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Experimental and numerical investigation on the deformation and failure behavior in the Taylor test

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ABSTRACT

The present paper presents an experimental and numerical study concerning the deformation and failure behavior in the Taylor impact test. Projectiles manufactured from a commercial high strength and super-hard aluminum alloy 7A04-T6 with a nominal diameter of 12.6 mm and a length of 50.8 mm were fired against a hardened tool steel plate by a one- and two-stage compressed gas gun within the velocity range of 175–370 m/s. Three different deformation and failure modes were observed from the test: mushrooming, shear cracking and fragmentation. Individual velocity ranges and the transitions between the deformation/failure modes are identified by both experiments and numerical simulations. Slightly modified Johnson–Cook models of strength and accumulative damage failure are employed in 3D numerical simulations to describe material behavior of the striking cylinders. Good agreement between the numerical simulations and the experimental results was found. Detailed computational results of each scenario are offered to understand the deformation and failure mechanisms.

1. Introduction

Impact and impact related problems have been an active research topic not only due to the military demands but also the civilian motivation, especially since the September 11th attacks. A review of the literature on impacts at sub-ordnance and ordnance impact velocities shows that most publications focus on the penetration and perforation caused by rigid projectiles (see Refs. [1–3]), and that few papers dealt with deformation in an impacting projectile itself, especially fracture.

In addition to large plastic deformation, normal impact of a projectile at sufficiently high velocity often results in failure in the impacting projectile itself, even against soft targets, e.g., Børvik et al. [4,5]. The deformation and possible fracture would greatly influence the final impact performance. Investigations on the deformation and fracture of a kinetic energy projectile can advise warhead design. It is interesting to note that the deformation and fracture characteristics of a projectile can be approximately obtained by Taylor impact test [6–8], which involves the normal impact of a metal cylindrical rod onto a stationary rigid anvil. It is useful in high strain rate material tests because strain rates of 10^4–10^5 s^{-1} can be easily realized. Such strain rates are just beyond the available strain rates produced by the Split-Hopkinson Pressure Bar and the Flayer Plate Test [9]. Thus it is widely used to estimate the dynamic yield strength of the rod material and to evaluate constitutive models, e.g., Hawkyard et al. [10], and Johnson and Cook [11].

According to Walley [12], more than 400 papers were published over the past 50 years on the Taylor impact test. Most investigations concentrated on obtaining dynamic yield stress and validating constitutive models. While relatively few published papers deal with fracture phenomenon and fracture mechanisms in the Taylor test [13]. Woodward et al. [14] found tension splitting and fragmentation due to spiral shear cracking in some steel projectiles. Couque [15] observed several 45° shear cracks on the lateral surface of both the projectile and the target cylinders in the symmetric Taylor test [16]. Chapman et al. [17] observed petalling at the impact end of projectiles of aluminum alloy Al-6082–T6 in both the classic and symmetric Taylor test. They also found void nucleation in the central axis of both the projectile and the target rods for symmetric version of the Taylor impact test when the impact velocity is greater than 514 m/s. They further proved that the void nucleation is due to the coalescence of radial release waves at the specimen axis by FEM simulations. By numerical simulations, Teng et al. [13] found three distinct fracture modes: confined fracture inside the cylinder, shear cracking on the lateral surface and petalling. Anderson et al. [18] conducted several Taylor impact tests and examined the ability of numerical simulations to reproduce ductile damage as a function of impact velocity by using the multi-material, nonlinear Eulerian wavecode CTH. They found fracture around the circumference at the impact end of a rod. In addition, they found that it is not sufficient to describe the ductile

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