED-20.

In the case of rice husk ash, with an increase in its content of silicon dioxide and a decrease in the concentration of organic components (with an increase in the temperature of its production), the degree of adsorption of ED-20 on the surface of the filler decreases (table 4).

Table 4. The degree of adsorption of ED-20 on the surface of the rice husk ash and its oil absorption.

| Type of filler                        | Adsorption rate, % | Oil consumption, % |
|--------------------------------------|--------------------|--------------------|
| Rice husk ash obtained at 350 °C     | 3.28               | 146                |
| Rice husk ash obtained at 800 °C     | 2.36               | 110                |

*The filler content is 10 parts by weight per 100 parts by weight of ED-20.

These data correlate with the results of evaluating the oil absorption of rice husk ash (table 4).

4. Conclusion

The use of rice husk ash as a filler for epoxy coatings cured by AF-2 causes an increase in their wear resistance and hardness with a significant decrease in the coefficient of static friction. In this case, a denser network structure is formed, probably due to the influence of the filler on the curing process of epoxy oligomers by amines, due to selective sorption by the developed solid surface of the components of the epoxy composition.

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