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The comparison of numerical simulation of projectile interaction with transparent armour glass for buildings and vehicles

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ABSTRACT

In the paper, results of a research project based on the numerical simulation of projectile interactions with transparent armour glass for protected objects such as banks, houses of important person or VIP vehicles and of cores in the anti-terrorist systems for the civil population protection (such as barrier around Eiffel Tower) as per STANAG 4569 AEP-55, Volume 1, are presented. The research was concerned with the impact of projectile interaction on the life cycle of transparent armour glass. The study investigated the scope of damage, the delamination of individual layers of transparent armour glass and the depth of projectile penetration at Protection Level 2 [PARTIAL] (7.62 mm × 39 API BZ) and Level 3 (only projectile 7.62 mm × 54R B32 API) at the temperatures of −32 °C, 20 °C and 55 °C. Using the Finite Element Method (FEM), a transparent armour glass simulation model was created for multihit by two projectiles at a predefined distance. For the purpose of calculation, the LS-Dyna explicit solver was employed allowing the evaluation of theoretical numerical models reliability for a specific application of a projectile (pressure wave) impact on an assembly composed of multiple materials.

1. Introduction

Transparent armour glass is a significant element of objects of high importance as banks or houses of VIP persons or its cars. Windows shall allow the user safe view from a building while meeting the protection criteria defined for a particular ballistic protection level. In view of these requirements, suitable transparent armour glass for a specific application shall be selected based on the knowledge and understanding of brittle material failure mechanisms. [1]. Due to a great variability of possible transparent armour glass arrangements, it is practically impossible to solely rely on experiments.

Thus, reliable numerical simulation methods shall be applied. The efficiency of these methods depends on the reliability of created material constitutive models as well as failure criteria; in addition, a whole number of other relating issues also plays its part.

When analysing the reliability of armoured glass in buildings and also VIP vehicles, degradation of transparent armour glass in the form of a non-transparent white layer on the armour glass surface was observed. (Fig. 1). The phenomenon developed after approx. 3 years of use in the different geographical areas with different climatic conditions such as Central Europe, Central Asia or south of the Africa. The numerical simulation of the impact of projectile interaction on the life cycle of transparent armour glass had to be carried out in the temperature range corresponding to the climatic conditions in which the building is build.

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Fig. 1. Transparent armour glass after 3 years of use at Central Asia.

2. Behaviour of impact-loaded materials

In the framework of the research, material constitutive models used in numerical simulations of high-speed dynamic events were explored. The numerical analysis is based on the search for a particular problem solution within a selected set of entities while maintaining theoretical physical relations [2].

The behaviour of materials under high pressures has been a subject of scientific studies since the 19th century, when numerous measurements of the behaviour of slowly-, or even statically-loaded materials were made. The process occurring in a body exposed to impact loading differs to a great extent from that occurring in a statically or quasistatically-loaded material. Therefore, research into the effects of impact loading has also been carried out simultaneously.

An important difference in the behaviour of statically- and dynamically-loaded materials lies in the character of the material strain. With the static or quasistatic strain, there is a static equilibrium at any moment of the process while the sum of all forces acting on any part of a body is very close to zero [3].

Nevertheless, when the strain acting on a body from outside is very quick, one part of the body is stressed while another part is still unloaded. In other words, stress within a body moves at certain rates, called waves, and these rates can be determined. That is why the dynamic strain includes stress waves or stress pulses propagation, via which all force effects are transferred into bodies, and the influence of inertial forces shall also be taken into consideration.

Methods and accelerating devices have been developed in order to identify material parameters for constitutive equations used in numerical simulations of armour impact-loaded by a projectile. In the chapters below, the constitutive models employed are described. The material parameters used in the numerical simulations were obtained at the temperature of 20 °C [4,5].

2.1. Viscoplasticity

Viscoplasticity is a theory in continuum mechanics that describes the rate-dependent inelastic behaviour of solids. Rate-dependence in this context means that the strain of the material depends on the rate at which loads are applied. The inelastic behaviour that is the subject of viscoplasticity is plastic strain which means that the material undergoes unrecoverable strain when a load level is reached. Rate-dependent plasticity is important for transient plasticity calculations. The main difference between rate-independent plastic and viscoplastic material models is that the latter exhibit not only permanent deformations after the application of loads but continue to undergo a creep flow as a function of time under the influence of the applied load [6].

For metals and alloys, viscoplasticity is the macroscopic behaviour caused by a mechanism linked to the movement of dislocations in grains, with superposed effects of inter-crystalline gliding. The mechanism usually becomes dominant at temperatures greater than approximately one third of the absolute melting temperature. However, certain alloys exhibit viscoplasticity at room temperature (300 K). For polymers, wood, and bitumen, the theory of viscoplasticity is required to describe behaviour beyond the limit of elasticity or viscoelasticity [7].

2.2. Johnson-Cook model (JC)

The most commonly used constitutive equation describing the behaviour of impact-loaded metals is the Johnson-Cook model:

$$\sigma_y(\varepsilon_p, \dot{\varepsilon}_p, T) = [A + B(\varepsilon_p)^n][1 + C\ln(\dot{\varepsilon}_p^*)][1 - (T^*)^m] \quad (1)$$

where ε_p is the equivalent plastic strain, $\dot{\varepsilon}_p$ is the plastic strain-rate and $\dot{\varepsilon}_p^*$ is the normalized strain-rate calculated as:

$$\dot{\varepsilon}_p^* = \frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_{p0}} \quad (2)$$