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IMPACT OF DEFORMABLE STAMP WITH A MULTILAYERED WALL

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Abstract

In this paper, was performed by numerical work according to the difference scheme. Analysis of the numerical results showed: one of the important issues of contact interaction is to determine the duration of the impact of the colliding bodies. Obviously, under the condition of a hard clutch, sticking of the striker from the barrier will not occur. To study the process of complete breakage of mechanical contact (appearance of separation zones), we will use boundary conditions that simulate a perfectly smooth impact. Analysis of the dynamics of contact resistance has shown that its magnitude and features of evolution over time substantially depend on the geometric and physicomechanical parameters of the deformable system, as well as on the type of boundary conditions. An increase in the acoustic rigidity of the impactor leads to an increase in the amplitude and duration of the impact. The impact of a less rigid punch or the presence in the barrier of a shielding layer of a polymeric material reduces the contact resistance of the plate, but the force interaction between the impacted bodies is longer. As the analysis of the results shows, the evolution of contact stresses is characterized by a number of specific features. For example, there is a direct correlation between the height of the cylinder and the time of its complete detachment from the obstacle, which corresponds to the vanishing of the function $\sigma_k(t)$. An increase in the acoustic rigidity of the impactor leads to a sharp increase in the amplitude of the total resistance and an increase in the duration of the contact interaction. Thus, the contours of the isolines provide a visual representation of the configuration of the areas at which points the stresses develop, immediately preceding the appearance of elastoplastic deformations for spall fractures (for brittle materials).

Keywords: two-dimensional thermoviscoelastic waves, stability of a difference scheme, convergence of a solution of a difference problem, indenter, deformation, stress tensor.

Аңдатпа

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КӨП ҚАБАТТЫ БӨГЕТІ БАР ДЕФОРМАЦИЯЛАНАТЫН ШТАМПТЫҢ СОҒЫЛУЫ

Бұл жұмыста айырымдық схемасы арқылы сандық есептеулер жүргізілді. Сандық нәтижелерді талдау: өзара байланыс іс-қимылының маңызды мәселелерінің бірі болып табылып жатқан денелердің соққы ұзақтығын анықтау болып табылады. Механикалық түйісудің толық бұзылуы процесін зерттеу үшін (үзілу аймағының пайда болуы) тамаша тегіс соққы беретін шекаралық жағдайларды қолданамыз. Байланыс кедергісінің динамикасын талдау оның шамасы мен эволюциясының ерекшеліктері уақыт бойынша деформацияланатын жүйенің геометриялық және физикалық-механикалық параметрлеріне, сондай-ақ шекаралық шарттарының түріне байланысты екенін көрсетті. Соққының акустикалық қаттылығының жоғарылауы амплитуданың ұлғаюына және соққының ұзақтығына әкеледі. Шамалы қатты штамптың соққысы немесе тосқауылда полимерлі материалдан жасалған экрандаушы қабаттың болуы плитаның түйіспелі кедергісін азайтады, бірақ соғылатын денелер арасындағы күштік өзара іс-қимыл ұзағырақ болады. Нәтижелерді талдау көрсетіп отырғандай, түйіспелі кернеулердің эволюциясы бірқатар ерекше ерекшеліктермен сипатталады. Мысалы, цилиндр биіктігі мен оның кедергілерден толық ерекшелену уақыты арасындағы тікелей корреляция байқалады, бұл $\sigma_k(t)$ функцияның нөлге айналуына сәйкес келеді. Екпіннің акустикалық қаттылығының артуы жиынтық кедергі амплитудасының күрт көбеюіне және байланыс әсерінің ұзындығына әкеледі. Осылайша, оқшауланған эпюралар нүктелерінде салқын қираулар үшін (нәзік материалдар үшін) серпімді пластикалық деформациялардың пайда болуының тікелей алдында кернеулер дамитын облыстардың конфигурациясы туралы көрнекі түсінік береді.

Түйін сөздер: екі өлшемді термотұтқырсерпімді толқындар, айырымдық схеманың орнықтылығы, айырымдық есептің шешімінің жинақтылығы, индентор, деформация, тензор, кернеу.

Аннотация

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СОУДАРЕНИЕ ДЕФОРМИРУЕМОГО ШТАМПА С МНОГОСЛОЙНОЙ ПРЕГРАДОЙ

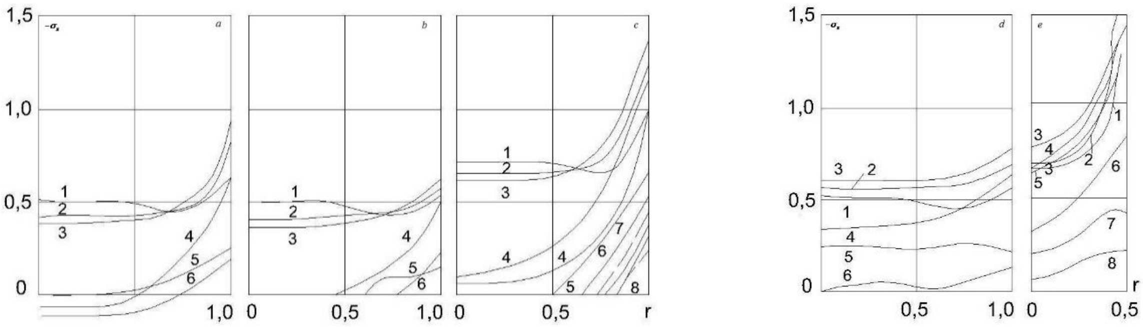
В работе проведены численные работы по разностной схеме. Анализ численных результатов показал: одним из важных вопросов контактного взаимодействия является определение продолжительности удара сталкиваемых тел. Очевидно, что при условии жесткого сцепления отлипания бойка от преграды не произойдет. Для исследования процесса полного нарушения механического контакта (появления зон отрыва) будем использовать граничные условия, имитирующие идеально гладкий удар. Анализ динамики контактного сопротивления показал, что его величина и особенности эволюции во времени существенно зависят от геометрических и физико-механических параметров деформируемой системы, а также от типа граничных условий. Повышение акустической жесткости ударника приводит к увеличению амплитуды и продолжительности удара. Удар менее жесткого штампа или наличие в преграде экранирующего слоя из полимерного материала уменьшает контактное сопротивление плиты, но силовое взаимодействие между соударяемыми телами оказывается более продолжительным. Как показывает анализ результатов, эволюция контактных напряжений характеризуется рядом специфических особенностей. Так, например, прослеживается прямая корреляция между высотой цилиндра и временем его полного отлипания от преграды, что соответствует обращению функции $\sigma_k(t)$ в нуль. Увеличение акустической жесткости ударника приводит к резкому всплеску амплитуды суммарного сопротивления и возрастанию длительности контактного взаимодействия. Таким образом, эпюры изолиний дают наглядное представление о конфигурации областей, в точках которых развиваются напряжения, непосредственно предшествующие появлению упругопластических деформаций для откольных разрушений (для хрупких материалов).

Ключевые слова: двумерные термовязкоупругие волны, устойчивость разностной схемы, сходимость решения разностной задачи, индентор, деформация, тензор, напряжения.

When implementing a difference scheme carried out in [1], the original problem was presented in a dimensionless form. Numerous calculations were carried out to determine the characteristics of the process.

We turn to the analysis of the results.

In Figure 1. r profiles are shown along the normal stress σ_z in the cross section $z = 0$ for a sequence of times with a step $\Delta t = 0{,}5$ (curve I corresponds to $t = 0{,}5; t = 2; t = 1{,}0$, etc.).



a) *b)* *c)* *d)* *e)*

Figure 1.

The spatial profiles in (Fig. 1. *a*) are formed during the elastic collision of a solid aluminum cylinder $R = h_0 = 1$) with a uniform aluminum plate of unit thickness (h=1) under the condition of rigid adhesion of the contacting bodies. At time t=0.5 in the central part of the impactor, the wave process due to direct compression waves is one-dimensional. Due to the occurrence of diffraction fronts propagating from the side surface of the cylinder $r = R$, the stress amplitude at t=1 and t=1.5 slightly decreases in the region adjacent to the axis of symmetry, while in the zone localized near the free boundary a significant concentration of compressive stresses is observed (curves 2 and 3) . The simultaneous arrival on the contact surface z=0 of the discharge waves from the opposite end of the cylinder t=-1 and the rear surface of the barrier t=1 greatly reduces the level of compression stresses and their concentration at the corner point r=1, z=0 (curves 4-6).

The stresses monotonously decrease in amplitude over the entire segment up to the appearance of a zone where they become tensile.

One of the important issues of contact interaction is determining the duration of the impact of the bodies collided. Obviously, under the condition of a hard clutch, sticking of the striker from the barrier will not occur. To study the process of complete breakage of mechanical contact (appearance of separation zones), we will use boundary conditions that simulate a perfectly smooth impact.

In one-dimensional approximation, when the rod strikes an obstacle the rebound moment is determined from the condition that the voltage vanishes at the contact point [2, 3]. In contrast to the one-dimensional theory, a contact surface arises in a spatial problem during collision, with the points of the lower end of the cylinder and the front side of the obstacle being separated from each other non-simultaneously due to the heterogeneity of the wave field along the radial coordinate r. For the moment of complete sticking, it is natural to take the time at which the normal voltage σ_z will vanish on the entire contact area [4, 5].

Note that as a result of interference and interaction of waves of various types with free boundaries, some points of the base of the cylinder, separated from the obstacle, can come into repeated contact.

The condition $\sigma_z \geq 0$ in general is only a condition of sticking. For a complete rebound of the stamp from the obstacle, it is necessary to change the sign of the normal impulse to the opposite one ($\int \rho \vartheta d\Omega < 0$).

If there is no friction at the contact area of the pair $Al_1 \rightarrow Al$ (the index below means the radius of the striker) (see Fig. 1, b), then the general laws of the dynamic version $\sigma_z(r)$ with $t \leq 1{,}5$ are preserved with the only difference that the level of stress localization at the corner point decreases. The expanding region of zero voltages is formed quickly enough, and at time $t = 3{,}5$ the wave development of the process leads to the complete sticking of the punch from the target.

Figure 1. c, presents profiles $\sigma_z(r)$ for the case when the drummer is made of acoustically more rigid material ($Fe_1 \rightarrow Al$). At the moments of time t=0.5, t=1 and t=1.5, and in the vicinity of the axis of symmetry, stabilization of the dynamic reaction is observed, which is mainly due to straight plane waves, and near the corner point there is a pronounced concentration of compressive stresses $\sigma_z(r)$. Higher amplitude values of compression stresses are explained by greater rigidity of iron compared to aluminum. The unloading waves that came to the contact area significantly decrease the voltage amplitudes at subsequent points in time and lead to the emergence of a zone of zero values (this zone originates on the axis of symmetry and expands to the surface).

In the same figure, for the moments of time $t = 2{,}0$, $t = 3{,}0$ and $t = 4{,}0$, the stresses caused by the impact of the iron cylinder on a viscoelastic uniform plate with viscosity parameters $\eta_1 = 3,\ \beta_1 = 1$ are plotted with dashed lines. Taking into account the viscous properties of the target leads to a decrease in normal stresses $\sigma_z(r)$ in the entire contact area, which is explained by the dissipation of energy within the viscoelastic medium. However, this does not cause a significant (advanced) growth of the sticking zone, and the duration of contact interaction remains almost the same as for the elastic barrier.

The evolution of stresses $\sigma_z(r)$ when an aluminum cylinder strikes a layer package $0{,}5Al - 0{,}5Fe$ is represented by the corresponding curves in (Figure 1. d). The effect of the stratification of the barrier compared to a homogeneous plate is an increase of an average of 20% compressive stress, which is caused by the reflection of direct compression waves from the flat interface of dissimilar metals. The distribution of $\sigma_z(r)$ at the contact area when $t \geq 2{,}0$ becomes even more uniform, and a lower concentration of stresses is observed at the corner point.

Figure 1(e) reflects the results for the pair $Al_{0,5} \rightarrow Al$, where the radius of the cylinder is half the thickness of the target plate. The spatial distribution of stresses $\sigma_z(r)$ indicates a significant effect of diffraction waves propagating from the lateral surface r=0.5 increasing the stress concentration at the corner point. The zone of zero values $\sigma_z(r)$ for the considered moments of time is absent, but when $t = 3{,}1$ complete detachment occurs, i.e. there is a more uniform separation of the points of the lower end of the cylinder from the surface of the plate.

To study the dynamics of the stress state in the contact zone and determine the moment of complete sticking, it is convenient to use the integral characteristic $\sigma_k(t) = 2\pi \int_{r_0}^{R} \sigma_z(r,0,t) r dr$ - the total contact resistance of an obstacle to the impact effect of a spinless die. The vanishing $\sigma_k(t)$ of a perfectly smooth shock corresponds to the time of complete breakdown of the mechanical contact, i.e. From this moment on, there is no force interaction between the striker and the slab and their further unsteady deformation occurs independently.

The initial stage of the evolution of contact resistance for different pairs of a drummer-plate is shown in (Figure 2), where $1 - Al_1 \rightarrow Al$ (rigid adhesion on the contact area); $2 - Al_1 \rightarrow Al;$ $3 - Al_1 \rightarrow 0{,}5Al - 0{,}5Fe;$ $4 - Fe_1 \rightarrow Al;$ $5 - Fe_1 \rightarrow Al$ (viscoelastic plate :); $\eta_1 = 3$ $\beta_1 = 1$); $6 - Al_{0{,}5} \rightarrow Al;$ $7 - Al_1 \rightarrow 0{,}5CTKT - B - 0{,}25Al - 0{,}25Pb;$ $8 - CTKT - B_1 \rightarrow Al;$ $9 - 0{,}5Fe_1 \rightarrow 1{,}5Al$ (the height of the drummer is 0.5, and the thickness of the slab is 1.5).

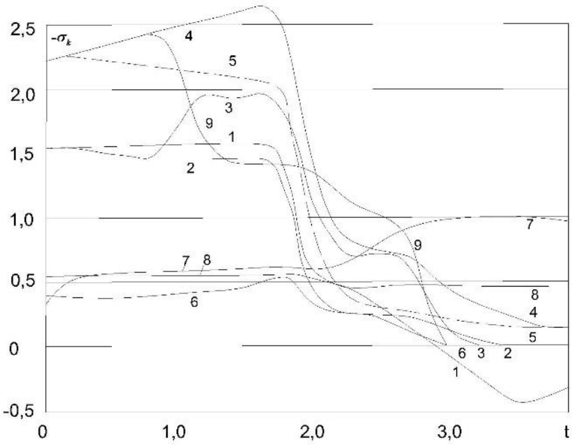


Figure 2.

Comparison of curves I and 2 shows that at the initial stage of interaction, the contact resistance weakly depends on the type of boundary conditions and until the time t=3.0 point the various branches $\sigma_k(t)$ do not differ quantitatively. When t>3.0 in case of hard contact, tensile stresses develop, although small in magnitude. For a perfectly smooth strike the function $\sigma_k(t)$ vanishes at the moment t=3.5, which corresponds to the time of complete disruption of the mechanical contact of the target and the striker (the geometric contact can be preserved). Curve 3 initially completely coincides with curve 2, but from moment t=8.0 due to the redistribution of the impact energy in the layered barrier, the level of values rises sharply $\sigma_k(t)$. A sharp decrease in the contact resistance at subsequent points in time, due to the reflection of compression waves from the free boundaries, leads to its zeroing at (sticking of the impactor).

The impact of the iron punch on the surface of the aluminum plate increases its contact resistance by about 50% compared to the impact of the aluminum striker. On the considered time range $\sigma_k(t) < 0$ and t=4 there is only partial contact disturbance (see Fig. 1, c). Comparison of curves 4 and 5 shows that in the initial phase of the impact up to the point in time t=0.2, the viscous properties of the obstacle do not manifest (there is an instantaneous elasticity of the model), but when t>0.2 there is a noticeable divergence of the curves due to the relaxation of shear stresses and redistribution of normal stress components (ball stress in Maxwell's model does not relax). As already noted, taking into account the dissipation of energy in the plate practically does not affect the duration of the impact. A two-fold reduction in the radius of the cylinder-impactor reduces four times $\sigma_k(t)$ on average (curve 6). The variation $\sigma_k(t)$ for a three-layer metal-polymer plate is characterized by stabilization of amplitude values in the time interval $0 \le t \le 2{,}2$ and when t>2.2 it is replaced by a gradual increase to a value twice the initial amplitude. Compared to a homogeneous aluminum barrier, the contact resistance of a three-layer package in the initial phase of interaction decreases almost three times, however, the duration of the joint deformation of the stamp and plate increases significantly.

Upon impact by the polymer cylinder on the surface of the aluminum plate, the contact resistance initially has a small rise interval, which then quickly stabilizes at a constant level of 0.55. The arrival of reflected extension waves from the rear surface of the barrier only slightly reduces the amplitude $\sigma_k(t)$ to 0.45. The nature of the change in contact resistance when struck with an iron cylinder with a single radius and a height of 0.5 on the surface of a uniform aluminum plate with a thickness of 1.5 is reflected on curve 9. At the initial stage of the impact ($0 \le t \le 0{,}8$), the time dependences of curves 4 and 9 are the same, but an earlier arrival in the cross section z=0 of the reflected from the opposite end of the cylinder waves leads to a sharp decrease of $\sigma_k(t)$, which at the moment t=3.05 vanishes (complete detachment).

Analysis of the dynamics of contact resistance has shown that its magnitude and features of evolution over time substantially depend on the geometric and physicomechanical parameters of the deformable system, as well as on the type of boundary conditions. An increase in the acoustic rigidity $\rho_0 a_0$ of the impactor leads to an increase in the amplitude $\sigma_k(t)$ and duration of the impact. The impact of a less rigid stamp or the presence in the barrier of a shielding layer of a polymeric material (see curves 7 and 8) reduces the contact resistance of the plate, but the force interaction between the impacted bodies is longer.

Graphs in (Figure 3) illustrate the change in time of the total contact resistance of a barrier to the shock effect of a solid iron cylinder with a unit height ($h_0 = 1$) and a radius of 0.5.

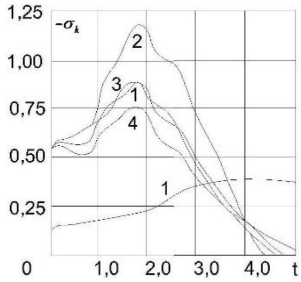


Figure 3.

Curve I refers to a uniform aluminum plate of unit thickness ($Fe_{0,5} \to Al$); 2 - corresponds to the system $Fe_{0,5} \to 0{,}5Al - 0{,}5Fe$; 3 - refers to a two-layer barrier $Fe_{0,5} \to 0{,}5Al^* - 0{,}5Fe$, in which the upper layer is viscoelastic ($\eta_1 = 3\ \beta_1 = 1$); dynamic resistance in the system $Fe_{0,5} \to 0{,}5Al^* - 0{,}5Fe$, with the parameters of viscoelasticity $\eta_1 = 1,\ \beta_1 = 0$ marked with number 4; the contact resistance curve of a three-layer metal-polymer plate ($Fe_{0,5} \to 0{,}5CTKT - B - 0{,}25Al - 0{,}25Pb$) is denoted by 5. (In the conventional symbol for the impactor – obstacle pair, the index below indicates the outer radius of the cylinder; the factor before the designation of the material corresponds to the height of the impactor or the thickness of the layer; an asterisk indicates a viscoelastic material). A distinctive feature of the variation of curves 1–4 is the existence of a pronounced maximum of the contact resistance, which is reached at a time instant t=1.8. The replacement of aluminum with iron in the area $0{,}5 \le z \le 1$ of the barrier increases the peak value of the resistance of the plate to the impact of a stamp by 30%.Accounting for the viscous properties of the upper carrier layer in a bimetallic composition lowers the level of $\sigma_k(t)$, but the duration of the shock interaction increases somewhat compared with the elastic case. For a three-layer packet, the shock pulse strongly stretches over time and the duration of the impact increases significantly. The change in time of the total contact resistance of the plate when interacting with a hollow cylinder is shown by oscillograms in (Figure 4) for various combinations of drummer-barrier:

$$1-Al_1^{0,875}\to Al;\quad 2-1{,}5\,Al_1^{0,875}\to 0{,}5Al;\quad 3-Fe_1^{0,875}\to Al;\quad 4-1{,}5Fe_1^{0,875}\to 0{,}25Al-0{,}25Fe;$$

$5-1{,}5\,Al_1^{0,875}\to 0{,}25Al-0{,}25Fe$ (indices at the bottom and at the top correspond to the outer in the inner radii of the cylinder). At the initial stage of braking of a hollow cylinder, there is a time interval in which the dynamic resistance depends only on the physic-mechanical properties of materials of the colliding bodies and does not depend on their geometry.

Curves in (Figure 5) illustrate the time evolution of the total contact resistance of an obstacle to cylinder impact:

$$1-0{,}5Al_{0,25}\to 1{,}5Al;\ 2-Al_{0,25}\to Al;\ 3-1{,}5Al_{0,25}\to 0{,}5Al.$$

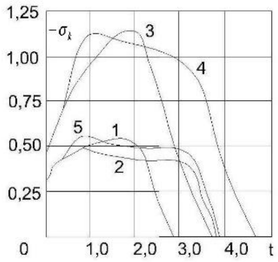


Figure 4.

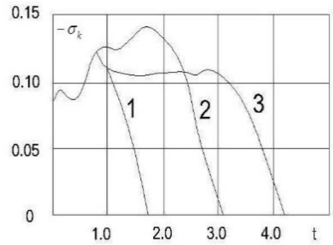


Figure 5.

As already noted, at the point in time at which the function $\sigma_k(t)$ vanishes , there is a complete detachment of the impactor from the obstacle. There is a direct proportional relationship between the height of the cylinder and the duration of the contact interaction.

It is noteworthy that at the initial stage of braking (before the extension waves reflected from the free boundaries on the contact surface) the total resistance does not depend on the geometry of the bodies being pushed. When t>0.8 there is a bifurcation of shock resistance, which for the pair $Al_{0,25}\to Al$ is characterized by the presence of a number of local extremes replacing each other. The change in time of contact stresses is more intense at the beginning and end of the force interaction stage between the cylinder and the plate.

Figure 6 presents the variations in z, the integral characteristics $\sigma_k(z,t)=2\pi\int_0^R\sigma_z(r,z,t)rdr$ at different points in time for the system $Fe_{0,5}\to 0{,}5CTKT-B-0{,}25Al-0{,}25Pb$ (a) and $Fe_{0,5}\to Al$ (b) zero corresponds to: $t=0{,}5;\ t=1{,}0;\ t=2{,}0;\ t=3{,}0;\ t=4{,}0.$

a) *b)*

Figure 6.

The lamination of the structure of the metal-polymer plate causes a decrease in the function gradient $\sigma_k(t)$; at the stage of braking of a solid impactor, the alignment of the numerical values of the integral characteristic is observed, the amplitude of which is twice as low as for a homogeneous aluminum obstacle. In the mechanical system $Fe_{0,5}\to Al$ there are small areas where the material experiences tensile stress on z, while three-layer composition has no such stress. Zeroing of $\sigma_k(z)$ at a point z=0 means a complete breakdown of the mechanical contact between the impinged bodies. For a single-layer slab, the latter takes place at t=4.4, and the duration of a strike with the composite slab is 9.3 (see also Figure 3). The kinetic energy (originally stored in a drummer moving at a constant speed $E_0 = \frac{m_0 V_0^2}{2}$, m_0 is the mass of the cylinder), is transformed in the process of impact into the potential energy of deformations and the kinetic energy of particles of the whole mechanical system, the total energy of which for the case of an elastic medium remains constant in time. Let us denote by E_* the sum of the kinetic and potential energy of the inertia-free striker after its detachment from the slab and we will call the energy transfer as a coefficient of impactor to the obstacle $f^* = I - \frac{E_*}{E_0}$.

Some generalized ideas about the moments of complete violation of mechanical contact t_k and the values of the coefficient f^*. Note that the energy transfer coefficient for a two-layer plate $0{,}5Al - 0{,}5Fe$ is slightly lower than for a single-layer aluminum barrier, with the same collision mode. This means that a smaller part of the energy of the impactor is transferred to the layered structure, and therefore its carrying capacity is often higher than that of structures made of a uniform material. The value f^* at impact of an iron cylinder on an elastic plate is 14% higher than for a viscoelastic target under the same loading conditions. In addition, in a viscoelastic medium, part of the energy is expended on viscous internal friction, which reduces the level of the stress state, as a result of which the impact resistance of the obstacle increases.

Reducing the radius of the impactor has virtually no effect on the energy transfer coefficient, but reduces the total duration of the impact interaction. This indicates a greater rate of flow of energy from the hammer to the plate through the contact area. Very little energy is transferred to a metal target from aluminum when it strikes a striker of polymeric material $CTKT - B$. The function $f(t) = I - \frac{E(t)}{E_0}$ (E(t) - the total energy of the impactor at the moment of time) monotonously increases in the collision interval up to the moment of sticking, starting from which the total energy of the obstacle stabilizes at a constant level. The noted pattern is characteristic of all specified “drummer-plate” pairs. For a three-layer barrier, the coefficient f^* reaches a value of 0.93, but the rate of absorption of the impactor’s energy is significantly lower than in the process of striking a uniform slab. The presence in the mechanical system of three layers with different properties leads to a stretching in time of the shock pulse while maintaining its total value. During the contact interaction of the striker with a metal-polymer plate, a decrease of $f(t)$ is observed in the interval $5{,}0 \le t \le 6{,}1$, i.e. a process of reverse flow of a small part of the energy from the plate into the cylinder hit takes place:

$$f(5) = 0{,}943, \; f(6{,}1) = 0{,}898.$$

Reducing the length of the drummer to 0.5 increases the f^* value and speed of the flow of energy from the drummer to the plate. At the time t=2.0, the value of f(t) is 0.95.

The curves in (Figure 7) represents dependence of radius R on the energy transfer coefficient f^* for three pairs of colliding bodies:

$$1 - Al_R \to Al; \; 2 - Fe_R \to Al; \; 3 - Fe_R \to 0{,}5CTKT - B - 0{,}25Al - 0{,}25Pb.$$

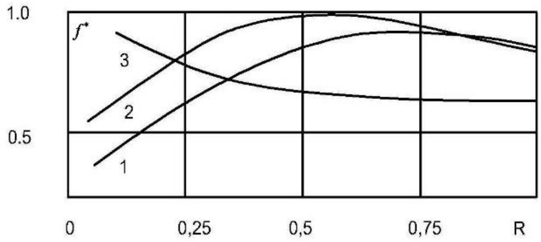
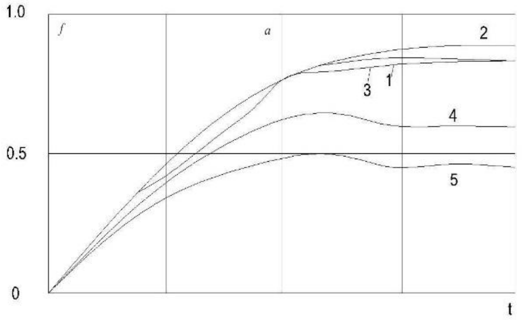


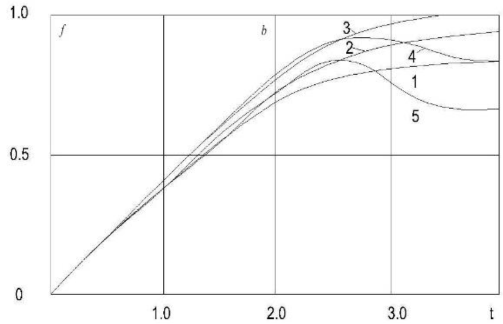
Figure 7.

Noteworthy is the fact that for a homogeneous obstacle, the function $f^*(R)$ first increases monotonically and then decreases. Thus, there is an optimal value for the radius of the impact stamp, at which the maximum amount of energy is transferred to the plate. When $R \approx 0{,}8$, the coefficient of energy transfer to a homogeneous medium does not depend on the rigidity of the impactor. For a three-layer composite plate, the function $f^*(R)$ monotonously decreases at $R \le 0{,}5$, and then stabilizes at a constant level.

Dependencies $f(t)$ for two systems $Al_R \to Al$ (a) and $Fe_R \to Al$ (b) are shown in (Figure 8), where curves 1 - 5 correspond to $R=1;\ R=0{,}75;\ R=0{,}5;\ R=0{,}25;\ R=0{,}125.$



a)



b)

Figure 8.

At the initial time interval, the energy transfer weakly depends on the radius of the cylindrical striker, however, at subsequent points in time, the influence of the parameter is very significant. For both pairs $R \le 0{,}25$, with (curves 4 and 5), the function $f(t)$ monotonically decreases on the interval $2{,}5 \le t \le 4{,}0$. This means that part of the energy flows back from the plate into the cylinder to be hit. Note that the maximum amount of energy (about 90%) is transferred to a homogeneous plate in the case of an impact of an aluminum punch, and for iron striker with a radius of 0.5, the function $f(t)$ reaches 0.995. Thus, for different pairs of impacted samples there is an optimal radius at which the target is reported the largest part of the originally stored energy of the cylinder.

Relations $f(t)$ for $Fe_{0,5} \to 0{,}5Al - 0{,}5Fe$ (curve I); $Fe_{0,5} \to 0{,}5Al^* - 0{,}5Fe$ (2); $Fe_{0,5} \to Al$ (3); $Fe_{0,5} \to 0{,}5CTKT - B - 0{,}25Al - 0{,}25Pb$ (4) are shown on Fig.9. (an asterisk indicates Maxwell's viscoelastic material with parameters $\eta_1 = 1\ \beta_1 = 1$).

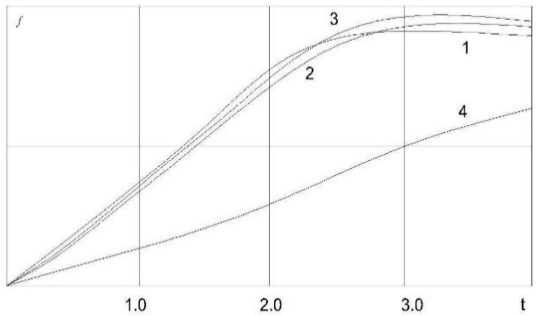


Figure 9.

Comparison of the results shows that at the considered time points the smallest part of the energy is transferred to a three-layer target, the rate of energy overflow is close to constant. For a bimetallic composition (curve 1), the function $f(t)$ monotonically decreases on the interval $3{,}0 \le t \le 4{,}0$, i.e. the energy of the slab is transferred back to the impactor. The viscosity of the material of the shielding layer increases the amount of energy transferred to the two-layer barrier, and reaches its highest value $\max_t f(t)$ when struck with an iron striker on a uniform slab. This means that a smaller part of the impact energy is transferred to the layered structure, and therefore its impact resistance is often higher than that of targets made of a uniform material.

In (Figure 10), in the plane rz for the moment of time t=1.5, the isolines of the intensity of tangential stresses σ_i are shown. This is due to the fact that many materials undergo significant plastic deformations before failure, and equality $\sigma_i = \dfrac{\sigma_S}{\sqrt{3}}$, where σ_s is the tensile yield strength, is often used as a plasticity condition (according to Mises).

The lines of equal values σ_i in (Figure 10. *a*), correspond to the impact of an aluminum cylinder of unit radius on the single plate. At the considered moment of time, the zone of greatest values σ_i is formed near the contact area and in the vicinity of the corner point ($r = 1,\ z = 0$); as the distance from the surface increases $z = 0$, σ_i decreases.

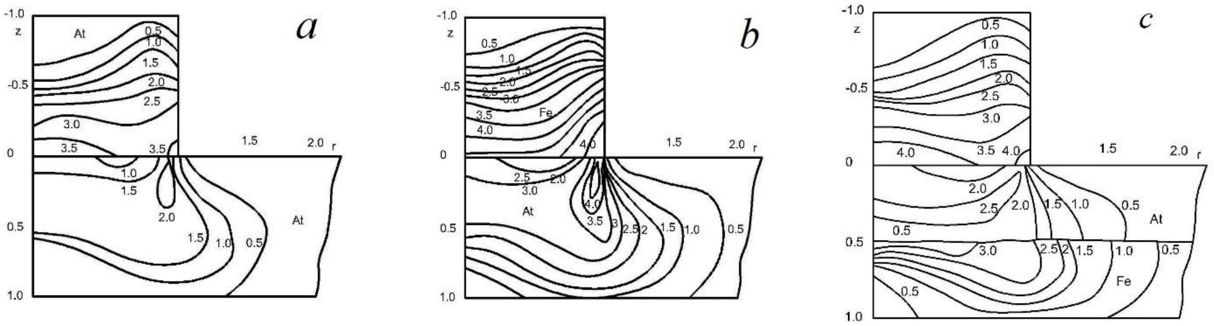


Figure 10.

If an iron drummer of the same dimensions interacts with the surface of a homogeneous aluminum plate (Figure 10. b), then localized zones of high values of the intensity of tangential stresses more clearly appear. The field is $\sigma_i(r, z)$ are characterized by large gradients in spatial variables, and the obstacle material is prone to a faster transition to a plastic state. Isolines $\sigma_i(r, z) = const$ when hitting an aluminum stamp on the surface of a bimetallic plate $0{,}5Al - 0{,}5Fe$ are shown in (Figure 10. c). In the deformable system, two sources of concentration of the intensity of tangential stresses are observed, one of which is located near the corner point, and the other in the vicinity of the plane separating dissimilar to metal layers. Note that in all cases analyzed here, the maximum σ_i is located in the impactor, which is associated with the dispersion of the impact energy in the horizontal direction by an obstacle.

Thus, the contours of the isolines σ_i provide a visual representation of the configuration of the areas at which points the stresses develop, immediately preceding the appearance of elastoplastic deformations for spall fractures (for fragile materials).

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