Surface express ultrajet diagnostics of space vehicle materials

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Abstract. The article substantiates the possibility of using waterjet hydrophysical diagnostics for the express estimation of features of physical and mechanical properties of structural materials obtained by selective laser sintering. It is shown that, based on the results of ultrasonic diagnostics, functionally necessary information is obtained to improve the quality of implementation of all stages of products’ life cycle in production of which it is promising to use additive technologies. On the example of the constructive element of the Russian Observatory "Millimetron "(Spektr-M project) it is shown that the approaches proposed by the author can be used in the process of technological preparation of rocket’s production and space technology (RST), aircraft building, turbo-power engineering, etc.

Keywords: selective laser sintering, ultrajet diagnostics, anisotropy of material’s properties, physical and mechanical properties

Introduction

Modern additive manufacturing of Rocket and space equipment products allows the manufacture of ready-for-use or requiring minor modifications of parts. Progressive company, leading participants in this market, emphasize that additive technologies can have broad prospects for implementation in various branches of technology. Currently, companies that produce only equipment for 3D printing, as a rule, also implement a full cycle of additive manufacturing of parts for the aerospace industry. This solves the problem of determining the characteristics of the materials used, carries out technological processes of finishing parts, including heat treatment, hot isostatic pressing, mechanical processing on CNC equipment, as well as quality control using modern diagnostic tools. Currently, economically capacious high-tech developments transferred to the relevant enterprises, primarily of the military-industrial profile.

In the Academician of RAS N.P. Aleshin works and scientists of “Bauman Moscow State Technical University”, as well as the work of other authors [1-4] shows the need for adequate information and diagnostic support by non-destructive quality control methods for products made from materials obtained by additive technologies, in particular, selective laser fusion (SLF). However, the question of the operational determination of the geometrical microscale instability of the physic mechanical properties (PMP) of these materials remains open. Therefore, the task of rapid assessment of the anisotropy parameters of the PMP of structural materials obtained by SLS is relevant, since the quality of the working surfaces of products from them usually determines the operational and resource parameters of the structure as a whole, especially various types of detachable joints and friction mates of responsible use.

On the basics of the above, the research and scientific goal of the research formulated: to determine the functional and structural relationship between the instability of the physic mechanical properties of materials obtained by selective laser alloying and the specifics of their local fracture with the waterjet.

To achieve this goal was necessary to solve the problem of methodological support of the waterjet...
technology, as well as to illustrate its functional and technological capabilities with specific examples.

**Rationale for research performance**

At the initial stage of research by using the methods of expert-analytical analysis proposed in [5, 6]. This method let to show the broad functionality of waterjet hydrophysical diagnostics. In the works [7, 8] was shown that by analyzing the products and results of local erosion-fatigue destruction by a high-speed waterjet of the surface layer of the diagnosed material it is possible to obtain objective information about the parameters of its state. Mainly about the PMP and operational life indicators, particular functional damage to the working surfaces of the analyzed structural element of the investigated product. In this regard, the possibility of a detailed analysis of the local micro geometric anisotropy of the surface properties of the products obtained by SLF opens up, since it’s the instability of working surfaces formed by the PMP that is often the limiting factor of their operational and technological reliability.

In [7, 9], the general structure of the model of hydro erosion-fatigue fracture of the surface layer in the case of its PMP isotropy was proposed. Therefore, using the well-known algorithmic approach to the construction of this model, we introduce into it a significant physical and technological difference, due to the different-scale variation-cyclic instability of the PMP materials obtained by the SLF method. This difference consists in the frequency of changes in the parameters of technological microdefects of the structure of the material formed in the process of its fusion. Moreover, this periodicity is commensurate with the geometrical dimensions of the region of laser alloying of the initial dispersed powder supplied to the zone of structural and shaping structural material and at the same time the part itself at the SLF process operation as shows on the Figure 1.

**Figure 1** - The nature of the change in the size of technological microdefects (micro- and submicrocracks) in the material obtained by the SLF method

1. The analyzed sample obtained by the SLF technology;
2. The possible trajectory of the laser beam in the (xy) plane;
3. Laser-deposited layers of material in the axial direction (oz);
4. Zones of possible increased instability of the structure of the material, the occurrence of which is due to a change in the trajectory of the laser beam;
5. The trajectory of the scanning diagnostic effects of US on the surface of the sample.
6. lx, ly, lz - respectively, the expected change in the size of microdefects along the axes: ox, oy and oz (lz> ly> lx);
7. (--- →) - the direction of movement of the laser beam.
8. Moreover, in work [10, 11], the question of the quantitative coordinate instability of the PMP of images obtained by SLF, which as a whole determines their strength and, mainly, fatigue and surface-friction characteristics, was experimentally studied.
Methodical features of research

Using the phenomenology of the features of the distribution of initial technological defects, presented in Figure 1 and the algorithm of hydro erosion destruction, considered in [9] after performing the corresponding design procedures, we obtain the following results of the simulation of the UWJD process on the surface layer of a sample of material obtained by SLF, which are graphically shown in Figure 2. In Figure 2a shows a sectional view of the sample, with the profile of cavities formed as a result of diagnostic exposure, having a corresponding bottom surface micro relief. In Figure 2b is a diagram illustrating how the depths h of the cavity and the micro relief of its bottom R vary with the angle φ as a result of the diagnostic effect on the sample.

**Figure 2** - A generalized diagram of changes in the depth h and the microrelief of the surface R of the bottom of the hydrocourt obtained under various conditions of the diagnostic effect of waterjet on the material formed by SLF technology

In Figure 2a, it is accepted:
1 - control and diagnostic high-speed waterjet;
2 - the surface of the studied sample material;
3 - the microrelief of the surface of the bottom of the hydrocavity formed as a result of the WJ exposure to the material being diagnosed; ; $S_{YC}$ and $S_{L}$ - respectively, the direction of movement (feed rate) of the WJ and the laser beam ;
4 - diagram of variation of the depth h of the cavity depending on the angle φ - the angular mismatch between; ; $S_{YC}$ and $S_{L}$ (in the xoy plane)
5 - is a diagram of changes in the depth h of the cavity and profile (microrelief) of its bottom R depending on the angle φ in the planes yoz and xoz.

The averaged values of h and the variation of the R parameters — microgeometries of the cavern bottom profile with a diameter WJ (dc) substantially exceeding the size of the effective fusion zone (rc) largely depend on the planar factor of the formation of the material and the product as a whole, which is clearly shown in Figure 2b. This provision is fully correlated with the results of direct strength experiments.
presented in [10-12], however, the efficiency of their receipt by the WJD is incommensurably higher and much less expensive.

**Examples of the implementation of the capabilities of ultra-jet diagnostics**

The characteristic result of determining the value of h and the variation of the parameters R - microgeometry of the profile of the bottom of the cavity are shown in Figure 3. Test experiments were performed on samples obtained from LPW 316 brand aluminum powder traditionally used in rocket and space technology [13–15]. To obtain the samples, the system RenAM 500M from Renishaw (United Kingdom) was used. To implement the WJD procedure, a waterjet cutting machine from Multicam WaterJet (USA) had used.

The technological parameters were as follows: the pressure of the multiplier was 350 MPa, the feed rates of the nozzle head, i.e. the rate of scribing of the USS of the surface being diagnosed is 2 mm / s, the distance from the cut of the focusing tube to the surface of the sample is 5 mm, the interaction of the water jet without abrasive passed at a right angle to the surface. An image of the profile of the hydrocave was taken with a Carl Zeiss LSM 700 laser scanning confocal microscope (Germany).

![Figure 3](image-url)

**Figure 3** - Image of the hydrocoupler obtained at the WJD of a sample of aluminum alloy (1- the studied part of the specimen; 2- profile of the hydrocourt on its surface)

Note that the final diagrams of diagnostic results presented in Fig. 2b were obtained by summarizing the results of optical measurements of the geometric parameters of tracks left on the surface of the scanning ultra waterjet (UWJ) at different angles to the vector S_L - the direction of the laser fusion of the original powder for forming the part according to the SLF technology. Moreover, the angle α - formed by the UWJ and the diagnosed plane of the object under investigation plays a certain role in ensuring the effectiveness of the UWJD as a whole.

According to the results of the analysis performed, the following main conclusions some generalizations can be formulated:

1. The change in the microrelief of the surface of the cavity, its bottom part functionally and quantitatively copy the patterns of distribution of microdefects: lx, ly, lz. This circumstance is
the most important information and diagnostic parameter for the quality of additive technologies, in particular, SLF technology. The mechanism of this hereditary technological copying is described in detail in [14-15].

2. The quality of the SLF process itself can be judged by the difference in the depths of the erosive hydrocaverns formed on the surface of the sample during the “passing” and “counter” movement of the US with respect to the trajectory of the laser beam. This parameter is called the “kinematic factor” of diagnosis and applied to other conditions of its manifestation is also analyzed in [16-18].

3. In the zone of change of the path of movement of the beam - pos. 4 (see Figure 1), it is not yet possible to isolate clear patterns in the characteristics of hydro erosion destruction of the surface of the material obtained using the SLF technology.

Note that in the future, potentially very significant results on the UWJD of products manufactured using additive technologies, in particular, by using the SLF method, will be fully verified by their resource, for example, fatigue and / or friction tests, as well as after a certain period of operation of the products being analyzed. The WJ-diagnostic identification of the vector-kinematic nature of the layer-by-layer formation of operational and physical damage is highly likely, which is essential for reliable prediction of the residual life of products made from such materials, which are distinguished by special PMP, which are due to the technological specifics of their production. In this case, presented in Figure 1, the initial distributions of technological microdefects should be supplemented by the dependencies of their quantitative and dimensional changes during operation [19-20].

Conclusions
As a study result, the goal of the research had been resolved. The tasks on the scientific and methodological substantiation of the performance potential of ultra-jet hydro physical diagnostics of the parameters of anisotropic instability of PMP materials and parts realized by the SLS methods achieved. The physical and technological basis for achieving the goal and solving the tasks set was verified by field experiments on samples and models of real parts, the statement about the significant effect of the PMP spread of the surface layer of the material formed by the SLS method on the instrumentally diagnosed specificity of its local hydro erosion under the impact of the dynamic effect of the waterjet. In conclusion, we note that the theoretical and experimental substantiation of the effectiveness use waterjet method in additive technologies not only complements the well-known and developing arsenal of tools for studying their functional capabilities, but is also a tool for obtaining new knowledge about the specificity of PMP materials derived from these advanced technologies, in particular local anisotropy, which must be taken into account at all stages of the life cycle of CT products.

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