23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

ANALYSIS OF CERAMIC-METALLIC COMPOSITES OF BALLISTIC RESISTANCE ON SHOTS BY 5.56 MM AMMUNITION

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Abstract: *This paper presents a portion of the work focused on the development of innovative, lightweight composite materials with the prospect of constructing modern ballistic shields. The aim of the study was to determine the reinforcement of the ballistic resistant materials by the introduction of Al_2O_3 particles in the aluminum alloy matrix. Tests were performed on composites prepared by compression in a liquid-state based on an alloy of AC-44200 with the addition of Al_2O_3 particles. Produced materials were tested on the ballistic test field, subjecting them to shots of 5.56 mm by a Beryl rifle, Polish production. Damaged materials were subjected to metallographic analysis and identification of the destruction process. From the presented analysis and test results, we can conclude that tested materials with the participation of interpenetrating phases: plastic (matrix) and fragile (reinforcement) can be an attractive alternative to currently used materials.*

Keywords: Composites, Fracture Mechanics, Mechanical Properties, Cermets, Ballistic Impact.

1. Introduction

The progress of materials science is focused on the search for new material solutions. In this context the energy-intensive materials play a significant role, their objective is primarily to disperse as much impact energy as possible. In this regard, military technologies take an important part. Based on analysis (Hazell, 2006) it is shown that in the second half of the twentieth century, there was a significant increase in the participation of innovative composite material sets in the production of ballistic protection systems. In this way, mobility of military vehicles and the passive safety of the crews were highly increased (Hogg, 2003). Constant competition between the development of projectiles and armor drives the progress in search of different solutions. Understanding the mechanisms of the destruction of ballistic structures or their weight reduction (Abrate, 2009 and Demir et al., 2008) allows the development of better and more efficient ballistic shields. In earlier work authors (Bocian et al., 2015) sought optimal solutions of material composition while describing the mechanism of destruction of composite structures considering mathematical models.

In this study, the main focused is on materials which parameters are characterized as ballistic ceramic but with improved mechanical properties. In this way, the process of searching for effective ballistic shielding, which are resistant to penetration by rifle bullets containing hard cores, as a replaced for steel armor can be performed.

2. Recognition of the problem

The process of fracture in the ceramic material is related to fracture propagation. Scheme of the destruction for critical conditions at released energy are presented in the form:

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$$G_{IC} = \frac{(1-\nu^2)K_{IC}}{E} = 2\gamma_F \tag{1}$$

where: γ_F – surface fracture energy, E – Young's modulus, ν – Poisson's ratio, K_{IC} – brittle fracture toughness.

Microcracks in the ceramic structures are accompanied by absorption of part of the energy by fracture propagation, identified in the equation:

$$\gamma_F = \gamma_0\left(1-\frac{d}{d_s}\right)+\gamma_p \tag{2}$$

where: γ_0 – surface fracture energy of polycrystalline in the absence of microcracks for $d \leq 1$ μm, d_s – grain size at which there is a spontaneous development of a fracture.

The energy absorbed by the microcracks (γ_p) identified in the equation:

$$\gamma_p = qW_p \tag{3}$$

where: q – number of microcracks per unit of area, W_p – average energy absorbed by one microcrack.

In this case, the process of destruction of the material is related to the kinetic energy of the projectile. It was assumed that the overall energy of the projectile is converted into plastic deformation of the projectile and into the process of material fracture. If the projectile is fragmented it must be taken into consideration in the equation as fragments velocity.

Thus, the deformation energy can be written as the product of force and displacement:

$$U = \int_{L_0}^{L} F dl \tag{4}$$

where: L_0 – length/initial diameter, L – length/final diameter, F – force used for deformation, U – work done per unit of material volume to achieve strain, it is equal to the area under the strain curve – on the assumption that v_{mat} = const.

3. Objective and scope of the study

Tests were done on newly developed material based on aluminum AC-44200 containing ceramic particles of Al_2O_3 (Kurzawa et al., 2015). Materials prepared for the study contain 20 % and 40 % of reinforcing particles in their volume. Samples prepared for firing had a cylindrical shape of a diameter of 120 mm and a height of 14 mm (Fig. 1). Due to the different reinforcing particle content materials had a hardness of 70 HB to 150 HB. Samples were shot with 5.56 mm SS109 ammunition according to the methodology specified by the standard (CEN EN 1522). Destroyed samples (Fig. 2) were subjected to metallographic examination and the analysis of impact energy absorption. This paper attempts to describe the process of damage development and attempts to determine the work necessary to destroy the sample

Fig. 1: A general view of a cermet sample.

Fig. 2: Sample after firing.

4. Results and analysis

The results of ballistic tests were registered as the records of the sample destruction process. Based on the analysis of the destruction process and the models described in the literature (Feli et al., 2010 and Nayak et al., 2013) with the focus of comparing effective work of destroying the material to such an extent as to maximize dispersion of the impact energy in a layer at the cermet front, provided for a multi-layered ballistic shield (projectile blunting, its fragmentation) and increase the local absorption-area of this energy in the composite layer based on fibrous materials (Kevlar, Twaron, etc.). Based on the research and the observation of measured velocity of the projectile by the means of the Doppler Weibel SL-525PE radar, parameters at the time of the collision were estimated, change in the speed after hitting the target and its change in volume (Fig. 3).

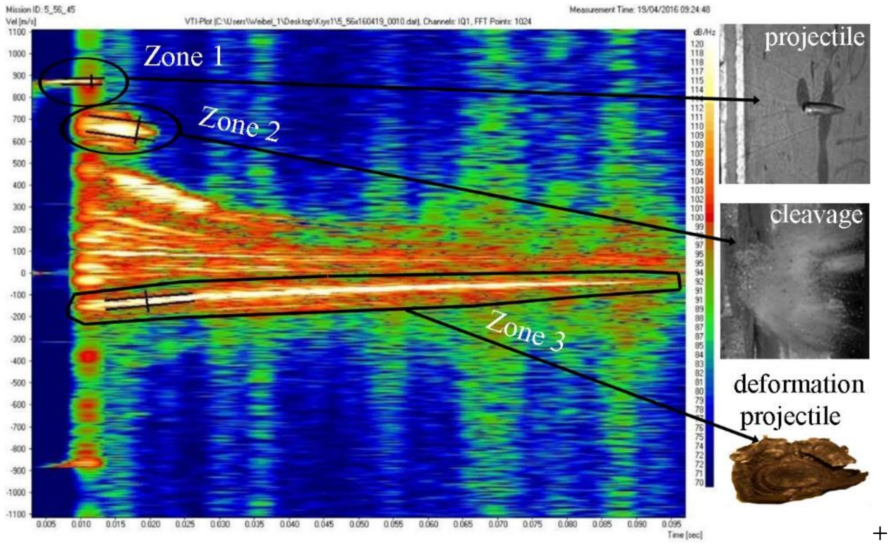

Fig. 3: Image of the projectile velocity obtained in the WinDopp software with projectile fragments for a sample of AC-44200 with 30 % of Al_2O_3.

From charts obtained by the radar field range, the size of the deformed projectile can be specified. For the sample containing 30 % of alumina, a projectile of a diameter of 5.56 mm defines a trace of 1.5 mm width (Zone 1), and measuring traces for the fragments on the graph (9.5 mm) an outlet diameter of 35 mm is obtained (Zone 2), as confirmed by visual inspection of the sample (e.g. see Fig. 2). The bandwidth for the deformed projectile is 3.5 mm (Zone 3), which gives a distorted field of 12.5 mm. By estimating the size of the projectile deformation it is possible to estimate the amount of dispersed energy in the process of energy absorption by the tested sample. The sample surface in the vicinity of major fractures that occur as a result of firing as well as breakthrough fracture are subjected to metallographic examination. SEM images were used for the description of the mechanics of the samples destruction after projectile impact. As shown in Fig. 4 as a result of acting forces the sample will fracture in a perpendicular direction to the projectile path. Fracture is a type of a mixed breakthrough with a predominance of a brittle fracture. Observations indicate that the destruction of the material follows the outline of Al_2O_3 particles and it was less likely to fallow the reinforced particle. Within damaged area a slight plastic flow of the material also occurs, as indicated by the distribution of the reinforced strip regions of the sample in a direction parallel to the trajectory of the projectile (Fig. 5). Such a deformation occurs mainly in composites of 20 % by volume, of Al_2O_3 particles. The advantage of brittle fracture is observed in samples of 40 % by volume of reinforcing particle.

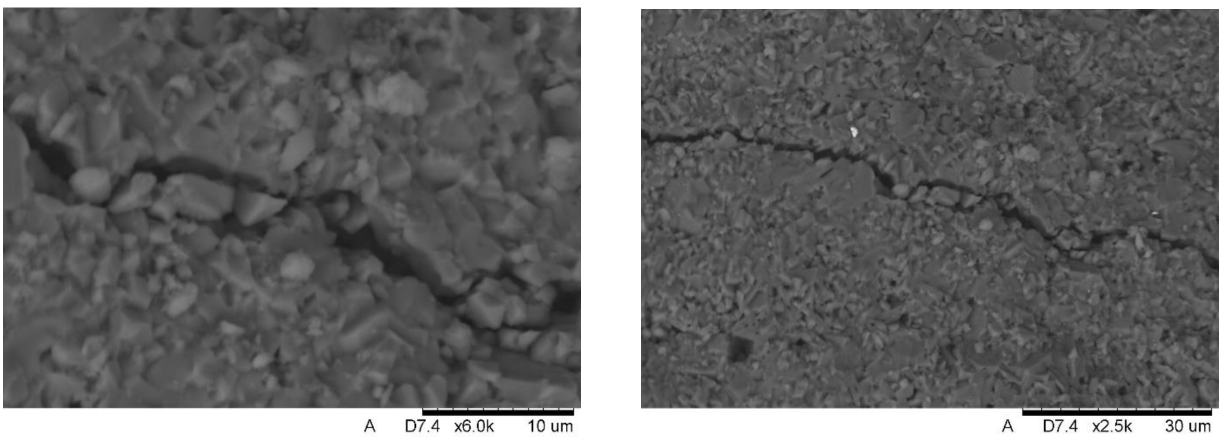

Fig. 4: The process of fracture propagation in AC-44200 with 40 % of Al_2O_3.

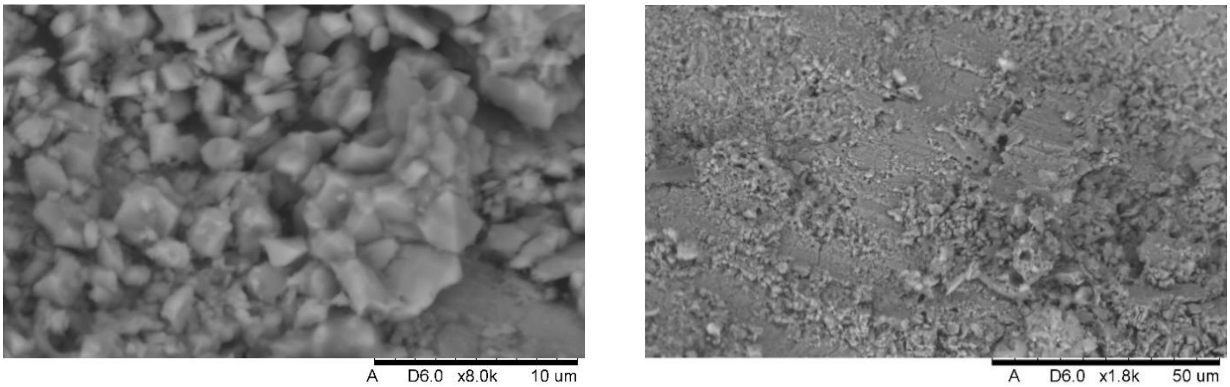

Fig. 5: Fracture of a sample after firing containing AC-44200 with 40 % of Al_2O_3.

5. Conclusions

The study attempted to determine the energy-intensity of a metal-ceramic material composite produced by a compression of the liquid, subjected to fire with an ammunition of 5.56 mm diameter. As it is shown, the introduction of 20 % reinforcing particles by volume to the AC-44200 alloy causes approx. 28 – 31 % impact energy dispersion. Increasing the volume of Al_2O_3 particles to 40 % alters the impact energy dispersion to the range of 47 – 50 %. This represents an approx. fivefold increase in impact energy dispersion capacity when compared with the pure non-altered AC-44200 alloy, which decelerates the impact energy only by approx. 8 – 10 %. After examination, such a large reduction of kinetic energy is associated with 2.5 fold increase in hardness of the composite material (40 % of Al_2O_3 by vol.) with respect to the base material.

Resulting materials reveal a reduction in mass in comparison to the conventional alumina ceramics by approx. 10 – 14 %. However, in comparison to a popular ballistic material of a boron carbide the mass is still higher by approx. 20 – 21 %. Therefore, application of the proposed materials for ballistic shields brings the desired shields weight reduction and reasonable economic factors.

Mechanical aspects of fracture creation during the firing based on the brittle fracture has a significant effect on the scattering of high energy concentration points at the contact of shield-projectile. At the time of impact occurs a fragmentation of the samples, which may preferably influence the further process of dispersion of kinetic energy, e.g. in combination with layers of ballistic laminates imposed on the test sample. Therefore, in the further work the authors will present studies of applying the composite metal material in combination with ballistic laminates. The authors are also predicting conducting a research on bullets containing armor piercing cores.

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