Development of a new diagnostic method for materials abrasion resistance

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Abstract. The article deals with the development of a new diagnostic method for materials abrasion resistance. It lists the advantages of the proposed ultra water-jet abrasive diagnostics method and the disadvantages of existing ones. The implementation diagram of the method, the results of the experiments and the samples images with traces of abrasive jet interaction are presented. The phenomenological ideas of the nature of erosion of interacting materials are highlighted.

1. Introduction

One of the main requirements for some materials and products is their abrasion resistance, e.g. working surfaces of nodes and mechanisms. The surface damages like scratches, chips, sore from rubbing, loss of color (or dullness) may prevent product acceptance or require its removal from service. To ensure testing and control of abrasive effect prone surfaces during process design, the special devices called abrasers are used. The application area of such devices is extremely wide. We can use them to control painted surfaces, anodized and powder coatings, laminated material, fabrics, glass and rubber, metals, lacquered surface, leather and leather-like material, plastics, paper and cardboard, linoleum, natural and faux stone, ceramics.

Traditionally, abrasers are used to test the wet or dry abrasion resistance of various films, coatings and paint materials. Testing is carried out by simulating daily wear resulting from general use or cleaning processes. It is also possible to determine the minimum number of cycles for which the coating is destroyed (or loses its appearance), to conduct various tests for scratching and abrasion.

Some designs of abrasers, e.g. TQC Taber 5135 (rotational), are designed to test the wear resistance and abrasion of various materials, such as plastics, ceramics, metal, leather, rubber. Testing methods may vary based on the purpose of the product, for example, abrasion using abrasive particles. The analysis showed that the existing diagnostic methods and the implementing equipment have mainly an abrasive effect on the material, and as a result, we can talk about the mechanical form of abrasive wear [1]. However, we do not always face abrasive wear as a result of frictional contact of two or more bodies in practice [2]. Elements of hydraulic equipment for pumping oil products, coal, and ore experience not only frictional contact with the working medium, but dynamic loads [3]. An example of such equipment is centrifugal slurry pumps for pumping abrasive fluids and cement mortars, abrasive fluids in mine drainage systems [4]. Separate abrasive particles are able to accelerate in the fluid flow and have a quick dynamic effect on the surface of the nodes and assemblies.
of pumping systems [5]. Another problem could be the assessment of the abrasion resistance of coatings and materials subjected to abrasion. The issues of assessing the abrasive wear impact on equipment performance are also very important, especially in airspace engineering. Here, a special place is taken by the abrasive wear of the outer contours of aircraft units, which are hit by solid sand particles carried away by the air stream [6]. As a result, erosive wear of the working surfaces occurs, including the formation of a surface with densely located “holes” or cavities, and also the numerous scratches and chips of the paint coatings [7]. And we are talking about important units of airplanes and helicopters, such as nozzles, gas turbine blades, walls of combustion chambers, etc. This requires the formation of new approaches and the development of simulation diagnostic methods to assess the quality of the surface layer of units under the dynamic flow of abrasive particles [8].

2. The development of a new simulation diagnostic method
The goal to assess the adaptability of the method of ultrasonic diagnostics for the quality assessment of materials and coatings with an abrasive-liquid ultra-jet was set to the SM-12 department (Special Mechanic Engineering) “The Technology of space rocket engineering” of Bauman Moscow State Technical University [9].

The difference of the new method is in the usage of suspension containing abrasive powder for diagnostics instead of previously used water. The method was developed for metallic materials and coatings. It can be assumed that it will also be effective for composite polymer materials. There can be some problems with the implementation of the method if the applied coating has very weak adhesion with the base and the coating can fall off from the surface only because of the centrifugal forces. In this case, it is necessary to implement other kinematic schemes. As a result of preliminary experiments on the effect of abrasive-liquid flow on the surface layer of materials, this effect was found not to provide an opportunity to analyze erosion parameters. Moreover, a negative result was obtained even when choosing processing methods with maximum technically feasible axis velocity, minimum pressure in the hydraulic system and the maximum permissible distance of the focusing tube to the sample surface [10]. As a result of this experiment, assumptions about the need to impose an additional velocity component were made. Such velocity can be created due to the rapid movement of the sample. Since linear drive units will obviously not give a noticeable result, an option with the implementation of the rotation of the sample has been proposed. With the need to vary the velocity to select the optimal velocity indicators for the experiments, we used Sturm AG9012TE angle grinder (manufactured in China) with the following technical characteristics – power is 1000 W, voltage is 220 V. A distinctive feature of this angle grinder model is the ability to change the speed of rotation. This technical solution opens up additional possibilities for choosing technological parameters that can be adjusted, depending on the material being studied [11].

Figure 1 shows a principle diagram of ultra water-jet abrasive diagnostic process. Experiments of the implementation of this process were carried out at Moscow State University, Physics Department, Hydrophysical Research Center. The formation of abrasive-liquid suspension was carried out using water-jet cutting machine Flow Mach 3 3131b (manufactured in the USA).

Figure 2 shows the machine-tool attachment of angle grinder to the water-jet machine. The attachment with the angle grinder fixed in it was fastened to the worktable of the water-jet cutting machine.

3. Experimental testing
The experiment was carried out with the following technological parameters: 1) pressure in the hydraulic system 100 MPa, axis velocity of the jet forming head \( S = 212 \text{ mm/s} \) (the maximum possible for this water-jet machine); 2) the distance from the cut of the focusing tube to the surface is 150 mm (the maximum possible, taking into account the height of the tool with the angle grinder fixed in it); 3) the abrasive concentration is 100 g/min; 4) the spindle speed is 10000 rpm. After all the preparatory operations for placing and securing the machine-tool attachment with the angle grinder to the worktable and after selecting the indicated technological parameters, the abrasive-liquid flow
directly affected the sample. After turning on the angle grinder and reaching its stable operating mode, the hydraulic head section began to move to the center of the disk in a horizontal plane. High pressure water supply stopped as soon as the hydraulic head section was in the closest possible position to the center of the sample. The concentration of particle impacts increases as it approaches the center of the disk. This fact has a positive feature, since it seems possible to evaluate how the material or coating will behave at different particle impact densities. This data can be obtained on one single sample and there is no need to make additional test samples. As a result of this experiment, a surface with the presence of multiple impacts of abrasive particles was formed (figure 3).

**Figure 1.** The Principle Diagram of ultra water-jet abrasive diagnostics.
1 – the sample; 2 – focusing tube; 3 – head section of nozzle unit; 4 – water supply; 5 – lock valve; 6 – reduction gearbox; 7 – priming pump; 8 – filter unit; 9 – control system; 10 – intensifier; 11 – vibration damper; 12 – pipeline of high pressure; 13 – angle grinder.

**Figure 2.** The machine-tool attachment of angle grinder
1 – angle grinder
2 – support assembly
3 – fixing screw

Aluminum alloy was chosen as the diagnosed material [12]. A round sample was cut from a sheet, corresponding in size to standard cutting discs for angle grinders with external diameter of 125 mm, internal bore diameter of 22 mm, and thickness of 2 mm.
The results presented in Figure 3(a) do not allow assessing the degree and nature of the penetration of single abrasive particles into the material, but they can be used to assess the overall level of total erosion resistance of a particular material [13].

The sample is of great interest since it can be used to evaluate the penetration depth of the abrasive into the material, the geometric parameters of the prints and their shape [14]. The images of the surface of the sample have been taken by using the MBS-10 Microscope (manufactured in Russian Federation), and 100 times the power of zoom (Figure 3(b)). Figure 5 shows a surface area with holes formed as a result of impacts of abrasive particles.

The measurement of the depths of cavities can be carried out using optical microscope, optical profilometer or profilograph-profilometer. The best results were obtained using optical profilometers of the SURFIEW GLtech series (South Korea).
Figure 5. Photo of the sample surface with traces of interaction with the abrasive-liquid flow.

Obviously, disks made from a wide variety of materials, including composite materials, samples with various coatings, ceramic disks, etc. can be used as a sample [15]. There is no doubt that the nature of the erosion of their surface formed as a result of the application of the described diagnostic method can show a number of operational indicators of materials and products made from these materials [16]. The analysis and map of particle impacts on the surface is of great interest since the parametric characteristics of the water jet and the specifics of the movement of the abrasive powder in it are revealed. Figure 6 presents the expected surface profiles of samples from various materials.

Figure 6. The assumed damage on the surface of various materials as a result of the abrasive-liquid ultra water-jet machining:
(a) – Model of a thin-film coating, e.g. TiN, TiCN
(b) – Minor damage during surfacing (plasma coating)
(c) – Assessment of the dynamic ductility of metal and alloys
(d) – Local impact cracking determination of ceramics and composites.

Such parameters as the depth, width, length of the cavities, as well as the height of the plastic displacement rollers can give important diagnostic information useful for choosing a particular material, hardening technology, or surface modification according to the criterion of abrasion
resistance [17]. The use of this method in the future can take its rightful place in the development of aerospace engineering products and manufacturing technology development.

The rational implementation of the functional and physical capabilities of discrete ultra water jet diagnostics in the life cycle of rocket and spaceship equipment items is given below [18].

- Controlled simulation of local impact action on facial layer of details
- Erosive wear of blades and propellers of spaceship power plants
- Rapid recognition of erosive resistance of functional coatings
- Analysis of erosive change in solid-propellant rocket engine elements profile
- Rapid estimation of functional quality parameters of surface by means of locally dynamic indentation
- Quality control test (QCT) of hardening techniques of various materials and parts made from them
- Recognition of adhesive interaction of coatings and protected surfaces
- Rapid estimation of physical and mechanical properties of various powdery materials
- Experimental verification of finite-element models of impact hydrodynamic interaction of dispersed particles with solid target
- Functional properties of composite and ceramic materials
- Reliability support of getting rocket and space equipment parts in additive manufacturing

4. Conclusion
To sum up, there are brief general conclusions:

- Preliminary processing methods are established. They allow to obtain both quantitative and qualitative characteristics of surface erosion as a result of a single high-speed interaction of particles and investigated materials surface.
- According to a set of preliminary experiments, the method of ultra water-jet abrasive diagnostics is found to be the development of the already known technology of ultra water-jet diagnostics and replenishes abrasive materials control means.
- The phenomenological ideas of various materials erosion nature during the interaction between the materials and the abrasive flow of fluid are defined. The verification of the ideas requires a set of additional experimental studies.
- Areas of potential use of the ultra water-jet diagnostics method for solving various technological problems (primarily in airspace engineering) are defined.

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