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Evaluation of the fragmentation of an oxide-silicate material by image analysis

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Abstract. The study of the fragmentation parameters of non-metal objects, usually oxidesilicate, when colliding with metal barriers at various speeds is an important aspect of ensuring and assessing the reliability of the structure in aviation and space engineering, as they help simulate collision situations with striking objects in the air and space. With such an assessment, the size and number of fracture fragments are determined, as well as their speed and direction of movement at the moment of impact and after it. The problem of estimating the physical parameters of fracture fragments, such as size and weight, has been solved quite well, however, these methods are quite laborious. Evaluation of the speed and direction of movement of the fracture fragments is carried out, as a rule, when analysing the video recording of an experiment. The quality and information content of such an assessment depends on the quality of the video, shooting parameters and processing method. The paper proposes to use the image analysis implemented by using open source software ImageJ-Fiji for video processing and for estimating the parameters of fracture fragments. The paper discusses the experimental data on the impact of a spherical object of an oxide-silicate composition with a diameter of 23 mm with a static barrier - a sheet of titanium alloy 2 mm thick at a speed of 230 m/s. It is shown that using image analysis and statistical data processing, parameters such as the size and number of fracture fragments, the initial and final velocities of objects moving, as well as the direction of their movement can be set.

1. Introduction

In the operation of high-speed transport, including aviation, as well as in the operation of objects located in outer space, a factor increasing the risk of their accidental breakdown is the probability of a collision with small fast-moving objects of oxide-silicate composition [1-4]. Such objects can be micrometeors, fragments of destruction of rocks of anthropogenic and natural origin, pavement particles, and the like. To neutralize the possible harm from the action of such objects, passive protection methods are usually used (armour-resistant plates, etc.) [5-7].

When developing means of passive protection, an important aspect is how potentially dangerous objects behave after a collision with them, namely, what is the size, speed and nature of movement of the destruction fragments, whether they themselves become attacking objects after an impact. It is possible to predict the behaviour of an object in a collision with an obstacle with the help of various mathematical modelling tools, however, an important place in the evaluation of fragmentation processes remains behind the experimental studies, and therefore the evaluation of the data obtained in the experiment is an important issue. In addition, the significant cost of equipment and testing of this

kind requires the most efficient extraction of useful data from the experiment. Increasing the informativeness of experimental tests is currently achieved in various ways, including involvement of new software analytical tools, which involve image analysis. The aim of the study is to assess the fragmentation of an oxide-silicate material by image analysis and identify the parameters that can be established with such an assessment.

2. Materials and research methods

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The experiment was conducted with a spherical sample of an oxide-silicate material with a diameter of 23 mm, weight of 135 g, of the following composition, wt%: SiO₂ 43,0-46,0; MgO 2,0-16,0; Al₂O₃ 10,0-17,0; CaO 9,0-15,0; FeO 3,0-7,0; Fe₂O₃ 1,0-1,2; TiO₂ 0,4-0,8; Na₂O 0,3-1,0; K₂O 0,33-1,10; MnO 0,20-0,30; Cr₂O₃ 2,4-3,0; V₂O₅ 0,1-0,2; Fe₂S 0,02-0,06. The sample was used as a striking object. A sheet of aviation titanium alloy 2 mm thick was used ss a barrier simulating passive protection. To accelerate the sample of the oxide-silicate material to the speed of 230 m/s, a pneumatic installation was used, the length of the accelerating tube of which and its diameter were 3950 and 25 mm, respectively. The impact of a spherical sample on the surface of a metal plate was carried out at an angle of 90 $^{\circ}$ to the surface in the middle. To confirm the rate of movement of the sample from an oxide-silicate material, a control system equipped with laser emitters and corresponding receivers at the beginning and at the end of the control section was used. The system of high-speed video recording of the collision process consisted of Photron FastcamSA5 high-speed video camera and a lighting complex of seven light sources with a power of 1000 W each. The camera for capturing the collision process was set at an angle of about 45 ° to three orthogonal planes. The launch of the video registration process was carried out using a trigger signal generated by an automated experiment system; the shooting speed was 25,000 fps. Image analysis of video frames was carried out using ImageJ-FiJi software. With the help of the TrackMate plug-in, trajectories of movement of fracture fragments were tracked, which made it possible to establish their exact number (excluding double counting of one fragment on different frames), size and speed characteristics.

3. Results and discussion

Figure 1 shows the image of video frames. In total, information on 500 frames was analysed according to the results of the impact. It was found that during the collision 3,442 fracture fragments were formed, ranging in size from 0.8 to 5.7 mm. Analysis of the size distribution of fracture fragments made it possible to establish that two groups of fragments are distinguished, the first is 3.5–5.7 mm, the second is 0.5–3.5 mm. The size distribution of the fragments in each group corresponds to the normal distribution (figure 2). It was also established that the total number of fragments in the first group was 1,593, which is less than in the second one, where the number of fragments was 1,849.

The distribution of fracture fragments by size groups indicates that they were formed as a result of various processes, namely, the largest as a result of growth of main cracks, and the smallest as a result of dissipative processes, which is confirmed by studies of predecessors [8-10].



Figure 1. Shots of the experiment: a - before the strike, b - after the strike.



Figure 2. Histogram characterizing the distribution of fragments destruction by size.

Due to frame-by-frame analysis of the survey, it was found that the initial speed of movement of the fracture fragments was 1.0–40.0 m/s, with an average of 18.5 m/s, and the final one was 0.0–0.5 m/s. Meanwhile, different size groups had a different range of initial velocities. The average initial speed of 5.5 ± 3.2 m/s is characteristic for fracture fragments of size 3.5-5.7 mm. The average initial velocity of 20.2 ± 6.4 m/s (figure 3) is characteristic for fracture fragments with a size of 0.5-3.5 mm.



Figure 3. The distribution of the magnitude of the initial speed of movement of fracture fragments for size groups, mm: a) 3.5-5.7; b) 0.5-3.5.

3

When visualizing the paths of movement of fracture fragments with different speeds (figure 4), the following trend was established. Fragments with the size of 0.5-3.5 mm move in the opposite direction from the obstacle, fracture fragments 3.5-5.7 mm in size move along the surface of the barrier.

In conjunction an analysis of the experimental results indicates that under conditions consistent with experimental, passive protection performs its function, and fragments of damage do not inflict secondary damage on the element of passive protection.



Figure 4. Trajectories of movement of fragments of destruction, painted depending on the magnitude of the initial speed of movement.

4. Conclusion

Thus, the fragmentation assessment of the oxide-silicate material in a collision with a static metal barrier by image analysis allows setting the following fragmentation parameters: the number of fracture fragments, the size of the fracture fragments, the trajectory of their movement relative to the obstacle, the initial and final movement speed of the fracture fragments. As a result of the experiments, the parameters of fragmentation of a sample of an oxide-silicate material weighing 135 g were found upon collision with a sheet of titanium alloy 2 mm thick.

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