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Ceramic/polymer composite armours

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Abstract

Ceramic/Polymer Composite Armours are increasingly used as a protective barrier against 7.62 and 12.7 mm AP projectiles in various civil and military applications. The experimental behaviour of these composite armours shows a clear improvement compared to monolithic steel or aluminium alloy protections. This paper illustrates the experimental results of the ceramic tiles and polymeric composites under ballistic test. The observation of the materials before projectile interaction and the ceramic rubble after the experiments was a valuable application of the ESEM. The Environmental Scanning Electron Microscope allows the examinations of almost any kind of nonconductive sample without special preparation. The experimental results and analyses performed allow us to select the best way to increase the laboratory capacity for design and test of composite ceramic/polymeric composite protective structures under shock and impact.

1. Introduction

Armours have traditionally been of metallic type, generally of high hardness steel. The demand for lighter and more efficient armours led to the development of alternative materials, Sánchez-Galvez [1].

At present, polymeric composites are widely used in the manufacture of helmets and body vests while ceramic materials are used in order to reach a greater efficiency in vehicles and cabins.

The combined ceramic-composites armours are more effective compared to conventional metallic ones.

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The use of ceramic materials in the preparation of ballistic armours arises from the physical and mechanical properties of these materials. Among these properties are included:

1. Low density compared to metals.
2. High elastic module.
3. High rupture module
4. High resistance to erosion even under high temperature.
5. High hardness.
6. High rigidity.
7. Low degradation of mechanical properties under high temperatures, (1200°C).

The combination of these properties make ceramic materials specially appropiate for ballistic protection. However, those most used for this purpose are only those materials with the highest values of the aforementioned mechanical properties: boron carbide, silicon carbide, silicon nitride, titanium boride and alumina, which are included among the so-called technical ceramics.

Due to its accessibility and inexpensiveness, our development was based on the use of alumina for the manufacture of the armour module.

2. Phenomenology

Metallic and ceramic materials react in a completely different way against a ballistic impact. Metallic materials behave as follows:

1. Plastic strain in the impact area, because of the stress produced as a result of said impact.
2. This strain is localised and produced in a very short period of time. The impact varies between a hundredth and a ten-thousandth second and generates high temperature in the impact place.
3. Consequently, the material is softened and even partially melted allowing projectile penetration.

Ceramic materials behave as follows:

1. No plastic strain takes place.*
2. They have an elastic lineal behaviour until their rupture.
3. No local temperature increases are produced.
4. They maintain their properties up to at least 1200°C.
5. The ceramic is cracked as is the projectile. During this process, a great portion of its kinetic energy is absorbed.
6. Consequently, the projectile, or what remains of it, is stopped.

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* When a projectile penetrates a body with velocities exceeding the propagation velocities of brittle failure, condition are created for plastic deformation of the ceramic. The large effect of ceramic strength limits the range of applications of the hidrodinamic clasic model to higher velocities, 3000-4000 m/sec than for metals, (Kozhushko et al [2]).

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3. Behaviour of composites against impact

Composites are materials formed as a result of the combination of fibres with high strength to tension (i.e. glass fibres) and ductile organic resin matrices which are successfully used in light armours such as helmets or body velvets for personal defence. The development of new fibres with high strength against impact, such as aramidic fibres (Kevlar) have led to new advances in the development of these armours.

Nevertheless, composites cannot be used as armours for high energy penetrating projectiles. Their use is restricted to small calibre projectiles or fragments.

Composites were recently included as support materials in ceramic armours with the purpose of absorbing part of the kinetic energy of the projectile and increasing their strength against impact, (Sun [3]).

During the preparation of composite, high mechanical strength fibre glass fabrics were used (Fig. 1); these were soaked in polyester resin which adheres to both surfaces of the ceramic tile with the same monomeric resin; then it hardens through a polymerisation process forming a very high mechanical strength monolithic system, specially against impact.

4. Ceramic armours

The main characteristics of ceramic armours in these applications are: low density, high hardness, high rigidity and a very low resistance to tension stresses. This makes them unsuitable as ballistic armours unless they are adhered to more ductile materials such as certain metals or composites in order to absorb those tension stresses produced by impact,(Chocron Benloulo and Sánchez-Gálvez [4]).

Therefore, ceramic armours are systems formed by three different layers: a composite or metallic frontal layer to confine ceramic rubble produced by impact; a ceramic tile that constitutes the armour itself and a base or ductile composite or metallic support, with high adherence to the ceramic tile with the purpose of absorbing the tension stresses. (Fig. 2)

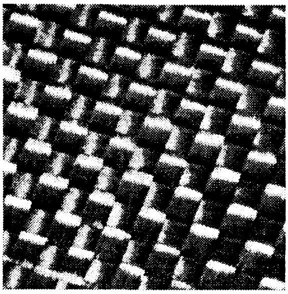

Fig. 1. Fiber glass (6x)

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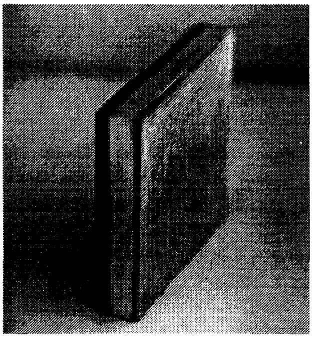

Fig. 2. View of the module

5. Experimental

5.1. Preparation of the Ceramic Tile

5.1.1. The processing. In a general way -and for the use of alumina in particular- the technology to obtain a ceramic tile requires some parameters to be fulfilled in order to obtain pieces with the highest feasible densities -as close to theory as possible-, without porosities, and consequently, with the highest mechanical strengths.

The processing includes the following stages:

1. Grinding in a ball bearing mill up to a granulometry of approximately 5 to 10 microns.
2. Mixing with other ceramics that have a lower fusion point (bonds) to make the sintering process easy.
3. Adding of organic adhesive to make the compaction process easy.
4. Drying and pelletization of the said mixture.
5. Compaction of the pelletised material in steel matrices.
6. Sinterization of compacted pieces.

The thickness of the tiles is mainly dependent on the diameter of the projectile to be stopped.

5.1.2. Mechanical test. The strength of the ceramic itself was measured according to the MIL-STD-1942 (MR). A MTS-810 testing machine was employed with the bend fixture model 642.05A-01 and 532.06H-20 extensometer, Fig. 3a, b. The specimen size was 4.00 mm with 3.00 mm thickness and 40.00 mm span.

Charpy Impact testings were performed in a Shimadzu, Fig. 4, testing machine JIS 4J (0,4 kgf.m). The notched parts were 10 x 10 x 90 mm.

5.1.3. Ballistic tests. Ballistic tests were carried out at CITEFA Shooting Gallery. The target was made up of a 50mm duralumin base, covered by one, two or three superposed ceramic modules of 8, 16 and 24mm thickness, respectively, Fig. 5a, b. These tests were carried out in order to determine the strength of each armour against the impact of projectiles of 7.62 and 12.7mm diameter with hard core. The speed measurements of the said projectiles were taken with a DR 5.000 Doppler Radar.

In the case of projectiles of 7.62mm diameter, the distance to the target was of 15m, and of 12.7mm diameter, the distance was of 20m.

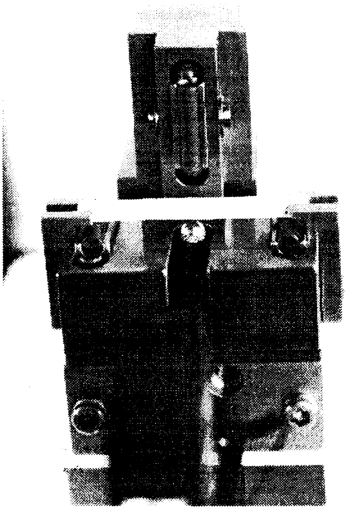

Fig. 3a. Bend fixture

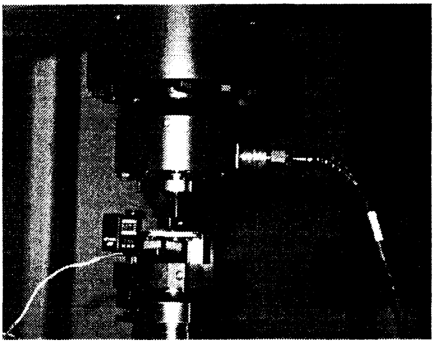

Fig. 3b. Bend test

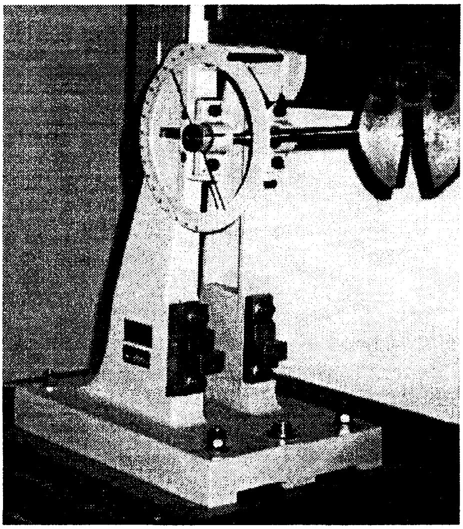

Fig. 4. Shimadzu Impact machine

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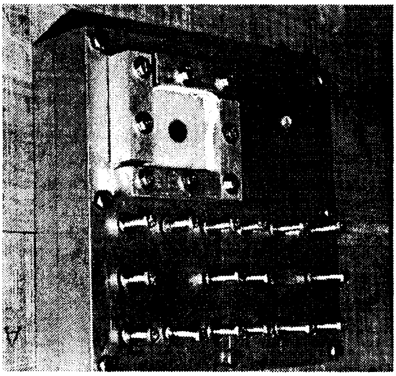

Fig. 5a. View of the ceramic/composite armour

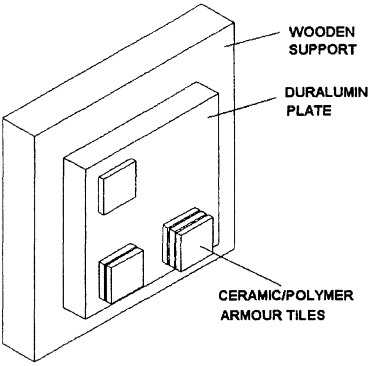

Fig. 5b. Schematic representation of armour

5.1.4. Microscopic observation. The structure of the material was analysed after and before ballistic test, in a Wild M8 Stereoscopic Binocular Microscope with Leica Photographic System of Automatic Exposure.

A 2010 Philips ElectroScan Environmental Scanning Electron Microscope (ESEM) was also used, allowing the structure of the sample to be analysed without previous preparation, (Corbellani at el, [5]). After the ballistic test was carried out, the chemical composition of incrusted particles in the ceramic material was determined with an EDAX 9.100 Electronic Microprobe, that was coupled to a Philips 515 Scanning Electron Microscope.

6. Results

6.1. Results of the Mechanical tests

The results of the flexural tests is shown in Fig. 6, where Weibull plot of the rupture module is presented. The same, for the Charpy impact test is shown in Fig. 7.

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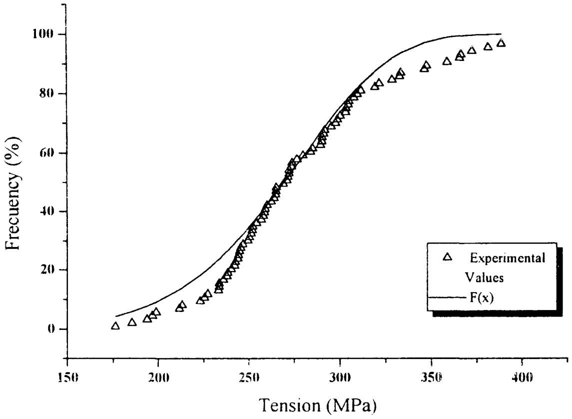

Fig. 6. Cumulative Density Function of bend test data with a Weibull distribution of two parameters: β=6.5 (shape parameter) and α=285 (scale parameter).

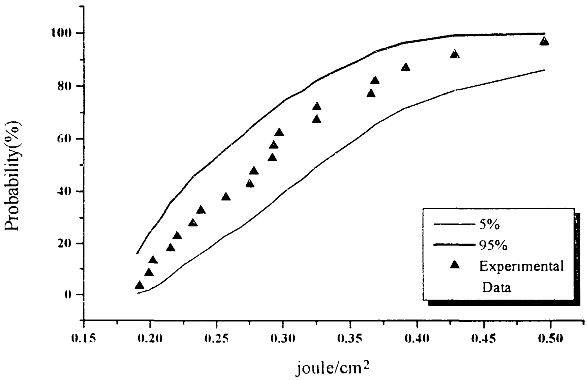

Fig. 7. Tolerance bands of Charpy impact data with a Weibull distribution of three parameters: τ=0.173 (threshold parameter), β=1.35 (shape parameter) and α=0.310 (scale parameter); the bands represent 90% confidence limits.

6.2. Results of Ballistic Tests with 7.62 mm diameter projectiles

The average speed of the projectiles was of 834 m/sec (average of four different shots considered). The residual kinetic energy is almost null, with a ceramic module of 8mm thickness.

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Comparative impacts at 30°, 45° and 90° on a TAM tank armour steel plate of 10mm without protection showed a penetration of the whole thickness in all cases.

Impacts on ceramic modules show a fracture on the plate without affecting either the composite or the base metal.

The projectile was destroyed during the impact. Internal ceramic tiles were not affected, showing that only the first one is enough to stop the projectile. Ceramic tiles were simply confined laterally with the composite and a surface layer of composite to ensure that the rubble is held.

6.3. Results of Ballistic Tests with 12.7 mm diameter projectiles

The average speed of the projectiles was of 1200m/sec. (average of four different shots considered) .

The armour, which was made up of three ceramic layers, does not resist the impact. The projectile showed a penetration in the base metal (duralumin) of 1.5cm. The said projectile was stopped within the duralumin of 50 mm thickness.

The impact on the base metal (duralumin) without protection showed that it was penetrated with a high residual energy allowing it to pierce the last wooden support of 10cm and to lodge in the retaining wall of the Shooting Gallery.

Ceramics are fractured in all layers and rubble is not separated; they are kept in the module. The ceramic armour absorbs a great part of the energy of the impact, preventing the complete penetration of the metal base.

In Fig. 8 a), b) and c) the standard view of the modules tested is shown.

From the point of impact, a system of radial and concentric cracks is repeated in all cases, showing a standard model of ceramic rubble formation. Those results are not influenced by the addition of a second tile.

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Fig. 8a. View of a polymeric composite/ceramic armour module with an alumina tile.

Fig. 8b. View of an armour module similar to the one shown in Fig. 8a -but with two tiles.

Fig. 8c. Details of previous ones. Wild M8 Stereoscopic Binocular Microscope.

In Figure 9, the view of the sintered ceramic material that was analysed with ESEM

put to ballistic tests. The size of the alumina grains and the binding material -without showing either pores or cracks- can be observed.

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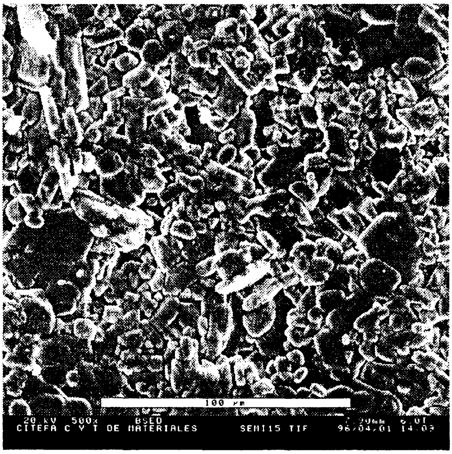

Fig. 9. Microstructure of the ceramic material.

In Figures 10a, b and c, results of the said material after the impact can be observed. The said results were obtained with ESEM Microscope.

In Figure 10a, an almost uniform band appears in a lighter colour than the rest of the photograph. Studies through the use of EDAX Microprobe show that it was a piece of brass from the projectile with hard core, incrusted in the ceramic. On the top left area, the fractured ceramic material is seen; and on the lower left area, a dark material inclusion with a rich composition of aluminium with silicon and with a portion of magnesium is shown.

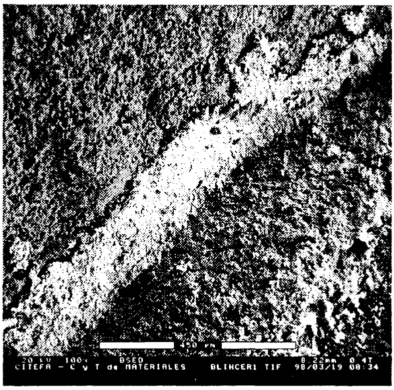

Fig. 10a. ESEM after ballistic test

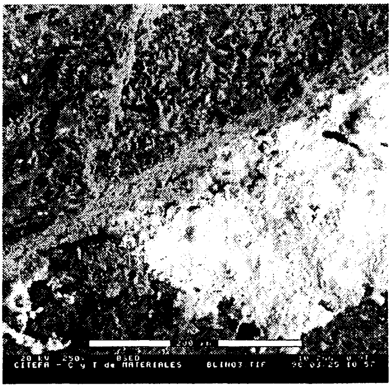

Fig. 10b. Detail of Fig. 10a

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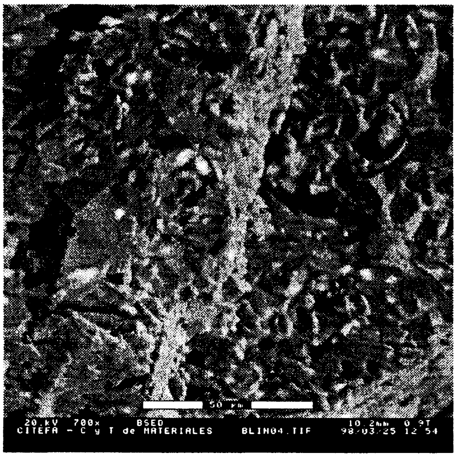

Fig. 10c. Detail of Fig. 10b.

7. Conclusions

These results show the high performance of these ceramic/composite systems as materials for ballistic armours in contrast with conventional steel armours.

As regards 12.7mm calibre, although the systems tested neutralise a great portion of its kinetic energy preventing the complete penetration in the metal base material, these developments must continue in order to obtain tiles with a higher strength to neutralise all the kinetic energy that the said projectiles produce and to achieve a system capable of providing protection to these demands.

Acknowledgements

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