STUDY ON THE BALLISTIC PERFORMANCE OF MONOLITHIC CERAMIC PLATES

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To defeat small calibre rifle bullets ceramic armour is used for personal protection. The earlier designs were flat inserts with square tiles. Nowadays monolithic plates are used, because they can be made multi-curved. These anatomically shaped plates are more comfortable to wear and the joints that were introduced with former designs (square tiles) showed a reduced ballistic performance.
Used monolithic plates were investigated on the presence of cracks. The monolithic plates with cracks were impacted by a projectile directly on or close to a crack. Furthermore, a realistic multi-hit distance for testing of the plates was investigated. In peace keeping operations the individual soldier operates more and more in urban areas. Therefore, the chance of being hit by multiple projectiles separated at a short distance is more likely. Trials with six types of weapons are performed in order to determine which spread could be expected at short ranges.
The outcome raises the question whether the multi-hit resistance of monolithic ceramic armour plates is sufficient and whether the multi-hit distance should be further reduced. New technical armour solutions show that the crack resistance of armour plates can be improved and that smaller multi-hit distances are possible. As a result of this research, The Netherlands MoD has chosen an armour solution which minimizes the chance of cracks and which offers an improved multi-hit performance.

BODY ARMOUR PLATES

Ceramic plates for body armour are designed to defeat small calibre Armour Piercing (AP) bullets. Nowadays most body armour plates are made of two basic parts: a hard ceramic top layer and a ductile composite backing glued together. Regularly, 7.62 mm AP bullets with a hardened steel core are used as worst case design criteria for body armour plates. Differences between ballistic standards in the description of testing the plates vary from the used projectile (.30-06 APM2 or 7.62 mm NATO AP), test condition (stand-alone or in conjunction with soft armour), number of impacts on the plate, impact velocity, etc.. All these criteria primarily influence the quality, weight, thickness and cost of the plate.

The process of defeating the hard core projectiles is that the hard ceramic top layer breaks up the projectile core during impact. From the small impact point of the bullet nose a cone is formed through the ceramic resulting in a larger load surface on the composite backing (see Figure 1). This cone forming process is due to the initial support of the composite behind the ceramic. The other purpose of the composite is to catch, decelerate and finally stop both the ceramic and projectile debris. The enlarged load area on the composite backing by the cone in the ceramic is one of the mechanisms that cause the bullet to stop with a relatively thin ceramic plate. This armour principal of a hard (ceramic) top layer with a ductile backing is often used to defeat hard core bullets in all sorts of armour applications.

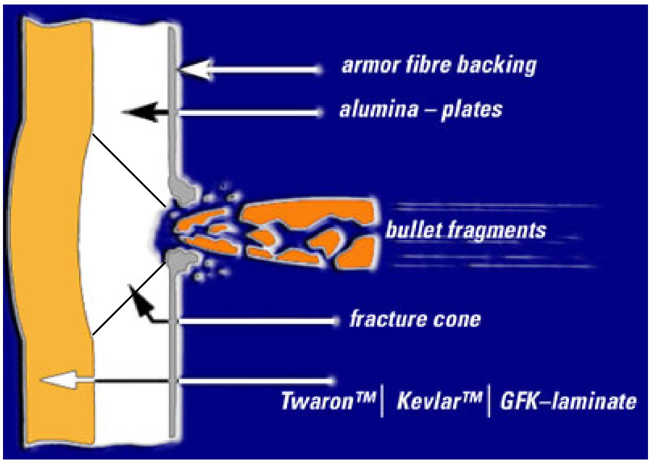

Figure 1. Schematic view of the bullet defeat process by a ceramic armour plate (source: http://www.etec-ceramics.de/www/web/english/ballistik/index.html)

INVESTIGATION ON ARMOUR PLATES

After introducing the monolithic ceramic plate in the Dutch army in the beginning of the 90's, the Dutch MoD investigated the condition of the plates on a regular basis. One of the standard checks was to investigate the ballistic resistance of the plates. Following the standard procedure a number of plates was randomly taken from a batch and tested according to the ballistic standard that was applicable at that time.

A few years later another check was introduced for investigating irregularities in the plate by making x-ray recordings. This revealed a number of plates having cracks in the ceramic top layer (see Figure 2). When the above described cone forming process is interrupted by a crack in the ceramic, the load on the composite surface could be concentrated on a smaller area and therefore the chance on a perforation increases. Also the process of breaking the projectile core can be disturbed because a smaller portion of ceramic is used and thus a lower contact pressure between projectile and ceramic is possible.

In figure 2 two plates are shown. Both returned from a mission but one was found damaged with a crack in the middle. Both were shot with a 7.62 mm AP round at 830 m/s, the one with the crack was hit just above the crack (hit position in Figure 2). This plate was completely penetrated whereas the undamaged plate stopped the AP round. In general it is found that the less ceramic is destroyed the larger the residual projectile fragments are, having more kinetic energy. Such fragments could be capable of penetrating the composite backing resulting in the armour to fail.

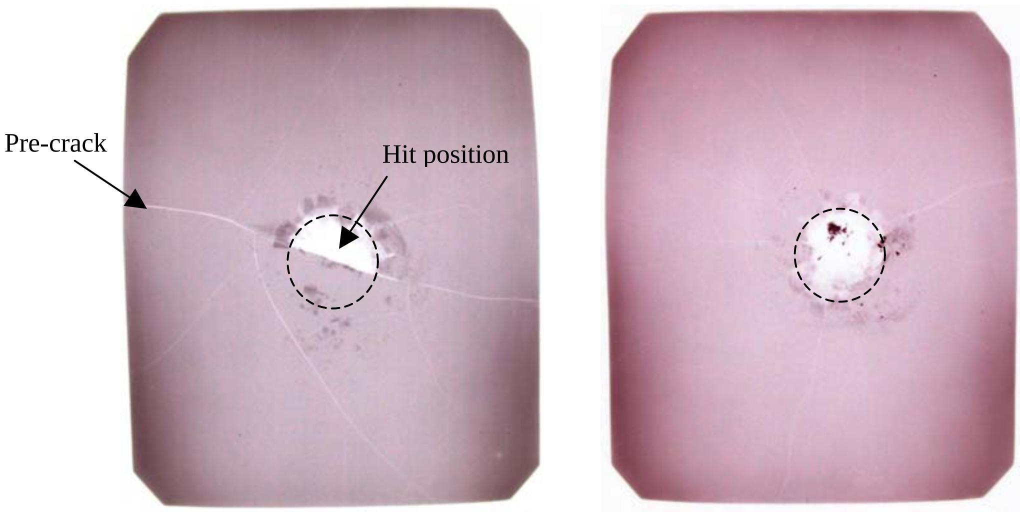

Figure 2. The left picture shows a pre-cracked plate, on the right an undamaged plate. Both plates were tested against a 7.62 mm AP projectile at 830 m/s. The left plate was perforated; the plate on the right stopped the bullet.

Apparently the plates had suffered from the usage in the field. It is unknown what causes the cracks but it is suspected that rough handling and dropping of the plates are the main causes. Due to this the operational lifetime of the plates was shorter than expected. To prevent these kind of defects in future it was decided to introduce a drop test for the plates. All new purchased plates have to withstand a certain blunt impact on the ceramic plate to verify the crack resistance of the plates. Therefore a drop test was defined for two situations (see Figure 3) to test a number of plates from a batch:

1) a drop test with a steel ball (1041 g) from 2 m height in the middle of the plate
2) a guided drop from 2 m height on one of it's four corners

As described above cracks behave as a joint between ceramic tiles and could result in a decrease of the ballistic resistance. For the Dutch MoD more than 1200 plates have been investigated with x-ray after return from a mission. During this research approximately 5 % of the plates were found having one or more cracks. These plates were taken out of service and were investigated on their ballistic performance. The position of the crack was determined from the x-ray recording. After this the plates were tested against their highest threat level (NIJ 0101.03 level IV) [1]. From these ballistic experiments it appeared that 14 % of the plates failed the test. Sometimes a hit directly on the crack resulted in a stop (a normal cone was formed) whereas a hit near the crack resulted in a perforation (half a cone was formed). Also when the ceramic had very thin cracks (hard to see at the x-ray recording) it was still possible to stop the bullet.

Figure 3. Left: drop test with steel ball, right: guided drop on one of the corners.

MULTI HIT CAPACITY

The multi-hit capacity of ceramic plates is an issue in defeating rifle projectiles especially the AP rounds. Some ballistic standards specify a multi-hit impact with AP projectiles on ceramics plates for example the Technischen Richtlinie Ballistische Schutzwesten [2]. The required distance between the impacts in this specification is 10 cm and the bullets should be defeated even if there are cracks in the ceramic by previous impacts. The AP rounds however shows to be a problem because the ceramic is tested to its maximum performance. In this case an impact near a crack (or joint) could disturb the defeating mechanism resulting in a perforation of the projectile core as seen in Figure 2. Secondly after a hit the surrounding ceramic in the direct neighbourhood of the impact is no longer supported by the composite liner. Once the support is gone the ceramic alone offers almost no protection. The impact distance on the plate is therefore critical and usually chosen such that the impacts are spaced relatively wide from each other.

Not looking at the minimum possible multi-hit distance of monolithic body armour plates, the Dutch MoD decided to investigate the bullet dispersion of 6 types of weapons at relatively short distances to answer the question what distance between impacts on a plate can be expected when operating in urban areas.

Experiments were performed to investigate the spread of projectile impacts at relatively short distances [3]. From 6 types of weapons the spread at different ranges was determined: the Diemaco C7, Kalashnikov AK 47, Machinegun PK 61, Minimi, FN MAG and Dragunov. The shot patterns of these weapons were collected at 5 ranges varying from 10 m – 300 m. From the AK 47 and the Diemaco C7, 6 single shots and twice a 3 round burst were fired and investigated separately. With the machineguns FN MAG and PK 61 a 6 round burst was investigated. All shots were fired with a supported weapon (worst case scenario) and were repeated 4 times with 4 different gunners.

The results at 30 m showed that for machinegun fire (FN MAG and PK 61) the smallest distance found between two impacts was 15 mm. At 50 m range the smallest distance was 20 mm. This result raises the question whether the multi-hit distance of current armour plates is sufficient and if it should be further reduced.

CERAMIC TOP LAYERS

First generations of ceramic faced armours were made from square ceramic tiles forming a flat surface. This construction had the disadvantage that the joints that are introduced by this kind of construction and especially the T-joints generally show a reduced ballistic performance. On the other hand the joints functioned as a crack stopper reducing the damage to the surrounding ceramic tiles in case of a hit. Another disadvantage was the shape, only flat panels could be constructed.

The build up of a ceramic top layer by means of square ceramic tiles has more or less been abandoned by the monolithic plate. Monolithic plates nowadays can be made in one piece, without any joints, and can be made (multi) curve shaped and therefore more comfortable to wear. However when a monolithic plate is hit, cracks propagate through the whole plate. These cracks reduce the ballistic resistance just like the joints do for the square tiles.

A third concept is the use of ceramic pellets (LIBA concept in Figure 4). The principal of defeating the threat with this concept is also by breaking up the hard steel core, but no cone is formed in the ceramic. Due to the small size (hit surface) the ceramic pellets have to be thicker than a monolithic plate. But the fact that the round pellets do not completely cover the whole area (a small opening is left between every three pellets), the areal density is in the same order as a monolithic plate. Also (multi) curved shapes can be made with this solution. A disadvantage is that the load on the composite backing is higher when only one pellet is hit. The diameter of the pellet then represents the load area. Also the small openings can be weak spots. Small calibre bullets like the 5.56 mm SS109 have a hard steel tip that can penetrate between three pellets. This problem however can be solved with special pellets.

Figure 4. Picture of an insert with ceramic pellets (LIBA). The insert was hit 8 times with 5.56 mm SS109 projectiles at muzzle velocity and once with a .30-06 APM2 according to NIJ 0101.03/level IV. All impacts were stopped by the insert.

At this moment the LIBA armour plate from Ten Cate Advanced Armour is being worn by Dutch Soldiers. This plate fulfilled the drop test requirement and the ballistic requirements (NIJ level III/IV + 6 shots 5.56 mm SS109). The weight and thickness of the plate is rather high and therefore the search for the ultimate body armour plate continues.

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