NUMERICAL SIMULATION OF THE PENETRATION OF 7.62 AP PROJECTILES INTO CERAMIC ARMOURS

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The paper deals with the numerical simulation of the experimental set up for the ballistic testing. This experimental arrangement represents a modification of the methods described in MIL-STD-376A which is appropriate for ballistic resistance testing against long-rod KE projectiles. A production of so large samples of advanced ceramics is actually very expensive (for some materials even beyond present technological possibilities). In this context, the configuration of target for testing the resistance against 7.62 ammunition has been adopted. The following materials were considered: AlN, AlON, alumina, titanium diboride, glass ceramics, Pyrex glass, aluminosilicate glass, soda lime glass and borosilicate glass. The numerical results are compared with some preliminary experimental results.

INTRODUCTION.

In the last few decades, non-metallic materials, such as ceramics and composites, have been increasingly incorporated into efficient lightweight armours. Lightweight armour design and analysis has been approached from all three analysis angles, namely: empirically, analytically, and numerically. Numerical models, based on solving all the governing equations over a spatial grid at successive time increments, have proven to be valuable design tools since they can help achieve a comprehensive understanding of the ballistic impact process. A number of numerical models simulating the ballistic impact process on two-component ceramic–metal and ceramic–composite armours have been published since the early 90s [1-5].

In the present study we have focused on the numerical simulation of some experimental arrangement which can be used for the investigation of the ballistic efficiency of ceramics and other brittle materials like glasses. This experimental set up enables to use of the very small specimens. This is very desirable because production of large specimen of advanced ceramics is very expensive and sometimes impossible from the technological point of view.

EXPERIMENTAL SET UP.

Schematic drawing of the target is shown in Figure 1 together with its photo . Considering the dimensions of described components, the ceramic samples are typically in the form of cylinders with the height of 7 mm and the diameter 35 - 50 mm (the width of the polycarbonate Lexan is 3 mm). The outer diameter of the frame around the sample is 90 mm, the height being 10 mm. The height of the backing cylinder is 80 mm and the diameter 90 mm.

Two different projectiles have been considered :

1. 7,62 x 54 R API B32. The core of this projectile is made from steel. The impact velocity was taken as 854 m/s.
2. 7,62x51 AP8 NAMMO. The core of this projectile is made from tungsten carbide. The impact velocity was taken as 930 m/s.

In finite element modelling of dynamic events (e.g. impact processes or manufacturing processes such as high speed cutting) three basic material models are needed: (1) An equation of state (EOS) which relates the density (or volume) and internal energy (or temperature) of the material to pressure. (2) A constitutive relationship which describes the strength of the material by relating the stress in the material to the amount of distortion (strain) required to produce this stress. (3) A failure model to specify the material failure behaviour.

Our research involves the following materials :

1. The alloy Al 2024 – T351 – backing block in Fig.1
2. Polycarbonate (Lexan) – see Fig.1
3. AlN, AlON, glass ceramics, Pyrex glass, soda lime glass, borosilicate glass – materials for the ballistic testing
4. WC Alloy – core of the NAMMO projectile
5. High strength steel – core of the 7,62 x 54 R API B32 projectile

The detail description of the material properties are given e.g. in [6].

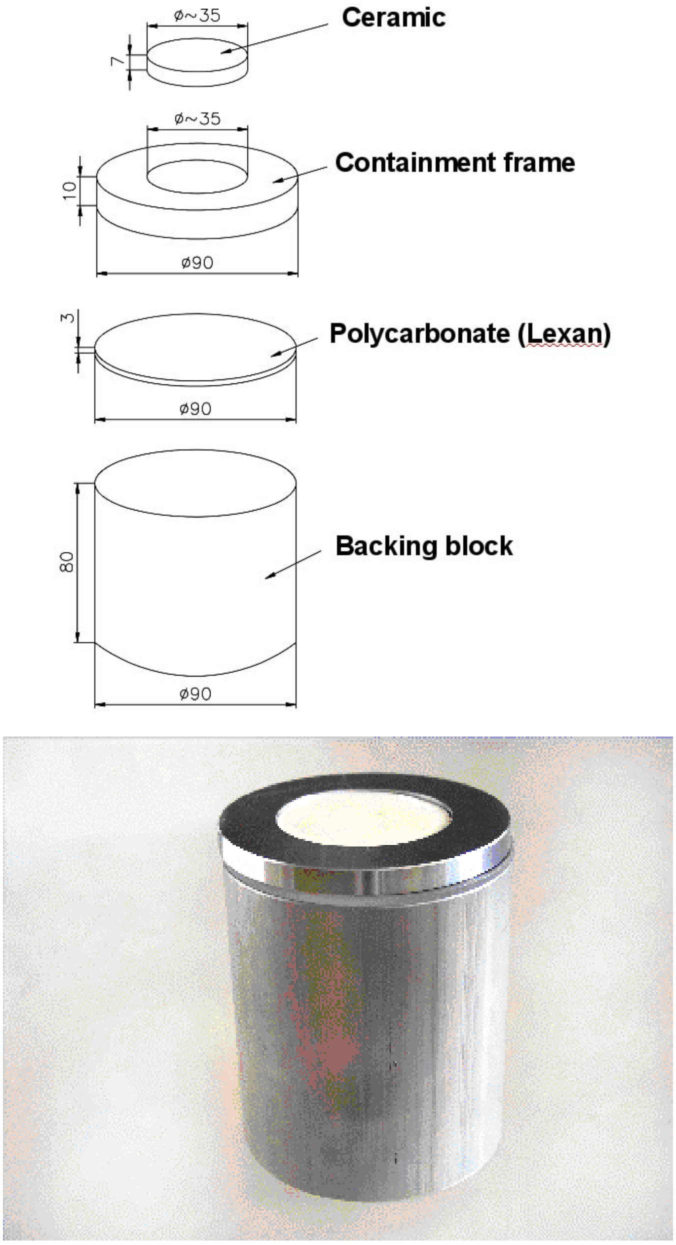

Figure 1. Schematic drawing of the Depth of the Penetration (DOP) experimental set up together with its photo.

In the next step the failure criteria of the considered materials have been specified. For the materials considered in this chapter two criteria are taken into consideration. One of them is the criterion of the maximum principal strain. According to this criterion the failure of the materials occurs if

$$\varepsilon \geq \varepsilon_{\max}$$

Where ε is the maximum principal strain and ε_{max} is the principal strain at failure. From the experiments we have fond that the principal strain at the failure did not depend on the kind of the projectile . The values of these strains are given in Table 1.

Table 1. Maximum strain at the failure

MATERIAL	Polycarbonate	Al 2024 – T351	Steel
CRITICAL STRAIN (1)	0.36	1.26	1.20

The failure of the remainin materials is described according to the criterion of the maximum of the principal stress :

$$\sigma \geq \sigma_{\max}$$

where σ is the principal stress and σ_{max} is the maximum of this stress at which the failure starts. This stress corresponds to the spall strength of the material. The values of this stress are presented in table 2.

Table2. Maximum of the principal stress.

Material	σ_{max} (GPa)
AlN	1,2
AlON	1,3
Bitossi glass ceramics	1,1
Sapphire	0.49
Pyrex glass	0,225
Aluminosilicate	0,250
Float glass	0,265
Borosilicate	0,275
WC (projectile)	2.5

The numerical simulation have been performed for the projectile normal incidence. The LS DYNA 3D finite element code has been used.

NUMERICAL RESULTS.

There are many data which can be evaluated from the numerical computations. For our purposes the projectile velocity and its displacement are meaningful. The example of the dependence of the projectile velocity on the projectile displacement is shown in the Fig.2.

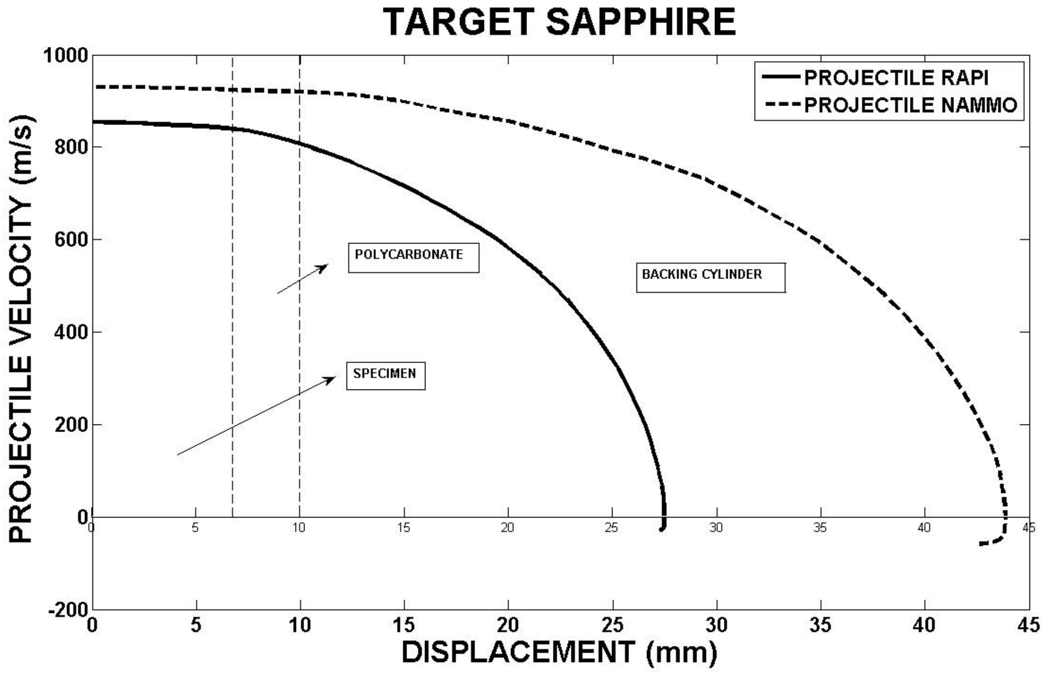

Figure 2. The projectile velocity vs projectile displacement. Negative values of the projectile velocities correspond to its reflection back.

These dependences obtained for all examined target materials exhibited the same qualitative features. In the next step the numerical simulation of the penetration for the different values of the spall strength of the targets has been performed. Example of this simulation is shown in the Figs. 3 and 4.

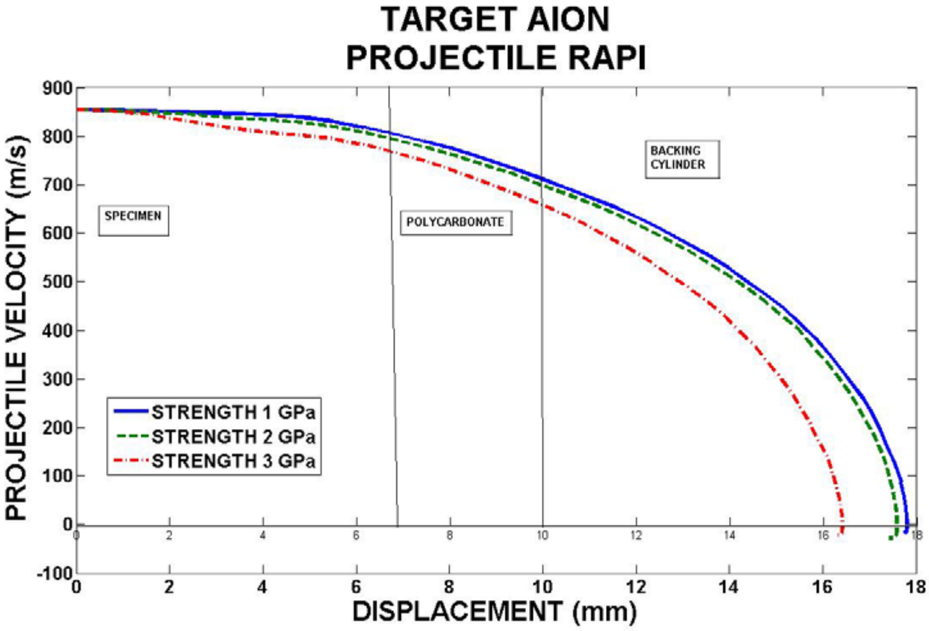

Figure 3. The influence of the target strength on the penetration process.

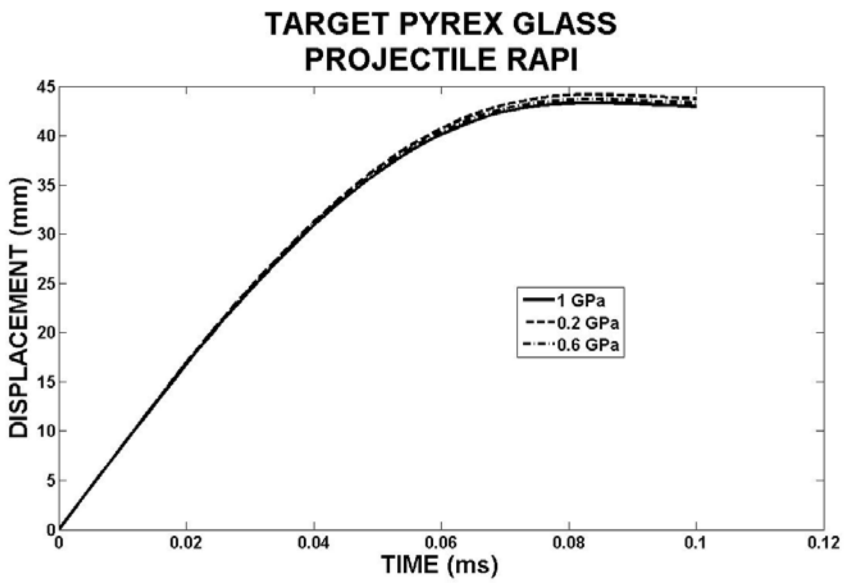

Figure 4. The influence of the target strength on the penetration process.

It can be seen that the increase in the spall strength from 1 to 2 GPa has a relatively small influence on the penetration depth. The significant decrease in the penetration depth can be reported for the spall srength of 3 GPa. This value is non - realistic.

In order to verify the reliability of the numerical simulations the computed results have been compared with the experimental ones. The only available experimental data are the depths of the penetration. The comparison was made for the AlON, Sapphire and Glass ceramics. The experimental data are given in the Table 3.

Table 3.Experiemntal data on the penetration depth .

TARGET	DEPTH OF THE PENETRATION (mm) PROJECTILE RAPI	DEPTH OF THE PENETRATION (mm) PROJECTILE NAMMO
AlON	17	40.1
Sapphire	26.7	44.2
Glass ceramics	48.4	49.1

From the numerical results the maximum of the projectile displacement has been taken. The following decrease corresponds to the projectile reflection back. The corresponding values are given in the Table 4.

Table 4. Numerical data on the penetration depth .

TARGET	DEPTH OF THE PENETRATION (mm) PROJECTILE RAPI	DEPTH OF THE PENETRATION (mm) PROJECTILE NAMMO
AlON	17.8	42.9
Sapphire	28.2	43.7
Glass ceramics Bitossi	46.0	45.1

The difference between theoretical and experimental data seems be very small. The dependence of the projectile velocity on the projectile displacement for the materials given in Table 3 is displayed in the Fig.5

CONCLUSIONS

In the given paper the numerical simulation of the ballistics experiments of two different kinds have been performed. During the testing of the single materials the influence of the material strength has been evaluated. It has been found that the variation of this parameter is not too significant. It has been found that the numerical results well agree with experimental ones. This conclusion has been obtained for the depth of the penetration. Even if this agreement has been obtained only for three materials one can conclude that the selected material models represent probably reasonable approach for the description of the ballistic experiments.

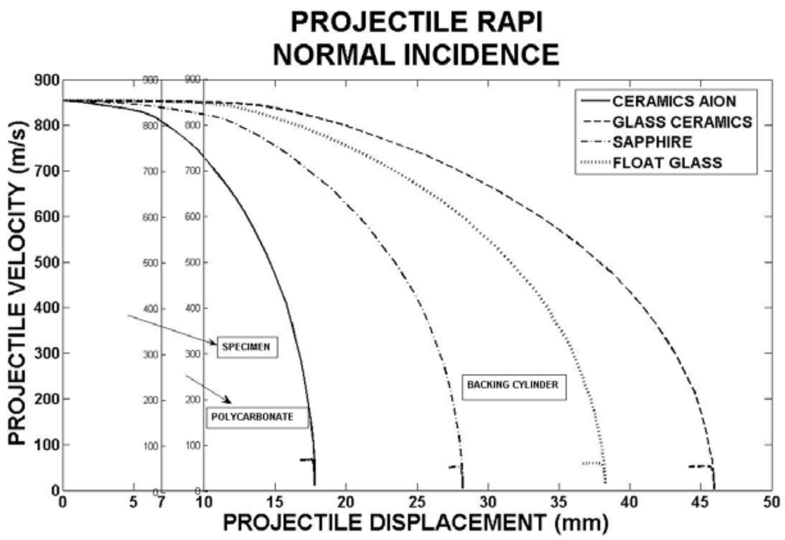

Figure 5. The projectile velocity vs. projectile displacement.

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