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Ballistic performance of bilayer alumina/aluminium and silicon carbide/aluminium armours

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Abstract

The ballistic performance of bilayer silicon carbide/aluminium (SiC/Al) armour is assessed and compared with the alumina/aluminium (Al_2O_3/Al) armour using numerical analysis. For the numerical simulation of impact phenomena, ANSYS/AUTODYN software and phenomenological material models are used. The phenomenological models are JH-1 and JH-2 for brittle materials such as silicon carbide and alumina respectively and Johnson Cook (JC) model for ductile materials such as steel and aluminium. This study results shows that the ballistic performance of SiC/Al armour is higher than the Al_2O_3/Al armour and also SiC/Al target made severe damage to the projectile. The failure modes of these armours against blunt and ogive nose projectile are also evaluated.

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Keywords: Bilayer armour; AUTODYN; Silicon carbide; Ballistic impact; Ceramic

1. Introduction

The usage of ceramic in armour application is increasing due its inherent properties such as low density, high hardness and high strength as compare to conventional metal armour materials. However, the brittle nature of ceramic material makes them to perform poorly when they are used as single layer armour. Therefore, ductile materials such as metal or composite layer have been used as a backing layer of the ceramic to produce efficient armours. The function of front ceramic layer is to blunt and decelerate the projectile and the back layer of ductile material is to keep the

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fractured ceramic fragments at its position and observes the remaining energy of the projectile. Therefore, bilayer ceramic/metal armours are being used for effective protection against the ballistic threats.

There are very few research studies have been carried out to examine the performance of different ceramic materials such as alumina (Al_2O_3), silicon carbide (SiC) and boron carbide (B_4C), and different bilayer ceramic/metal armours against projectile impact. Rozenberg and Yeshurun [1] has carried out depth of penetration (DOP) experiment to evaluate the ballistic efficiency of 50/50 of alumina/Boron carbide, SiC, titanium diboride (TiB_2) and B4C against 12.7 and 14.5 mm diameter AP projectiles. It has been reported that the ballistic efficiency of B4C is higher than other ceramic tiles and SiC is next to B_4C against both the projectiles. Moynihan et al. [2] also evaluated the ballistic performance of Al2O3, SiC, and B_4C against 7.62 mm diameter projectile by DOP test. This experimental results also show that the ballistic efficiency of B_4C is higher than other ceramic tiles and SiC is next to it. The high compressive strength of silicon carbide made more damage to the projectile than B4C. Wang and Lu [3] and Mayseless et al. [4] performed ballistic experiments to evaluate the ballistic performance of bi-layer alumina/aluminium targets and Hetherington [5] Wang et al [6] and Ben-Dor et al. [7] proposed empirical models to optimized the thickness of bilayer armours for given ballistic velocity. Serjouei et al. [8] has carried out both experimental and numerical study to optimise the thickness of bilayer Al_2O_3/Al target against blunt nose projectiles and a semi analytical model has been proposed.

The current study focuses on the performance of two different bilayer ceramic/metal targets ballistic performance is evaluated against steel 4340 blunt and ogive nose projectile using numerical simulations. The bilayer armours considered for present study is Al_2O_3/Al and SiC-B/Al. Ballistic performance of the armours are evaluated by examining the residual velocity and length of projectile, and failure modes of both target and projectile.

2. Numerical modelling

For all the numerical analysis, Lagrangian approach is used to simulated the projectile impact on bilayer armours to assess their impact resistance through ANSYS/AUTODYN 3D [9] software. The present numerical model is validated with the available numerical model [8] in the literature. The details of geometry, meshing, boundary condition and material models are provided in the following sections.

2.1. Material model

The ceramic material exhibits complicated response to high strain rates loading and developing an analytical model to capture its behaviour under impact loading is also very difficult. Therefore, two phenomenological models have been developed by Johnson-Holmquist that is JH-1 [10] and JH-2 [11] to describe their behaviour under impact loading. The JH-1 ceramic model is the linear segments model which allows material to soften/fail instantaneously after it is fully damaged. On the other hand, JH-2 model is a dimensionless analytic description of the strength and it allowed the strength to degrade gradually as the damage is accumulating in the material [12]. For most of the ductile materials, Johnson Cook (JC) model is used to describe their behaviours under high strain rate loading [8]. It is observed from the studies of [8, 12] that the suitable material models for numerical simulation of silicon carbide (SiC-B), alumina (Al_2O_3), and for both steel 4340 and aluminium 2024-T3 is JH-1, JH-2 and JC models respectively. The material parameters used for the current study is shown in tables 1 and 2.

Table 1. JH-1 material constant for Alumina (Al_2O_3 95%) [8] and silicon carbide (SiC-B) [11]

Constants with units	Al2O3	SiC-B
Density (g/cm3)	3.741	3.215
EOS	Polynomial	Polynomial
Bulk modulus, K1 (kPa)	1.8456e+8	2.2e+8
Pressure constant, K2 (kPa)	1.8587e+8	3.61e+8
Pressure constant, K3 (kPa)	1.5754e+8	0
Strength model	JH-2	JH-1
Shear modulus (kPa)	1.2034e+8	1.93e+8