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Review paper

Characterisation, significance and detection of manufacturing defects in Reaction Sintered Silicon Carbide armour materials

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Abstract

Ceramics with high hardness values (> 10 GPa), high elastic modulii (> 300 GPa) and good flexural strength values (> 350 MPa) make excellent armour materials. However, they are normally very expensive (> $10/kg) and difficult to shape. So, tiles of regular geometry (typically square or hexagonal) have been used in advanced armour systems, for military vehicles. However, for body armour applications, there is a need to form a monolithic ceramic into a double-curved, or even triple-curved, shape in order to better conform to the human torso. In a recent review, carried out by the Defence Materials Technology Centre of Australia, of the shaping techniques used for body armour components, uniaxial pressing of breastplates was still recognised to be the most feasible, and commercially available, process even though other techniques like Viscous Plastic Processing (VPP) were becoming established. One particular variant of the dry-pressing route is known as Reaction Sintering, or Reaction Bonding, in which a pre-pressed, dry powder compact is infiltrated, at elevated temperature, with a liquid metal. However, the process is prone to the formation of a range of manufacturing defects, some of which are extremely deleterious to impact behaviour and ballistic performance of the finished product. The origin, cause and effect of these defects are discussed in this paper, together with both current and future NDI techniques.

Keywords: Ceramic armour; Reaction Sintered Silicon Carbide; Manufacturing defects; Non-destructive inspection

Contents

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1. Introduction

Ceramics with high hardness values (> 10 GPa), high elastic modulii (> 300 GPa) and good flexural strength values (> 350 MPa) make excellent armour materials [1]. However, they are normally very expensive (> $10/kg) and difficult to shape. So, tiles of regular geometry (typically square or hexagonal) have been used in advanced armour systems, for military vehicles, offering high levels of protection against kinetic energy weapons like armour-piercing rifle bullets (up to 14.5 mm in calibre) and small-calibre cannon rounds (up to 30 mm in diameter) [2]. However, for body armour applications, Crouch reported in 2009 [3], that there is a need to form a monolithic ceramic into a double-curved, or even triple-curved, shape in order to better conform to the human torso. Fig. 1 shows a typical body armour production facility and associated products. In a recent review, carried out by Leo et al. [4], of the shaping techniques used for body armour components, uniaxial pressing of breastplates was still recognised to be the most feasible, and commercially available, process even though other techniques like Viscous Plastic Processing (VPP) were becoming established. One particular variant of the dry-pressing route is known as Reaction Sintering, or Reaction Bonding, in which a pre-pressed, dry powder compact is infiltrated, at elevated temperature, with a liquid metal. However, the process is prone to the formation of a range of manufacturing defects, some of which are extremely deleterious to impact behaviour and ballistic performance. The origin of these defects is discussed in this paper, together with both current and future NDI techniques.

Interest in this particular process is reflected in the use of Reaction Sintered Silicon Carbide (RSSC) as the main projectile-eroding material in many body armour components used by military personnel in both the United States (via M-cubed Technologies) and Australia (via Modern Ceramics Company (MCC)), since the late 1990s [5,6]. Prior to its widespread adoption in Australia by Australian Defence Apparel (ADA) around 2008, extensive characterisation of possible manufacturing defects had to be carried out and in-depth quality acceptance criteria established. This paper reports details of those quality control procedures and, in particular, compares the advantages and disadvantages of established, high-resolution, digital x-radiography with the use of ultrasonic methods, recently researched by Kesharaju [7].

2. Penetration mechanisms in ceramic armours

Fig. 2a shows the well-established steps in the penetration of a ceramic armour system which, in the main, consists of two layers: a ceramic element on the impact side, supported by a backing material on the distal side; this material is typically an aluminium alloy, steel or a fibre-reinforced polymer. The impacting bullet is partly eroded at the surface during a time-period known as dwell, followed by the formation of Hertzian cracks on the surface of the ceramic, and final failure through conoidal fracture. The formation of the conoid increases the area of contact with the backing material which then bulges and absorbs energy principally through membrane stretching. This local failure is accompanied by the formation of radial cracks (see Fig. 2b), which emanate from the

Fig. 1. Production of HAPs at ADA, Bendigo, Australia, circa 2010.