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Armour repair optimized by means of numerical simulations

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ABSTRACT

The paper deals with a possibility of the local repairing of damaged composite armours. The proposed repairs can be performed directly in the field, allowing thus to recover the full ballistic protection in a short time. Several solutions (temporary or permanent) were designed and tested both experimentally and using numerical simulations. Overlapping of the damaged area with patch from armour steel after filling the hole with ceramic balls showed to be optimal as a temporary repair. The calculation clearly showed that the depth of penetration of the projectile is reduced in all cases of designed permanent repairs in comparison to original armour configuration. The experiments confirmed supposed enhancing of ballistic resistance, but only some repair techniques met the requirements of multi-hit testing. However, the reason of failure after multi-hit could be clearly explained with the help of used numerical simulations.

1. Introduction

Nowadays development of a modern ballistic protection is focused on research in area of special materials and their combinations concerning improving ballistic properties of an armouring and reducing its mass as well. Of course, the price of the protection solution should be reflected from the other point of view.

However, in case of ballistic attack the armour usually lose the functionality and the standard procedure involves the replacing of the damaged armour with the new one. This approach is expensive (high costs of new armours) and time-consuming (ordering, delivery and mounting) and, moreover, the military vehicles cannot be used during this period due to the reduced level of armour protection.

With regards to all those reasons we started to deal with a possibility of the local repairing of a damaged composite armours. To our best knowledge, up to date only little attention was paid to the thorough research of armour repairing, whether temporary or permanent. A few technical reports papers or patents describe repair technique utilizing patches either from armour steel [1] or with composite structure [2,3]. Another type of repair involved the removal and replacement of all the destroyed layers [4,5], however high demands for technological equipment necessary for the repair preclude a common use.

The repair techniques, which are the subject of present study, are specifically designed to be performed directly in the field with the help of tools available on military bases, allowing thus to recover the ballistic protection in a short time.

More specifically, the proposed repair technique could be divided into two basic types. The first one is fast and simple overlapping of damaged area with patch from armour steel feasible directly in the battlefield and could be designed as temporary. The second one involves removing of damaged parts and replacing with spare parts, which requires the special equipment of the workshop to ensure high quality repairs. However, this type of repair restores the original armour ballistic resistance and the design.

To summarize, the aim of the work is designing of repair techniques suitable for repairs directly in the field and/or on military bases and their subsequent ballistic testing. Optimization and verification of methods will be performed also with the help of numerical simulations. The confirmation of the reliability of used simulations may in the future generate significant cost savings, whether by the design of new armour configuration or by their repairs.

2. Theory and calculations

Any investigation in ballistic protection should be based in good knowledge of a behaviour of all suitable materials and their combinations. It should be supported by many kinds of real experiments and presently many types of numerical simulations. A combination of numerical simulations supported by continuous experiments

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process enables to asses many historically well-known models of material behaviour during an armour and projectile interaction [6].

There is a significant difference in behaviour of materials during static or dynamic loading. A quick deformation during the dynamic loading can stress some part of a body earlier than a rest of this body.

The required numerical model is described by a geometrical shape and a theoretical material model based on set of material constants [6]. The behaviour of metal materials is usually described by the constitutive equation so called Johnson–Cook material model [7,8]. The flow stress is defined as relation (1):

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

where A, B, C, n, m are material constants, ε_p is effective plastic strain, T^* is homologous temperature.

Constitutive equations of standard brittle materials can be found in wide range of accessible literature [9,10]. The most common brittle material used in vehicle armouring—alumina—can be successfully used in front layer of the armour sandwich as a demolisher of the projectile. An investigation of interaction between the projectile and ceramic layers presents an influence of a ceramic stiffness decreasing during process with high velocity deformation. This stiffness loss is caused by small micro plastic deformations related to small micro fracture in ceramic material. The Johnson–Holmquist material model [11] was used in numerical simulations of the ceramic materials.

Besides that, some absorption materials such as cellular polymers were used in some analyzed armour configurations. The main goal of this layer in ballistic and anti-mine resistance simulations is absorbing of the impact wave impressed on the armour assembly. The cellular material placed in armour assembly is soft with low density. A stress versus volumetric strain curve was measured in set of experiments. Next, this relation was implemented in numerical material model of the cellular polymer. This model from Sandia research laboratory is convenient exactly for cellular materials with low density. This model is similar to so called Crushable-Honeycomb material model but a pressure of air inside the cellular structure is implemented according the relation (2)

$$\sigma_{ij} = \sigma_{ij}^{sk} - \delta_{ij}\sigma^{air} \quad (2)$$

There is a variety set of measurements methods and hardware setups, which are suitable to get some unknown constants required in related constitutive models [6,11]. The high strain-rate characteristics of a specific energy absorbing material can be measured e.g. by Split Hopkinson Pressure Bar apparatus (SHPB).

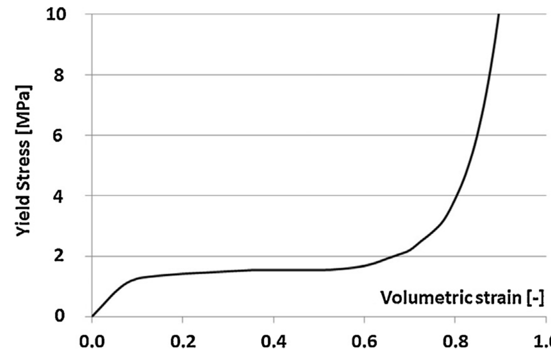

Fig. 1. Yield stress–volumetric strain dependence of cellular polymer from the used armour structure.

According to the wave propagation theory, the stress and the particle velocity associated with a single wave can be calculated from the associated strain measured by the strain gages. This method can be performed during a pressure loading and tensile or torsion loading as well.

SPHB experimental method was used during investigation of material constants of ballistic laminates implemented in armour configurations. The experimental results enable to define stress–strain relation of the analyzed materials. The value of the strain rate can be defined as well, see Fig. 1. The strain recorded on both measuring bars (front and rear) can be used in evaluation of the absorption value of analyzed material.

3. Experimental

For repair techniques design, the armour configuration used by the Army of Czech Republic was chosen, namely additional composite armour with protection level K3 according to STANAG 4569 (with base armour from armour steel with a hardness of 500HBW and nominal thickness of 7 mm). Areal weight of add-on composite armour is 49 kg/m^2 and thickness 23 mm. The composite add-on panel consists of ceramic layer (alumina) supported by two layers of special cellular polymer.

The damage of armours was carried out using gun-barrel with diameter 7.62 mm and projectile 7.62 mm × 51 AP (WC core)—threat of protection level K3 according to STANAG 4569. The samples were mounted in the test rig. The projectile impact velocity was measured by the light screen in the distance of 2.5 m from the target. After the tests and demounting of the armours the depth of projectile penetration and the damage of ceramic layer were

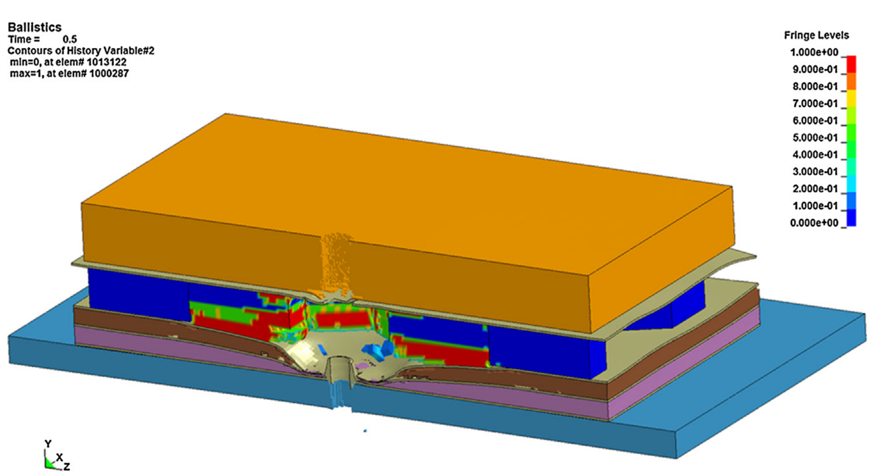

Fig. 2. The calculated penetration of projectile in case of temporary repairs with patch thickness of 16 mm.