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Identification of composite materials at high speed deformation with the use of degenerated model

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Analysis and modelling

ABSTRACT

Purpose: Composite materials on account of some their characteristics have application in a construction of ballistic shield. An example of the ballistic shield is laminate with the mix-structure materials such as layer pressed of aramid cloths on matrix polymer. Because of the shield's assignment the aramid cloths are exposed to impact loads caused by an energy made by impact force of cumulated mass (bullet). Previous analyses of the effect are based on linear-elastic reaction of resisting forces between the materials of a bullet and a shield. The article exemplifies the procedure of mechanical properties analysis in the punch effect of the ballistic shield with the use of some of the non-elastic models.
Design/methodology/approach: In the article the theoretical analysis of punch effect in the quasi-static load condition based on some of the degenerated models is also presented.
Findings: The results of the analysis make aware of demand for designing safety ballistic shields.
Research limitations/implications: The main conception was optimum material selection (composite) that has to be done according to the theoretical analysis, which is based on non-elastic models selected in the context of velocity and mass of punching bullet.
Practical implications: Application of the complex degenerated model allows to define more characteristics of the punching process of the ballistic shield. Determination of the effect of energy impact dissipation causes material damage of the ballistic shield is enabled to do because of implementation of boundary conditions.
Originality/value: Based on the boundary conditions of energy in the way of changing parameters of model we are able to describe non-destructive deformation process.
Keywords: Computational mechanics; Impact load; Impact; Composites

1. Introduction

The ballistic shields are multilayered structures composed of material combination with the proper strength properties. The combination involves such materials as aramid cloths. Energy dissipation of punching bullet of small arms is the main issue. Efficiency of the shields first of all depends on construction assumption and their design. Identification process based on models implementation of dissipated energy effect of mass unit impact has particular meaning in effective shields designing.

In majority of studies [1-4] a material is perceived as viscoelastic where constitutive compounds have the main influence on the material. In that example the mechanical properties such as velocity of deformation, temperature of the material, deformation type, make up an essential part of the material. Apart from this, the authors of [5-9] study present different points of view on the modeling process. In the examining case the way of material identification should be based on proper selected non-elastic models presented in the study [10-13]. Optimum selection of material (composite) should be done taking of theoretical analysis based on proper selected non-elastic models depending on velocity and mass of the bullet into consideration. Optimization of designing process of efficient ballistic shield should be carried out according to the following pattern: strength testing +theoretical model $\rightarrow$ material properties.

2. Problem description

Identification of material properties with the use of proper selected degenerated model is based on material punching in quasi-static test with constant punching velocity. The assumption is that in the time t=0 mass of bullet m achieves velocity v_0 and impact energy $E_0 \frac{mv^2}{2}$. For t>0 the bullet is under braking force S whose properties characteristic depend on material selected for the shied and its construction support. The force properties S are changed rapidly from the time when critical value h defined as yield point is achieved.

In according to the model presented in the Fig. 1. the assumption should concern two deformation phases:

a) Non-destructive deformation phase ($u<u_{gr}$),
b) Destructive deformation phase ($u>u_{gr}$),
where: u_{gr} – defines boundary displacement of impact mass with the result of material destruction.

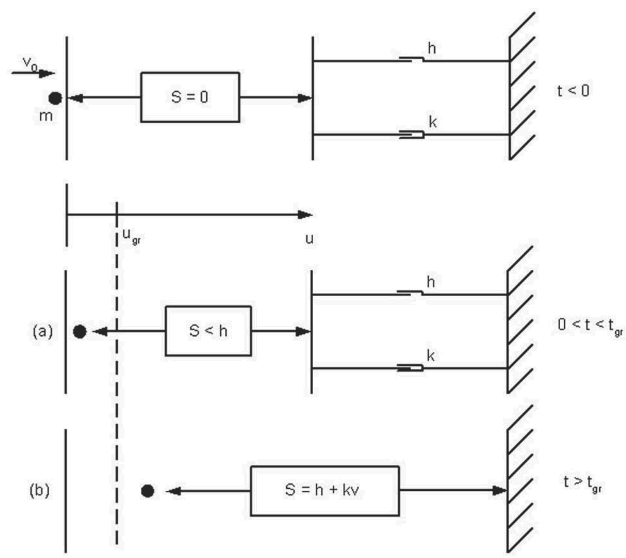

Fig. 1. Diagram of punching process: a) non-destructive deformation phase, b) destructive deformation phase

In the process the phase (a) is very important because when the value of u_{gr} is increasing we are able to eliminate destructive action of the material. It is obvious for ideally elastic materials where S=cu for $u<u_{gr}$. In the real materials the reaction force S of the bullet material is usually defined as velocity function $\dot{u}$ as well. In that case the more difficult the way of eliminating destructive action of material is, the more complicated the dependence $S(u,\dot{u})$ is. The dependence $S=S(u,\dot{u})$ comes from experimental characteristics obtained by static and quasi-static research (Fig. 2.).

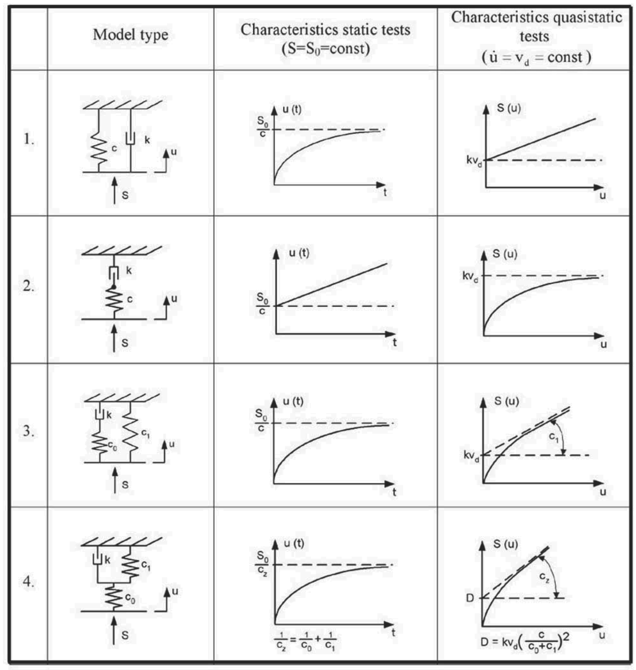

Fig. 2. Static and quasi-static characteristics for chosen rheological models

The form of the characteristics usually obtains by using simple analysis of the differential equation in two of the following cases:

a) static load $S=S_0$=const – static characteristics,
b) changing load S(t) where deformation velocity of a sample is constant $\dot{u} = v_d$ =const – quasi-static characteristics.

Models (1), (2) describe sudden reaction of the configuration what practically in case of real materials never happens. It is essential for rapid impulsive impact where the time of the process is particularly short and the action is close to t=0 may have decisive influence on all process.

Besides, in all of suggested models the quasi-static characteristics essentially depend on proper deformation velocity v_d, what always happens in the case of strength testing of real materials. From that point of view for the next analysis the model 3 is chosen because the behavior of model 4 is similar.

3. Analysis of degenerated models in the quasi-static tests

3.1. Analysis of model with Zener element

Analysis of the punching process is based on model 3. In the punching tests according to the model and study [12-13] with the constant dry friction h it was assumed that run of static increasing forces till the point of flowing process of the material. The maximum allowed deflection u_{gr} can be calculated using the following pattern:

$$u_{gr} = \frac{h}{c_1} \tag{1}$$

In analysis of model 3 configuration in the range of deflection $u \in (0, u_{gr})$ the following assumption are:

a) the bullet moves deep into the material till the point when the kinetic energy E_0 is not balanced by physical work of material reaction forces S,
b) mass of the bullet (and complete shield's parts weight) at the selected form of model 3 determines vibration of the bullet inside the material where amplitude and free vibration of the frequency also depend on the following constants c_0, c_1, k_0.

Consequently the construction condition of the safety ballistic shields comes down to comply with the following demands:

1) Material selection (with the constants c_0, c_1, k_0) for the reduction of impact energy E_0 in the following range of deflection $u \in (0, u_{gr})$,
2) If we can not comply with the demand no. 1 part of energy ΔE is equal:

$$\Delta E = E_0 - \int_0^{u_{gr}} S du \tag{2}$$

The energy must be reduced in the non-destructive process of the material. In that case constants c_0, c_1, k_0 should be selected for minimum of ΔE what we can calculate using the following pattern:

$$E_{gr} = \int_0^{u_{gr}} S du = \max \tag{3}$$

It is when the above integral achieves maximum possible value

3) Bullet movement deep into the material of shield till the point t_{gr} of destructiveness is described by sinusoidal function that amplitude $u(t_z)$ decreases for $k_0>0$. For $t>t_{gr}$ (force $S>h$) there is stable destructive effect of material and than bullet movement is not defined.

In accordance with analysis of demands above and study [9] we can determine $u<u_{gr}$ with the use of following relations:

– force S and displacement u(t):

$$S(u) = k_0 v_d + c_1 u - k_0 v_d e^{-\eta u} \tag{4}$$

– physical work caused by force S(u) and displacement $u \in (0, u_{gr})$:

$$E_{gr} = \int_0^{u_{gr}} S du = c_1 \frac{u_{gr}^2}{2} + k_0 v_d u_{gr} - \frac{k_0^2 v_d^2}{c_0}\left[1 - e^{-\eta u_{gr}}\right] \tag{5}$$

3.2. Analysis of model with Maxwell element

Conception of model's analysis comes down to use of nonlinear elastic element in the model in the parallel configuration of Maxwell type element.

It was assumed that in the punching process to the boundary value of u_{gr} deformation u(t) reaction of shield's material is the same as nonlinear Mexwell element model (Fig. 3.).

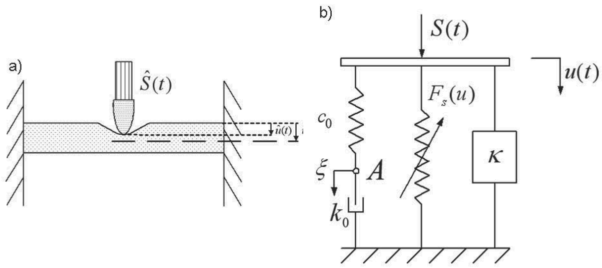

Fig. 3. Diagram of accepted configuration (b) simulating punching process of a material (a) for $u<u_{gr}$

It was assumed that when the deformation crosses a boundary ($u>u_{gr}$) the material is in irreversible processes of the destruction described by rheological model what not the main point of the article is.

But a way to select constants k_0, c_0, κ and function $F_s(u)$ of the model is essential that the boundary energy described by the pattern:

$$E_{gr} = \int_0^{u_{gr}} S(u) du \tag{6}$$

achieves the maximum value. As a result of it the rest of the energy $\Delta E = \frac{mv^2}{2} - E_{gr}$ (as minimum) causes minimum of the stable material deformation and at the same time its damage. It was assumed that the impact force S(t) is equal to resisting force of the material and it is a sum of 3 following summands:

$$S = S_1 + S_2 + S_3 \tag{7}$$

where: $S_1(t) = F_s(u)$ – force of non-linear ideally elastic element;
$S_2 = \kappa \dot{u} u^2$ m – force of mixed unit (it is assumed that this type of reaction in pondering topic may happen);
S_3 – force from the Maxwell element.
Equation of motion of configuration form:

$$S = c_0(u - \xi) + F_s(u) + \kappa \dot{u} u^2 \tag{8}$$

$$k_0 \dot{\xi} = c_0(u - \xi) \tag{9}$$

where: $\xi(t)$ – variable (non-measurable) describing the massless motion of point A. After the analysis of the equation of motion based on study [14], any function $F_s(u)$ has a solution in the form of:

$$S(u) = F_s(u) + \kappa v_d u^2 + k v_d \left(1 - e^{-au}\right) \tag{10}$$

where constant „a" is:

$$a = \frac{c_0}{k v_d} \tag{11}$$

It is noted that when the punching velocity v_d approaches zero only function of elasticity $F_s(u)$ describes the quasi-static characteristic S(u).

It is assumed that punched material behaviors as selected model in the first destructive deformation phase (fig. 3b) the value of the following estimators $\hat{c}_0, \hat{c}_1, \hat{c}_3, \hat{\kappa}, \hat{k}$ based on experimental approximation $\hat{S}(\hat{u})$ from the function (10) may be calculated. The estimators describe properties of the punched material in a selected range of deformation u and velocity v_d. Analyses on algorithms in that range by each of the authors are in progress ([15] Su=κvu, Fs(u)=cu and non-linear dumping instead of damping k_0).

4. Conclusions

As a result of the analysis it is noted that safety of ballistic shield increases when:

a) the minimum of the static stiffness of the ballistic shield (constant c_1);
b) the maximum of the dynamic stiffness of the shield (constant c_0);
c) suitable selecting of constant k_0 – description of energy reduction;
d) increase value of punching boundary force (constant h).

Besides, the analysis allows to observed that complex dynamic model in a degenerated form presented by the authors may be use for determination of the punching process description in the range of non-destructive deformation. That configuration can be use for any non-linear ideally elastic reactions (any form of the function $F_s(u)$). Apart from this, model's specifications of the punching process (constants c_1, c_3, κ, k, c_0) are not depended only on the type of material but on construction design as well. Consequently research of quasi-static punching for many other materials and different boundary conditions with the use of presented model will be continued in order to develop versatile identification method.

References

[1] J.K. Kim, T.X. Yu, Impact response and dynamic failure of composites and laminate materials, Part 2: Strain-Rate Effect, Energy Absorption and Modeling, Trans Tech Publications Ltd. Switzerland, 1998.

[2] P.D. Smith, R.C. Laible , Ballistic materials and penetration mechanics, Elsevier Scientific Publishing Company, Amsterdam-Oxford-New York, 1980.

[3] H.M. Wen, T.Y. Reddy, S.R. Reid, P.D. Soden., Indentation, penetration and perforation of composite laminates and sandwich panels under quasi-static and projectile loading, Key Engineering Materials 141-143 (1998) 501-552.

[4] A.L. Yarin, I.V. Roisman, K. Weber, V. Hohler, Model for ballistic fragmentation and behind –armor debris, Israel Institute of Technolog, Israel, 1999.

[5] A. Buchacz, Calculation of characteristics of torsionally vibrating mechatronic system, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 327-330.

[6] A. Buchacz, Sensitivity of mechatronical systems represented by polar graphs and structural numbers as models of discrete systems, Journal of Materials Processing Technology 175 (2006) 55-62.

[7] A. Buchacz, Influence of a piezoelectric on characteristics of vibrating mechatronical system, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 229-232.

[8] A. Buchacz, The expansion of the synthesized structures of mechanical discrete systems represented by polar graphs, Journal of Materials Processing Technology 164-165 (2005) 1277-1280.

[9] L.A. Dobrzański, R. Honysz, S.D. Fassois, On the identification of composite beam dynamics based upon experimental data, Journal of Achievements in Materials and Manufacturing Engineering 16 (2006) 114-123.

[10] M. Kulisiewicz, S. Piesiak, M. Bocian, K. Jamroziak, The deformation analysis of the composite material based on specific nonelastic material, The Issues of Development, Production and Maintenance of Weapon Systems 95 (2005) 197-206 (in Polish).

[11] K. Jamroziak, M. Bocian, M. Kulisiewicz, S. Piesiak, Application of degeneration model at a nonlinear loads of elastic element in identification dynamic properties of machine elements in puncture. Trends in the Development of Heavy Duty Machines, Technical Journal of Politechnika Krakowska, Kraków 1-M (2006) 139-146 (in Polish).

[12] K Jamroziak, Analysis of a degenerated standard model in the piercing process, Journal of Achievements in Materials and Manufacturing Engineering 22/1 (2007) 49-52.

[13] K Jamroziak, Process of description piercing when using a degenerated model, Journal of Achievements in Materials and Manufacturing Engineering 26/1 (2008) 57-64.

[14] K. Jamroziak, M. Kulisiewicz and others, Construction of multi-layer subject under impact loads. Modeling and experimental verification. Part. 1, Model and quasistatic test, Wroclaw WSOWL, Report 2003 (in Polish).

[15] M. Kulisiewicz, The way of determine the mechanical characteristics of materials, notification of patent number P383077 from day 6.08.2007.