Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 173 (2017) 369 – 374
Procedia Engineering
www.elsevier.com/locate/procedia

11th International Symposium on Plasticity and Impact Mechanics, Implast 2016

Experimental and Numerical Studies on Mild Steel Plates against 7.62 API Projectiles

K. Senthil*[a], M. A. Iqbal[b], P. Bhargava[b], N. K. Gupta[c]

[a]Department of Civil Engineering, National Institute of Technology Jalandhar, Jalandhar 144011, India
[b]Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee 247667, India
[c]Department of Applied Mechanics, Indian Institute of Technology Delhi, New Delhi, 110016, India

Abstract

The ballistic resistance of 12 mm thick mild steel plates has been studied against 7.62 API projectiles through numerical simulations carried out using ABAQUS/Explicit finite element code. The incidence angle was varied as 0°, 15°, 30°, 45°, 57° and 59°. The material parameters for the JC model proposed by the Authors were employed to predict the material behavior of the target, while the material behavior of the projectile was incorporated from the available literature. The numerical results thus obtained have been compared with the experiments reported in earlier study, wherein the incidence velocities of the projectile were considered close to 820 m/s. The experimental and numerical results with respect to failure mechanism, residual projectile velocity and critical angle of ricochet have been compared. A close correlation between the experimental findings and the predicted results has been found. In general, the resistance of the target has been found to increase with increase in target obliquity.

Peer-review under responsibility of the organizing committee of Implast 2016

Keywords: Mild steel; Oblique impact; Numerical investigation; ballistic limit; 7.62 API projectiles;

1. Introduction

The need for protection against small arms projectiles is very important from a military point of view. There are a large number of parameters which may influence the ballistic resistance of metallic plates such as material behavior, target thickness, angle of incidence, nose shape and size of projectile as well as target configuration, [1-15]. The

*Corresponding Author: Phone: 91-9458948743, 91-8267927382
Email Address: urssenthil85@yahoo.co.in; urssenthil85@gmail.com

Peer-review under responsibility of the organizing committee of Implast 2016
doi:10.1016/j.proeng.2016.12.032

majority of the ballistic studies are concerned with oblique impact against ordinary hardened steel projectiles, [1-9]. Further, the most of studies concerned with worst case scenario, which is normal impact, [10-13]. However, most real cases in light of military application, the armour piercing incendiary projectile will strike the target with some degree of obliquity, [14, 15]. Therefore, it is concluded that the studies on ballistic resistance at varying angle of incidence against armour piercing projectile is limited. In this paper, the ballistic performance of 12 mm thick mild steel targets has been studied against 7.62 AP projectiles at normal and oblique angles of incidence until the occurrence of projectile ricochet by carrying out finite element simulations on ABAQUS/Explicit finite element code. The Johnson-Cook [16, 17] constitutive model has been employed for predicting the material behavior of the projectile and mild steel targets. The ballistic results thus obtained have been compared with the experiments carried out Gupta and Madhu [14, 15].

2. Constitutive Modeling

In order to define the material behavior of mild steel target and armour piercing projectile the Johnson-Cook elasto-viscoplastic material model [16-17] available in ABAQUS finite element code was employed. The material model includes the effect of linear thermo-elasticity, yielding, plastic flow, isotropic strain hardening, strain rate hardening, softening due to adiabatic heating and fracture effects. The equivalent von- Mises stress $\bar{\boldsymbol{\sigma}}$ of the Johnson-Cook model is defined as;

$$\bar{\sigma}(\bar{\varepsilon}^{pl}, \dot{\bar{\varepsilon}}^{pl}, \hat{T}) = \left[A + B(\bar{\varepsilon}^{pl})^{n}\right]\left[1 + C\ln\left(\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0}\right)\right]\left[1 - \hat{T}^{m}\right] \quad (1)$$

where A, B, n, C and m are material parameters determined from different mechanical tests. $\bar{\boldsymbol{\varepsilon}}^{\mathbf{pl}}$ is equivalent plastic strain, $\dot{\bar{\boldsymbol{\varepsilon}}}^{\mathbf{pl}}$ is equivalent plastic strain rate, $\dot{\boldsymbol{\varepsilon}}_{\mathbf{0}}$ is a reference strain rate and $\hat{\mathbf{T}}$ is non-dimensional temperature defined as;

$$\hat{T} = (T - T_0)/(T_{melt} - T_0) \qquad T_0 \leq T \leq T_{melt} \quad (2)$$

where T is the current temperature, T_{melt} is the melting point temperature and T_0 is the room temperature.

The Johnson and Cook [17] extended the failure criterion proposed by Hancock and Mackenzie [18] by incorporating the effect of strain path, strain rate and temperature in the fracture strain expression, in addition to stress triaxiality. The fracture criterion is based on the damage evolution wherein the damage of the material is assumed to occur when the damage parameter, ω, exceeds unity;

$$\omega = \sum\left(\frac{\Delta\bar{\varepsilon}^{pl}}{\bar{\varepsilon}_f^{pl}}\right), \quad (3)$$

Where $\Delta\bar{\varepsilon}^{pl}$ is an increment of the equivalent plastic strain, $\bar{\varepsilon}_f^{pl}$ is the strain at failure, and the summation is performed over all the increments throughout the analysis. The strain at failure $\bar{\varepsilon}_f^{pl}$ is assumed to be dependent on a non-dimensional plastic strain rate, $\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0}$; a dimensionless pressure-deviatoric stress ratio, $\frac{\sigma_m}{\bar{\sigma}}$ (where σ_m is the mean stress and $\bar{\sigma}$ is the equivalent von-Mises stress) and the non-dimensional temperature, $\hat{T}$, defined earlier in the Johnson-Cook hardening model. The dependencies are assumed to be separable and are of the form;

$$\bar{\varepsilon}_f^{pl}\left(\frac{\sigma_m}{\bar{\sigma}}, \dot{\bar{\varepsilon}}^{pl}, \hat{T}\right) = \left[D_1 + D_2\exp\left(D_3\frac{\sigma_m}{\bar{\sigma}}\right)\right]\left[1 + D_4\ln\left(\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0}\right)\right]\left[1 + D_5\hat{T}\right] \quad (4)$$

Where $D_1 - D_5$ are material parameters determined from different mechanical test, $\dot{\bar{\varepsilon}}^{pl}$ is equivalent plastic strain rate and $\dot{\varepsilon}_0$ is a reference strain rate. When material damage occurs, the stress-strain relationship no longer accurately represents the material behavior, ABAQUS [19]. The use of stress-strain relationship beyond ultimate stress introduces a strong mesh dependency based on strain localization i.e., the energy dissipated decreases with a decrease in element size. Hillerborg's [20] fracture energy criterion has been employed to reduce mesh dependency by creating a stress-displacement response after damage is initiated. It also takes into account the combined effect of different damage mechanisms acting simultaneously on the same material.