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The Effect of Elastic Energy Accumulation and the Possibility of Controlling the Fracture Process in Complex Structures

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Abstract—The behavior and fracture of complex structures under dynamic loading conditions were studied by computer simulation using the method of mobile cell automats. Possibility of the effect of elastic energy accumulation is demonstrated. The character of fracture in the systems studied can be considerably modified by very slightly changing initial geometry of the structure. *© 2000 MAIK "Nauka/Interperiodica".*

INTRODUCTION

One of the major problems in modern technology is to provide for an increase in the viability of constructions serving under dynamic loading conditions. A well-known example is solving the task of ensuring the safety of passengers in cars and other vehicles in the case of collisions. In the general case, the solution consists in providing conditions for a controlled transfer of the kinetic energy of interaction (impact) into the energy of fracture liberated in less important parts and units of construction. It should be noted that an analogous problem is encountered in the materials science, since most of the modern construction materials are heterogeneous and possess complex internal structures. In optimizing the structure of a material intended for use under the dynamic loading conditions, it is necessary to take into account a possibility that redistribution of the elastic energy (related, e.g., to phase transitions, generation and accumulation of microscopic damage, etc.) would change the mechanical properties of the material in the course of loading [1–4].

Since real experiments involving the fracture of complex objects (e.g., crash tests) are rather expensive and the extraction of detailed information from the results of these experiments is usually a very difficult task, these problems are now frequently solved by methods of computer simulation. As a rule, the simulations are based on the methods of continuum mechanics. These methods provided a considerable progress in the fracture mechanics. Nevertheless, the continuum mechanics approach has certain restrictions related for the most part to the possibility of describing the production of damage and the formation and propagation of cracks. Problems of these kinds can be solved based on the method of mobile cell automats extensively developed in recent years. This method was successfully used in simulations of the fracture of various materials and constructions [4–8].

The purpose of this work was to study the possibility of controlled elastic energy "pumping" in the course of dynamic loading of complex structures. For correctly solving this task, it is necessary to thoroughly follow the behavior of a system, from appearance of the first damage to complete fracture of the construction simulated. For this reason, we have performed simulations using the method of mobile cell automats.

SIMULATION MODEL

Within the framework of the method employed, the material studied was represented by an ensemble of elements (cell automates) interacting with each other according to certain rules. In our model, in contrast to the classical method of cell automats [9, 10], the elements are allowed to move in space under the action of interactions between automats as well as external forces. Both translational and rotational motions are taken into consideration. The mechanical interactions are measured in terms of the automat overlapping and relative rotation [8]. In addition, each pair of elements is considered as a bistable automat characterized by the state of connection or disconnection, the transition from the former state to the latter representing an elementary fracture event. The equations of motion for the mobile cell automats derived within the framework of the Vinner–Rosenblut model represent a variant of the Newton equations for an ensemble of particles with an allowance for the multiparticle interactions [8].

This approach, by virtue of the mobility of individual elements, allows various processes occurring in real materials under loading to be simulated, including the mutual penetration and mixing of masses, generation

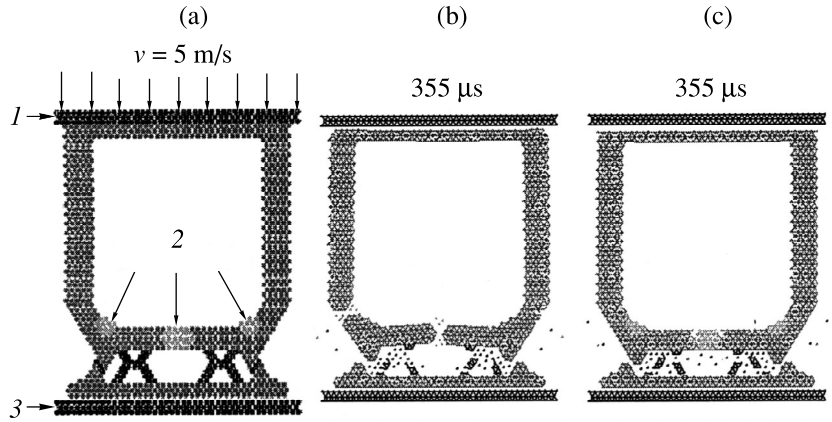

Fig. 1. Schematic diagrams (a) of the base model construction and the patterns of fracture in the frame (b) with and (c) without damping inserts at the time moment t = 355 μs: (*1*) piston; (*2*) damping inserts; (*3*) immobile obstacle.

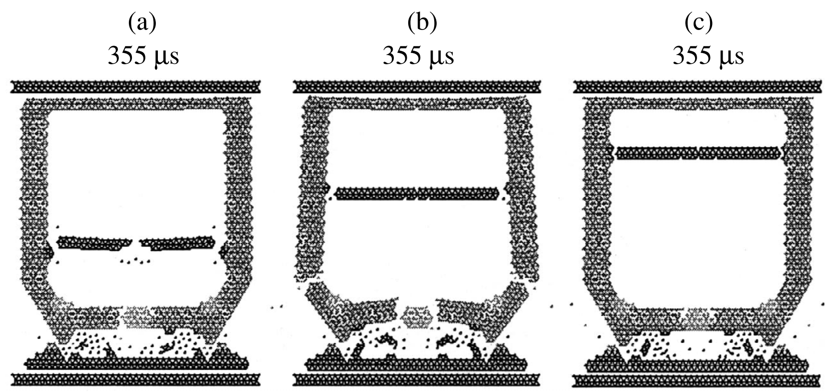

Fig. 2. Patterns of fracture in the frame structure with horizontal crosspiece in various positions at the time moment t = 355 μs.

and development of damage, and the formation of cracks. By setting special boundary conditions [5, 8], one may also simulate various regimes of loading, including compression, stretching, shear strain, etc.

In this work, we have simulated the loading of flat samples with a shape resembling construction of the front part of a car frame. The mechanical characteristics of a material studied corresponded to those of a ZrO_2 ceramics, for which the parameters of mobile cell automats are well determined [4, 8]. The sample, composed of the 0.1-cm automats, had a total width of 4 cm and a height of 5 cm. The sample shape and the loading mode are illustrated in Fig. 1a. The loading was effected by pushing the sample with a "piston" moving at a velocity of 5 m/s, so that the front of the construction collided with an immobile obstacle. Parameters of the obstacle automats corresponded to the mechanical properties of concrete.

RESULTS AND DISCUSSION

Multiply repeated experiments on the simulation of "collisions" showed that maximum local displacements are observed for elements at the center and corners of the front wall of the sample construction. In order to provide for a more uniform distribution of the energy "pumped into" the sample structure, we have introduced special damping inserts into these regions, made of a material with an elastic modulus equal to half of that for the base construction material. Figures 1b and 1c show the patterns of interautomat connections in the fractured samples with and without damping inserts, respectively, at the time instant t = 355 μs. As seen, the frame without inserts loses its carrying capacity, while the frame with inserts exhibits only insignificant damage.

An analysis of the simulation results showed that the presence of damping inserts in loaded samples leads to dynamic "accumulation" of the mechanical energy of collision. This effect is explained by the fact that, as indicated above, the regions of inserts are subject to maximum displacements in the course of loading. The inserts, because of their higher pliability, transfer the loading momentum along the sample rather than break, which leads to smearing of the stress concentrators and favors retaining of the structural integrity. This effect

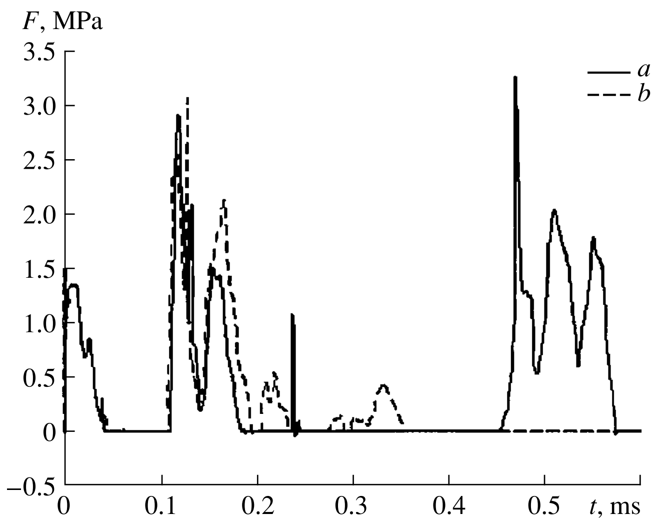

Fig. 3. Time variation of the response force acting upon the "piston" for the frame structures with crosspiece in different positions (curves *a* and *b* correspond to variants of the same notation in Fig. 2).

results in a significant increase of the threshold value of the energy that can be "pumped into" the structure, that is, of the energy that is absorbed in the sample until it would lose the carrying capacity. In fact, the elastic energy is "circulating" over the structure unless a stress concentrator would form with a power sufficient for the formation of a macrocrack.

In order to assess the possibility of controlling the variation of the pumped energy threshold by changing the structure geometry, we have studied a structure with a thin crosspiece in the internal region of the frame. The position of this crosspiece could be varied (Fig. 2). It must be noted that, irrespective of its position, the crosspiece was broken by a time instant of $t = 120$ μs. However, each structure with crosspiece exhibited a characteristic redistribution of the elastic energy flux in the system. In particular, the presence of the crosspiece led to the formation of a special "contour" featuring circulation of the elastic energy. This energy being liberated upon breakage of the crosspiece, each sample exhibited a particular dynamics of the formation and development of stress concentrators and, hence, was characterized by its own fracture history.

These results indicate that the response of a complex structure on the dynamic loading (Fig. 3) and the threshold value of energy "pumped into" the structure are not fully determined by general configuration (geometry) of the structure. For example, displacement of the crosspiece from back to the middle and closer to the front of the frame led to a significant decrease in the pumped energy threshold and altered the general pattern of fracture.

Thus, the results of our simulations clearly demonstrated the principal possibility of controlling the fracture process and increasing the viability of structures, which can be achieved both by slightly modifying their geometry and using special inserts.

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