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DEFORMATION ENERGY OF VEHICLES IN ROAD TRAFFIC ACCIDENTS

In this work, a method of determining the deformation energy of vehicle structural elements deformed as a result of a traffic accident has been developed, as well as a method of determining the deployment parameters of vehicle airbags is given.

The determination of the energy of deformation in the structural elements of vehicles during road traffic accidents (RTAs) plays a significant role in understanding collision mechanisms and the consequences of damage. One factor influencing the deformation of vehicles is the change in metal hardness due to deformation.

One way to determine the energy of deformation is to analyze the change in metal hardness due to deformation. Applying hardness measurements to damaged vehicle components provides information about the level of deformation, reflected in the change in material hardness.

To perform such measurements, portable hardness testing devices are often used, which can directly measure the metal hardness at the accident scene. These devices are based on various measurement methods, such as indentation methods or rebound methods. The obtained data on the change in metal hardness are used to calculate the energy of deformation. With this information and the use of appropriate mathematical models, it is possible to determine the energy absorbed by the material during deformation. This deformation energy is an indicator of the extent of damage and mechanical impact experienced by the vehicle.

Estimating deformation energy is critical to understanding the mechanisms of road traffic accidents (RTAs) and their consequences. It can help establish collision forces, vehicle speeds, and other parameters necessary for accident investigation. In addition, the determination of deformation energy can be used to assess the safety of vehicle structures and develop measures to improve their stability and protect passengers. The combination of several methods allows you to refine the energy absorption coefficients in computing programs.

Keywords: *road traffic accidents (RTAs), deformation energy, structural safety, metal hardness, airbag.*

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ЕНЕРГІЯ ДЕФОРМУВАННЯ ТРАНСПОРТНИХ ЗАСОБІВ ПРИ ДТП

В даній роботі розроблено методику визначення енергії деформації елементів конструкцій транспортних засобів, здеформованих в результаті дорожньо-транспортної пригоди, а також наведено методику визначення параметрів розкриття подушок безпеки транспортних засобів.

Визначення енергії деформації конструктивних елементів транспортних засобів під час дорожньо-транспортних пригод відіграє важливу роль у розумінні механізмів зіткнення та наслідків пошкоджень. Одним з факторів, що впливає на деформацію транспортних засобів, є зміна твердості металу внаслідок деформації.

Одним із способів визначення енергії деформації є аналіз зміни твердості металу внаслідок деформації. Вимірювання твердості пошкоджених компонентів транспортного засобу дозволяє отримати інформацію про рівень деформації, що відображається у зміні твердості матеріалу.

Для виконання таких вимірювань часто використовують портативні прилади для вимірювання твердості, які можуть безпосередньо вимірювати твердість металу на місці аварії. Ці прилади базуються на різних методах вимірювання, таких як метод індентування або метод відскоку. Отримані дані про зміну твердості металу використовуються для розрахунку енергії деформації. Маючи цю інформацію та використовуючи відповідні математичні моделі, можна визначити енергію, поглинуту матеріалом під час деформації. Ця енергія деформації є показником ступеня пошкодження та механічного впливу, якого зазнав транспортний засіб.

Оцінка енергії деформації має вирішальне значення для розуміння механізмів дорожньо-транспортних пригод та їх наслідків. Вона може допомогти встановити силу зіткнення, швидкість транспортних засобів та інші параметри, необхідні для розслідування ДТП. Крім того, визначення енергії деформації може бути використано для оцінки безпеки конструкцій транспортних засобів та розробки заходів щодо підвищення їх стійкості та захисту пасажирів.

Ключові слова: *дорожньо-транспортні пригоди (ДТП), енергія деформації, транспортний засіб, безпека конструкцій, твердість металу, подушка безпеки.*

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Introduction

Road accidents and traffic safety are urgent issues that hold significant importance for society. Every year, thousands of people become victims of road traffic accidents (RTAs), and this problem remains one of the most pressing issues in many countries. Understanding the causes and circumstances of RTAs is a key element in developing effective measures for prevention and reducing accident rates.

One of the most critical aspects of investigating RTAs is determining the speed of vehicles during the incident. Information about speed plays a crucial role in establishing the causes and details of collisions, as well as in determining liability. Accurate speed data is an essential component for legal proceedings, insurance claims, and the development of enhanced road safety strategies.

Analysis of research and publications

Traditional methods of determining speed, such as braking indicators, witness statements, and information about vehicle damage, are often not precise or conflicting. Therefore, in recent years, increasing attention has been given to the use of advanced technologies and methods for the objective and accurate determination of vehicle speed [1].

With the implementation of new technologies and methods, determining the speed of vehicles, taking into account structural damage, has become possible. This approach is based on the analysis of mechanical damage and deformations that occur on vehicles during road traffic accidents (RTAs). One of the main methods used to determine speed considering damage is the analysis of damage to structural elements of the vehicle. It is based on the idea that the scale and nature of damage can be related to the energy generated during a collision. After an RTA, detailed investigations of vehicle damage are conducted, including the body, frame, engine, and other essential components. By using photographs, measurements, and analyzing mechanical characteristics of damage, conclusions can be drawn about the minimum speed of the vehicle during the accident [1-4].

Another approach to determining speed, taking into account damage, involves the use of accident dynamics modeling. This method involves creating a computer model that reproduces the physical properties of the vehicle, its movement, and collision. The model takes into account the parameters of damage resulting from the RTA, and based on this data, the possible speed of the vehicle before the collision is calculated [2].

To create accurate models, data from experimental studies, real road traffic accidents (RTAs), and engineering calculations considering the physical properties of materials, vehicle construction, and other factors are utilized [5-8]. The use of computer programs allows for precise modeling of RTA dynamics and determining speed based on input data about damage.

However, it is important to note that determining the speed, considering the damage to the vehicle, is a complex process that requires high qualifications and expert analysis. To obtain the most accurate results, many factors need to be taken into account, including the type of vehicle, its mass, structure, and construction, as well as the specific details of the accident.

Therefore, determining the speed of vehicles, taking into account structural damage, is a crucial element of RTA investigations. The use of damage analysis methods and dynamic modeling provides objective speed data during accidents, valuable information for establishing the causes and liabilities of RTAs.

During an RTA, when a vehicle undergoes a collision, energy is transferred to its structural elements, leading to metal deformation. Depending on the intensity and type of collision, the metal changes its hardness, serving as the so-called "material memory" [3].

In conclusion, determining the energy of deformation in the structural elements of vehicles during RTAs through changes in metal hardness is an important step in understanding the mechanisms and consequences of accidents. This information assists in assessing the extent of damage, estimating collision force and vehicle speed, and developing measures to enhance the safety and stability of vehicles.

The purpose of this work is to develop a methodology for determining the deformation energy of vehicle structural elements deformed as a result of a traffic accident, as well as a methodology for determining the parameters of vehicle airbag deployment.

Research results

Determination of deformation energy of vehicle structural elements in road accidents

According to the methods described in [1, 3, 4], the costs of plastic deformation and fracture of vehicle structural elements were determined by measuring the hardness using a portable hardness tester "Temp-3" and calculated using the formula

$$W_{sp} = W_0 \, exp \, \frac{ln \, k_H / D}{C}, \tag{1}$$

where W_{sp} – is the specific potential energy in J/cm^3, $W_0 = \frac{\sigma_{0.2}^2}{2E}$ – is the elastic specific potential energy in J/cm^3, $\sigma_{0.2}$ – yield strength of the material in MPa, E – is the modulus of elasticity of the I degree in MPa.

D and C in formula (1) are the coefficients of the curve approximation $k_{HT} = f(k_W)$.

The value W_{sp} was also calculated using the formula

$$W_{sp} = \int_0^e \sigma_u d\varepsilon_u, \tag{2}$$

where σ_u – is the stress intensity in MPa, ε_u – deformation intensity (dimensionless value).

The curve $\sigma_u = f(\varepsilon_u)$ in the theory of plasticity is called the only flow curve that does not depend on the type of stress state. It is approximated by the equation

$$\sigma_u = A\varepsilon_u^n. \quad (3)$$

Then, substituting (3) into (2), we obtain

$$W_{sp} = A\int_0^e \varepsilon_u^n d\varepsilon_u = A\frac{\varepsilon_u^{n+1}}{n+1}, \quad (4)$$

where A, n are the coefficients of approximation of the flow curve that have a physical meaning: A – yield stress (in MPa) at strain intensityε_u= 1, n – the degree of deformation corresponding to the maximum load on the conditional tensile diagram.

The value ε_u in formula (4) was determined in each case either by hardness (k_H) or by the diagram of plasticity and stability [1, 3].

The data on material properties were obtained by identifying the material properties following [4].

According to this work, the initial yield strength $\sigma_{0.2}$ (MPa) is put in accordance with the initial hardness H_{T0}, following the equation

$$\sigma_{0,2} = B + 0{,}33H_{T0}, \quad (5)$$

where the coefficient B when measuring hardness with the Temp-3 hardness tester is equal to B = 176. The initial yield strength $\sigma_{0.2}$ is put in accordance with the coefficient of approximation of the material flow curve, following the equation

$$A = 1000\exp(-0{,}0008\ \sigma_{0,2}), \quad (6)$$

where A is the approximation coefficient of equation (3).

The coefficient n in formula (3) for various materials used in the automotive industry is in the range of $0.1 \le n \le 0.35$ and can be found from the equation

$$n = 0{,}35\exp(-0{,}0008A). \quad (7)$$

The value of W_{sp} obtained by formulas (1) and (2) was multiplied by the volume of the deformed metal of the structural element, which made it possible to calculate the value of the total potential deformation energy

$$W_{def} = \Sigma(W_{sp})_i \cdot V_i. \quad (8)$$

The influence of the velocity effect on the plastic deformation was taken into account according to the methodology described in the work [3].

This paper shows that a significant increase in the deformation rate for structural elements made of different steel grades leads to an increase in energy consumption. A material model sensitive to velocity effects was used in the study. Thus, the approximation coefficient of the flow curve A (see formula (3)) can vary depending on the deformation rate, following the equation

$$A_V = A\left[1{,}045 + \frac{ln(0{,}0027+\dot{\varepsilon}_u)}{135}\right]. \quad (9)$$

The coefficient n in formula (3) varies with the deformation rate, following the relation

$$n_V = n\,exp[-0{,}1273\,ln(1+\dot{\varepsilon}_u)]. \quad (10)$$

In formulas (9) and (10), A_V – the approximation coefficient of the flow curve that takes into account the effect of the deformation rate; $\dot{\varepsilon}_u$ – the rate of deformation intensity; n_V – the degree index that takes into account the effect of the deformation rate; A and n are the approximation coefficients of the flow curve constructed without taking into account the deformation rate (quasi-static deformation).

Determining the parameters of airbag deployment in vehicles In a collision with a fixed barrier

The main physical phenomenon in a car collision during an accident is an impact, in which there is an instantaneous change in the velocities of different points of a solid body (system of bodies). The reason for this change is the immediately applied force *F(t)*. The duration of the impact is denoted by τ (Fig. 1).

The action performed by a force on a body is determined by its shock impulse

$$S = \int_{tz}^{tz+\tau} F(t)dt. \quad (11)$$

The impact process is usually divided into two phases. The first phase is the compression phase, which lasts from the moment $t = t_z$ of the beginning of the impact to the moment $t = t_u$, in this phase the impact force *F(t)* monotonically increases from zero to its maximum value. The second phase is the recovery (restitution) phase, which lasts from time $t = t_u$ to time $t = t'_z = t_z + \tau$, in this phase the force *F(t)* decreases to zero (at the end of the period τ).

In the case of a car hitting a stationary barrier, the loss of speed is calculated by the formula

$$\Delta V = \frac{S}{m} \quad (12)$$

or

$$\Delta V = \frac{F_{sp}\cdot\tau}{m} = \frac{W_{def}\cdot\tau}{a\cdot m}, \quad (13)$$

where $F_{sp} = F_{in}$, a – shifting of the front part of the car, W_{def} – energy consumption of a longitudinal impact, τ – time of the shock pulse, which varies within $0{,}07 \le \tau \le 0{,}14$.

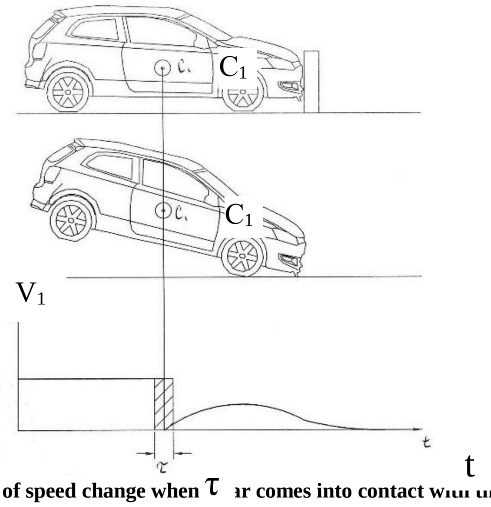

Fig. 1. Diagram of speed change when τ ar comes into contact with the barrier

The limit value for the loss of speed ΔV_{cp} above which the airbags are triggered is $\Delta V_{cp} \geq 5{,}6$ m/s.

Some automobile manufacturers take the deceleration of the vehicle (acceleration of the reverse sign) as a parameter for airbag deployment.

The deceleration j of a car is determined by the following relationship

$$j = \frac{\Delta V}{\tau}. \quad (14)$$

The limit value of vehicle deceleration at which the airbags must deploy is $j = 3g = 29.5$m/s^2.

Determining the direction of impact in case of an accident

To determine the direction of the main deforming force, the data on the hardness of the car hood were processed.

Fig. 2 shows the isolines of equal hardness, stress intensity, and strain intensity found by us from the hardness distribution [1, 3, 4]. Consider the isohardness line whose value corresponds to the hardness H_T = 420 units.

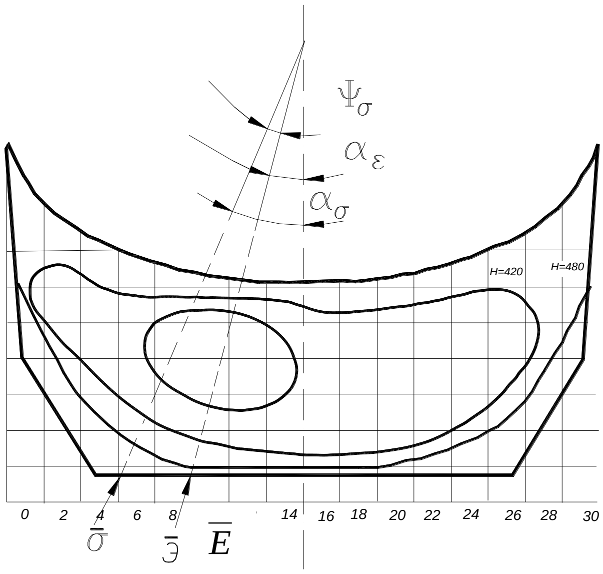

Fig. 2. Hardness isolines on the car hood

According to the graduation chart we built for steels used in the automotive industry (the correction for initial hardness allows us to link to the material used to make a car hood), this hardness number corresponds to a strain rate of ε_u = 0,16.

The line perpendicular to the tangent to the isohardness line H_T = 420 units determines the direction of the main displacements of the hood metal.

This determines the direction of displacement (normal to the isohardness line of accumulated strain intensities) α_ε.

However, this does not mean that the main deforming force acted at the specified angle.

Due to the fact that the hood material acquires strain anisotropy as a result of plastic deformation, it is necessary to take into account its effect on the degree of misalignment of the vector $\overline{\sigma}$ (stress vector, coinciding in our case with the vector of the main deforming force) with the deformation vector $\overline{E}$ (deformation vector, in our case corresponding to the angle α_ε). To find the angle of misalignment ψ_σ between these vectors, we refer to [1, 3].

In work [3], a methodology for calculating the angle of misalignment of the vectors $\overline{\sigma}$ and $\overline{E}$, based on the postulates of A. A. Ilyushin, was developed. Following this work

$$tg\psi_\sigma = \frac{\sqrt{3}\cdot\left(\sqrt{1+\frac{4}{3}tg^2\phi_\sigma}-1\right)}{1+3\cdot\sqrt{1+\frac{4}{3}tg^2\phi_\sigma}}, \tag{15}$$

where ϕ_σ is the angle between the major axis and the vector $\overline{\sigma}$

$$tg\phi_\sigma = \frac{\tau_u}{\overline{\sigma_u}}, \tag{16}$$

where τ_u – intensity of tangential stresses at the degree of deformation $e_u = const = 0{,}16$ accepted by us as the main isolation of the accumulated deformations of the hood material, $\overline{\sigma}_u$ – stress intensity (equivalent stress for a material with anisotropic strengthening). In our case, the flow curve of an isotropic material is described by equation (3).

For an anisotropic material, the approximation of the flow curve is as follows [3]

$$\overline{\sigma_u} = \frac{(1+\beta_m)+(1-\beta_m)\,exp(-100\varepsilon_u)}{2}A\varepsilon_u^n, \tag{17}$$

where β_m is the Bauschinger parameter determined experimentally in [3] and for steels of type 08kp, as well as a number of other materials, it is β_m= 0.3.

Thus, the direction of the deforming force is determined by the angle

$$\alpha_\sigma = \alpha_\varepsilon + \psi_\sigma. \tag{18}$$

If the direction of the main deforming force falls within ±30˚ of the longitudinal axis of the vehicle, this should ensure that the front airbags in the vehicle deploy.

Conclusions

A methodology for determining the deformation energy of vehicle structural elements deformed as a result of a traffic accident has been developed, and a methodology for determining the parameters of vehicle airbag deployment, namely, loss of speed, deceleration, and direction of impact, has been presented. The limit values of these parameters are given, which should ensure the opening of airbags.

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