1. Introduction

Armour performance has not been successfully correlated to a single material characteristic or static material property due to the dynamic nature of the ballistic event (nano to micro seconds). Several fundamental material properties have been used to rank various ceramics for the initial evaluation in resisting ballistic impact: chemical composition, microstructure, grain size, density, hardness, elastic modulus, strength, fracture mechanism, fracture toughness. They influence the weight of the armour system, the damage to the projectile, the multi hit resistance, and the energy absorption. Previous static and low velocity impact tests have been performed experimentally, followed by numerical simulation [1]. The influence of the microstructure of the zirconium toughened alumina ceramics was also analyzed [2].

In this paper digital image correlation (DIC) is used for analyzing the behaviour of the ceramic tiles for static testing. A detailed literature survey of the history of photogrammetry and DIC systems is done by Sutton et al. in [3]. Ballistic impact simulations are done by using AUTODYN.

2. Experimental Static Procedure

The compressive force is applied directly through a steel bullet in the middle of the ceramic tile, as suggested by the end user of these results. The speed of loading is of 0.3 mm/min. A specially designed device allows the transmission of the force from vertical to horizontal direction. The opposite face to the one on which the bullet acts can be viewed directly by the cameras of the ARAMIS system. In this way one can notice better what happens on most of the surface of the tile; the tile is supported on its edges along the perimeter. In Fig. 1 can be observed a lateral view of the device fixed in the lower hydraulic grip of the testing machine.

In this discussion four tiles have been analyzed: two of them are denoted CM 15-1 and CM 15-2 and are ceramic zirconium toughened alumina mixed with calcium-magnesium; other two are denoted CMC 15-1 and CMC 15-2, and are mixed with calcium-magnesium-chromium. All tiles are 40x40 mm. An initial calibration before loading is needed in order to define a zero position; for this type of experiment a caliber of 35x28 mm is used. The chosen facet size is 26x26 with a facet step of 13x13, and thus results a facet field of 87x17 facets. As the deformations are very small the averaging has size 5 and 4 runs are considered.

Mises strains are shown in Fig. 2 for specimens CM 15-1 and CM 15-2. The surface of the tiles is not perfectly flat; this leads to an uneven support of the tile on the perimeter of the frame of dimensions 32x32 mm. With the exception of tile CM 15-1 which rests more symmetrically...
on the four corners, the other three tiles are supported more on one or the other of the diagonals of the square. This influences of course the symmetry of the displacement fields and probably the maximum displacement in the middle of the tile.

Fig. 2: Mises strain fields before failure for ceramic tiles CMC 15-1 and CMC 15-2

The principal results obtained for the four tests are given in Table 1: maximum force and displacement at failure, and Mises strain in the last recorded frame with ARAMIS.

Tab. 1: Obtained displacements and strains by using DIC

<table>
<thead>
<tr>
<th>Tile</th>
<th>$P_{\text{max}}$ [N]</th>
<th>$w_{\text{max}}$ [mm]</th>
<th>$\varepsilon$ Mises [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM 15-1</td>
<td>11470.20</td>
<td>0.01512</td>
<td>0.1591</td>
</tr>
<tr>
<td>CM 15-2</td>
<td>8102.62</td>
<td>0.01180</td>
<td>0.1587</td>
</tr>
<tr>
<td>CMC 15-1</td>
<td>9493.57</td>
<td>0.01610</td>
<td>0.1596</td>
</tr>
<tr>
<td>CMC 15-2</td>
<td>7175.32</td>
<td>0.00914</td>
<td>0.1462</td>
</tr>
</tbody>
</table>

3. Ballistic Impact Simulations

Various 2D AUTODYN simulations have been done for ceramic tiles of different dimensions, in some cases backed with kevlar and steel plates. Speeds of the bullets from 300 to 1300 m/s were considered. Only as an example, in Fig. 3 the bullet (made from steel and copper) and the ceramic tile are modelled by SPH and impact is done at 900 m/s.

Fig. 3: Impact phenomena for a ceramic tile of 100x100x20 mm at 900 m/s

4. Acknowledgements

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5. References

