PULSED CUTTING OF BRITTLE BIOMATERIALS

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SUMMARY

The process of brittle materials pulsed cutting can be divided into several stages: 1st - accumulation of destroying stresses; 2nd - microcracks formation, knife blade penetrates into the depth of 0.05-0.1 relatively to a sample thickness; 3rd - formation of an advanced crack, the sample being destroyed to the degree of knife blade penetration and of formed advanced crack. Durin advanced crack growth there may be some situations when the sum of external energy and potential energy of elastic deformation will be equal to energy of ointeratomic connections (equilibrium condition) or lower it (stationary condition); in these cases growth of advanced crack is stopped and it is necessary to use a complementary external energy for its further growth. A dynamic modulus of elasticity (E_{din}) was determined, using the ultrasound method, for the samples of compact bone tissue extracted from different sections of tubular cattle bone. For this purpose diaphysis part of bone was divided into 5 zones. Samples were made according to 3 mutually perpendicular directions. Based on the results of calculations average values of dynamic modulus of elasticity (E_{din}) for each zone were obtained.

INTRODUCTION

A study into performance of brittle biomaterials aimed at determination of connections between the processes of pulsed loading and material reactions, firstly, its deformation and destruction, has a significant practical and scientific interest. Such a connection constitutes the basis for rational designing of new equipment taking into account a real performance of the studied material under loading, and provides a proper selection of technological processes using pulsed machines. Pulsed loads are characterized by the fact that a high level of stresses in the material achieves some tens of thousands of N per mm^2 during a short period of time due to a high speed of loading as related to time and, as a consequence, to a high rate of deformation. OA high speed of pulsed cutting is connected with a high rate of material deformation. At high rate cutting diagramms of cutting and mechanical properties of brittle biomaterials will differ from the same diagramms and properties of materials that are characteristics for low rates; that is why it is necessary to determine these differences. Let's consider the influence of deformation rate on mechanical properties of brittle biomaterials. McElhaney and Byars (1) studied mechanical properties of bone tissue as related to deformation rate. They determined ultimate stress at pressing, energy absorption at destruction, modulus of elasticity, deformation at destruction for human tibial bone at deformation rate range of $1.0 \times 10^{-3} - 1.5 \times 10^{3} s^{-1}$. It was found that at deformation rate increase such mechanical properties as ultimate stress at pressing and modulus of elasticity increase too. Studying bone tissue penetrability Becker et al. (2) determined dynamic relations "stress-deformation" at pressing samples of compact bone tissue cutted parallely to the longitudinal axis of cattle thigh bone. Results were used for analysis of objective classification of destruction degree. The authors determined the following stages of destruction process:

- maintaining of strength;
- microcracks formation;
- macrocracks formation;
- full destruction.

Some other investigators studied these dynamic properties. A review of experimental studies into the influence of deformation rate on mechanical properties of brittle biomaterials allows to make the following conclusions: schemes of interactions of knife blade at pulsed cutting of brittle biometarials and the procedure of their determination are not described; values of dynamic modulus of elasticity for compact bone tissue samples extracted from various sections of cattle tubular bone are not determined.

MATERIALS AND METHODS

For more precise study into pulsed cutting schemes an experiment was made using a test rig equipped with a control-measuring apparatus. The rig (Fig. 1) consists of a pendulumic pile driver, an accelerated filming apparatus, a tenzoamplifier with power block, an accelerated oscillograph and a block controlling measuring unit. Accelerated filming allowed to follow visually the interaction of knife blade and a cutted material. Using tenzomeasuring apparatus and accelerated oscillograph shear force values for the samples of brittle biomaterials were obtained.

RESULTS AND CONCLUSIONS

It is found that the process of brittle biomaterials pulsed cutting can be divided into several stages: 1st - accumulation of destroying stresses; 2nd - microcracks formation, knife blade penetrates into the depth of 0.05-0.1 relatively to samples thickness; 3rd - formation of advanced crack (Fig.2). The sample is being destroied to the value of knife blade penetration and to the value of the advanced crack. As the result the sample is being destructed to its full thickness. This occurs when external applied energy and potential energy of elastic deformation, separated at destruction, are greater than total energy of interatomic connectionc. If the process of crack formation is stopped than energy components are equal (equilibrium condition) or total energy of interatomic connections is greater than external applied energy and potential energy of elastic deformation (stationary condition). At pulsed cutting of brittle biomaterials there can occur one, two, three and so on equilibrium-stationary conditions when complementary external energy should be applied to complete the cutting process.

For dynamic diagramms $\sigma \sim \varepsilon$ plotting the method(3) based on determination of longitudinal distuebance distribution rate in a sample at various levels of stresses was used. The process of waves distribution within non-linear-elastic, elastic-plastic and brittle media is described by the following equation:

$$\frac{\partial^2 u}{\partial t^2} = a_0^2 \frac{\partial^2 u}{\partial x^2} \qquad (1)$$

where $a_0^2 = \frac{1}{\rho} \frac{d\sigma}{d\varepsilon}$ (2).

Value a_o in expression (2) is the rate of sound distribution in a sample. It is dependant on sample material, namely, on modulus of elasticity $\frac{d\sigma}{d\varepsilon}$ (in elastic area of deformation curve $\frac{d\sigma}{d\varepsilon} = E = const.$) and density - ρ and together with them it is one of the stable physical characteristics of each material. Simultaneously rate of longitudinal disturbance distribution along a rod is determined by the slope of a tangent line to a dynamic curve in the point characterizing the value of disturbance, i.e. $\frac{d\sigma}{d\varepsilon}$ - tangent modulus.

A dynamic modulus of elasticity (E_{din}) for the samples of compact bone tissue extracted from various parts of cattle tubular bones was determined using the ultrasound method. For that purpose diaphysis was divided into 5 zones, each of 3.5×10^{-2}m, starting from a proximal epiphysis. Nine samples of cylindric form ($d = 5 \times 10^{-3}$m $h = (6.0-12.0) \times 10^{-3}$m) were taken from each zone, by 3 samples from lateral, caudal and medial areas of bone cross-section. At the same time samples were made according to three mutually perpendicular directions, that corresponded to the selected system of coordinates: x, y, z(x - a longitudinal axis of tubular bone; y - a radial axis; z - an tangencial axis).

Rate of ultrasound longitudinal waves distribution (a_o) in samples was measured using apparatus DUK-20 at 150 kHz.

Dynamic modulus of elasticity (E_{din}) was determined according to the relation (3):

$$E_{din} = \quad x \, a_o^2$$

where a_o - rate of ultrasound longitudinal waves distribution, m/s;

ρ - bone density, kg/m^3.

Based on the results of calculations mean values of dynamic modulus of elasticity (E_{din}) were obtained for each zone (Fig. 3). The given relationships show that dynamic modulus of elasticity of bone tissue in the medium part of diaphysis has its maximum in the longitudinal direction and minimum in the tangencial and radial directions. In zones adhering to epiphysis there is a tendency to convergence of dynamic modulus of elasticity values of all directions, i.e. compact bone tissue of this areas represents its a material with nonsignificant degree of anizothrophy.

The obtained results have practical value for the development of scientifically substantiated calculation methods for tubular bones epiphysis extraction equipment.

LITERATURE

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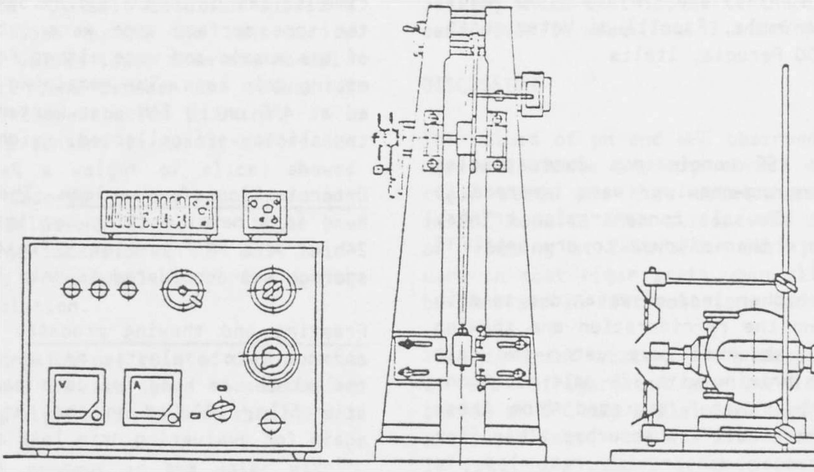

Fig.1. A test rig

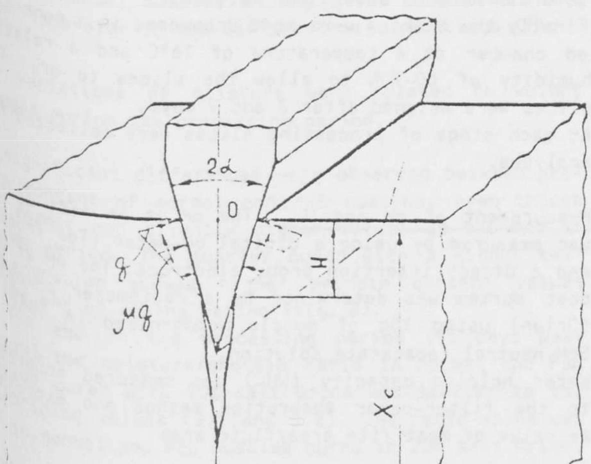

Fig.2. Scheme of biomaterials cutting with advanced crack formation

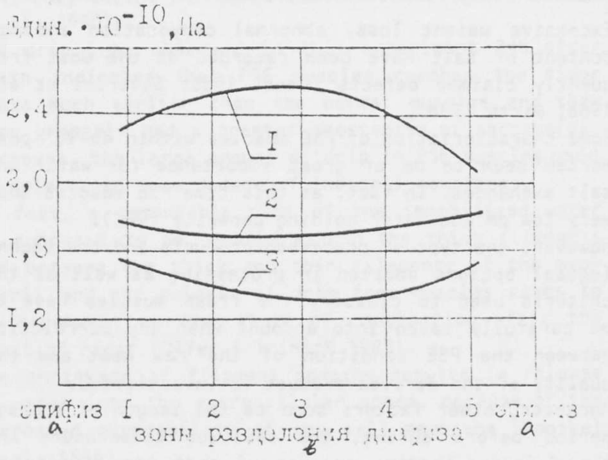

Fig.3. Change of E_{din} of compact bone tissue as related to section and direction in bone diaphysis
1 - longitudinal direction
2 - tangencial direction
3 - radial direction
a - epiphysis; b - zones of diaphysis