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CERAMIC ARMOUR

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Abstract. This paper reviews the failure mechanisms that occur when a projectile penetrates a ceramic armour. The advantages and disadvantages of using a ceramic-based system are presented and the application of the different ceramics available is discussed.

INTRODUCTION

It has long been accepted that ceramic materials can play an important part in ballistic protection. Their high hardness and low density make them ideal candidates for armour systems. In fact, it has been known since 1918 that a thin, hard enamel facing on a metal significantly enhances its ballistic resistance [1]. However, this work was never exploited until 1962 when R.L. Cook of the Goodyear Aerospace Corporation developed the first hard-faced composite armour [2]. Since then, extensive research has been carried out to examine the optimal properties, construction and uses of ceramic armour technology.

The first real use of ceramic armour technology was in US helicopters in the 1960's. Low level sorties in the jungle of Vietnam had made the helicopter and crew vulnerable to small arms fire. Hence, in 1965 the first [3] ceramic-based aircrew protection vest went into production. In 1966, the first monolithic boron-carbide vest was issued along with other improvements to the protection of the crew using parasitic airframe-mounted armour panels. In 1967, the integrally armoured helicopter seat was developed and by placing the ceramic tiles closer to the crew the area and weight of armour required for crew protection was minimised.

Figure 1. A Stingray Light Tank in service with the Royal Thai Army employing ceramic appliqué armour. Reproduced with permission from Jane's Information Group.

Ceramics have since been used in many civil and military applications where protection is required. Their high compressive strength and low density have led to the replacement of some relatively heavier types of armour. They have also provided opportunity to provide protection where metals had previously failed. These have included protective vests for the police force, parasitic armour for helicopters, transport aircraft, trucks [4], troop carriers, light tanks (Figure 1), hovercrafts and main battle tanks (MBTs).

MECHANISMS OF CERAMIC ARMOUR FAILURE

Although there was early interest in the use of ceramic materials as armours, the exact mechanisms of failure remained a mystery. Wilkins and his colleagues [5,6,7] provided the first notable analysis on ballistic failure processes in ceramic faced armours. Wilkins recognised that in order to optimise a two-component ceramic armour system it is necessary to understand the interactions between target and projectile. Using high-speed photography, flash x-ray and numerical models he was able to evaluate the ballistic failure processes. In the first 9µs of penetration it was postulated [8] for small calibre ammunition:

- The projectile tip is destroyed.
- A fracture conoid initiates at the interface between the projectile and the target. The cones that are formed spread the load of the projectile onto a relatively wide area enabling the energy of the impact to be dissipated by the plastic deformation of a ductile backing material.
- The backing plate yields at the ceramic interface.
- The tension that results in the ceramic as it follows the motion of the backup plate initiates an axial crack. This failure mechanism has since been argued as being a result of the impedance mismatch in the two-composite structure (for example, see [9]).

For larger threats such as Armour Piercing Discarding Sabot (APDS) rounds, thicker sections of ceramic and backing material are required. The failure patterns that occur when a rod penetrates a ceramic target are shown in a recent numerical simulation (Figure 2) using the hydrocode AUTODYN-2D [10]. Moreover, Shockey *et al* [11] performed experimental long rod penetration studies into thick blocks of confined ceramic in an attempt to discover the properties governing penetration resistance. They postulated that:

- Tensile fracture occurs soon after impact close to the rod periphery. The stress fields are initially elastic and the largest tensile stresses are in the radial direction. Therefore, the cracks that form, (normal to the direction of the maximum principal stress) are ring cracks concentric about the impact site.
- These cracks initially grow to approximately 1mm below the surface. However, upon continued loading a few ring

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