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Numerical simulation of ballistic impact of armour steel plate by typical armour piercing projectile

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Abstract

Ballistic impact of typical armour steel plate of medium thickness by ogive-nosed projectiles travelling with ordnance velocities has been investigated through numerical simulations. Johnson-Cook material and failure models have been used to simulate the behavior and failure of the material under impact conditions. The model constants have been derived from an experimental work done by the authors published previously. Simulation has been done in Altair-HyperWorks FE package. The stages of penetration have been predicted. The residual velocities, ballistic limit velocity andperforation times have been determined from the simulation results and found to match with experimental data.

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*Keywords:*ballistic impact; armour steel; Johnson-Cook

1. Introduction

The ballistic impact of armour plates has been a topic of active research since long. A lot of efforts have been put in for understanding the physics of the problem and develop a mathematical model for the event [1-7]. Corbett et al. [2] has presented a detailed review of the research work on penetration and perforation of plates by free-flying projectiles at sub-ordnance velocities. Special mention needs to be made on the books by Zukas et al. [4, 5] that deal with the subject, in general and analysis techniques, in particular. The investigationof ballistic impact had been based

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on experimental studies in the initial stage [8-10]. However, the cost of experimentation may be prohibitively high. Hence, empirical and analyticalmodels [11-15] have been proposed from time to time to analyse and predict the outcome of ballistic impact cases.

The extreme complexity of the ballistic impact event due to high non-linearities and dependence on a large number of parameters makes it impossible to have a closed form of analytical solution of the problem. This is where the numerical simulation approach based on finite element method finds an attractive application. In this method, simplifying assumptions are no longer a necessity and the equations of continuum mechanics are attempted to be solved through discretisation. Coupled with dynamic material characterisation and experiments, the numerical simulation technique is at present, the most versatile and powerful technique for analysis of ballistic impact problems. A review of the work done on computational models of ballistic impact can be found in Anderson et al. [16]. The earliest numerical simulation studies were centred on hypervelocity impacts where strength effects were neglected and metals were treated as fluids.

Ballistic impact studies on 1100-H12 Al plates have been reported by Gupta et al. [17]. Plates of different thickness were impacted by projectiles having different nose shapes at velocities in the sub-ordnance regime. Both experimental and numerical investigations were conducted. An elasto-viscoplastic material model proposed by Johnson-Cook [18] was used to simulate the material behavior under impact conditions and a failure model [19] proposed by the same researchers represented the failure. The model constants were determined experimentally. The models were implemented in the commercial FE package, ABAQUS. Lagrangian adaptive meshing was employed to tackle the problem of excessive distortion in the finite elements. The predicted values of the residual velocities and ballistic limit velocities for different target-projectile combinations were compared with the experimentally determined values and appreciable matching was observed. The von Mises stress, shear stress and plastic strains at the impact regions could be predicted by the simulationresults that helped in analysis of the penetration mechanisms in the different target-projectile combinations.

M.A. Iqbal et al. [20] further extended the work in investigation of the effect of target span and configurations (monolithic, double layered, spaced) on the outcome of the ballistic impact. It was shown that the monolithic targets exhibited better ballistic performance over the double layered and spaced plates. Variation of spacing had little influence on the performance. Ballistic limit velocity was found to increase with target span.

Again through a combination of experimental and numerical studies of ballistic impact of 1100-H12 Al plates, Tiwari et al. [21] showed that variation in the boundary conditions (fixity of the target plate) has negligible effect on the failure mode of the target. However, the mechanics of target deformation and energy absorption were significantly influenced.

Characterisation of mild steel followed by ballistic evaluation of 12mm and 16mm thick MS plates impacted by 7.62mm AP projectiles was doneby M.A. Iqbal et al. [22]. Through rigorous experiments, the Johnson-Cook material and failure model constants were determined and the same were used during numerical simulation of the ballistic impact. The residual velocities were predicted with an accuracy of 6 – 7.6%. The oblique impact of the plates was also investigated. Critical angle of ricochet was accurately predicted.

Borvik et al. [23] studied the ballistic impact of 12mm thick ballistic impact of Weldox 460E steel plates by blunt, cylindrical projectiles with diameter, 20mm. The projectiles were launched from a gas gun with velocities in the range 170 – 310 m/s. The impact event was observed through high-speed camera. The ballistic limit velocity and mechanics of penetration were observed and recorded. Characterisation of Weldox 460E steel material has been done and Johnson-Cook material and failure models used to numerically simulate the ballistic impact response of the target plates in the commercial FE package, LS-DYNA. The predictions have been found to appreciably match the experimental results.

In another work [24] with the same target, the effect of nose shape on ballistic penetration was studied. The ballistic limit velocities for hemispherical and conical nosed projectiles were found to be close to each other while that for blunt nosed projectiles was considerably lower. The impact cases could be appreciably simulated. Adaptive meshing was employed to overcome the problem of excessive deformation of mesh elements in case of conical nosed projectiles.

Ballistic impact of five different high-strength steel plates by 7.62mm AP and Ball ammunition has been reported [25] 6mm and 12mm monolithic and double-layered plates have been impacted by the projectiles fired from military weapon with various velocities in the range, 400 – 830 m/s. Material test programme was adopted for the calibration