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HYPERVELOCITY IMPACT OF TI6AL4V ALLOY MATERIALS

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This article presents a study of dynamic failure events in forged, layered, and additive manufactured (AM) titanium alloy subject to hypervelocity impact. Experiments were conducted using a two stage light-gas gun, 0.22-caliber Lexan projectiles, and different types of titanium target plates. A four-channel Photonic Doppler Velocimetry (PDV) system was used to study the free surface velocities to provide an understanding of the different failure mechanisms in these materials. The experimental measurements were used to validate computational simulations, which describe the behavior of these materials under shock. It was determined that AM, forged titanium, and multi-layered stacks produce similar velocity profiles during the early stage of impact, with the AM targets exhibiting spall at lower velocities and the multi-layered stacks exhibiting vibrations between plates. Simulations of solid and layered forged materials provide a good match to experimental data.

Introduction

The Electron Beam Additive Manufacturing process is currently being used in industry and a quasi-static analysis showed only a 3%-5% reduction in mechanical properties compared to a forged titanium counterpart. The different microstructural morphology influences the damage and fracture behavior of the AM parts, potentially making it more brittle-like and causing early onset of damage [1]. This study compares damage mechanisms between forged and AM target plates under impact conditions. The complex microstructure of the AM materials is difficult to model computationally. Layered target plates made from forged titanium were also studied to provide an intermediate level of complexity for validating simulations.

Impact experiments were designed to produce large deformations on the back surface of targets without allowing full penetration of the projectile. Time domain velocity profiles measured on the rear surface can be used to infer shock propagation information during impact. Deformation geometry and velocity profiles were used to validate LS-Dyna computational simulations.

Experimental Methods

A series of hypervelocity impact experiments were conducted with a two-stage light gas gun, which uses a powder breech to fire a plastic piston into a pump tube filled with hydrogen. The gas is compressed as the piston moves through the pump tube and a petal valve that separates the pressurized gas for the launch tube ruptures, causing the projectile to accelerate down the launch tube and into the experimental tank [2]. The projectile is a Lexan cylinder with a 5.6 mm diameter and 8.61 mm length. Impact velocities ranged from 4.8 to 6.9 km/s. Target configurations included a) solid forged titanium alloy, Ti6Al4V, 12.7 mm thick, b) two layers of forged titanium alloy, with 6.35 mm layer thickness, c) four layers of forged titanium alloy with 3.175 mm layer thickness, and d) three variations of EBAM titanium alloy with 12.7 mm thickness. A four-channel laser interferometry system, Photon Doppler Velocimetry (PDV), was used to record the basic dynamic failure mechanisms in these complex structures. PDV is a heterodyne interferometer that gathers velocity data constructed by measuring displacement using optical fiber probes [3].

Computational Methods

Computational simulations of the solid and layered forged targets being impacted by a 0.22-caliber Lexan projectile were performed using a Smooth Particle Hydrodynamics (SPH) code in LS-DYNA. Johnson-Cook material models with Mie-Grüneisen equation of state (EOS) were utilized [4]. Two dimensional axisymmetric models were created for projectiles and targets and no boundary constraints were applied. Particle spacing for these models was 0.1 mm. This modelling approach was verified for homogeneous materials in previous studies [2 & 5].

Results and Discussion

Differences in deformation and failure of six types of titanium were documented for three different impact velocities. The AM, forged titanium, and multi-layered stacks produced similar velocity profiles during the early stage of impact, with the AM targets exhibiting spall at lower velocities and the multi-layered stacks exhibiting vibrations between plates. Figure

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1(a) compares target back surface velocity profiles for six target configurations. The forged computational model compared with experimental data is shown in Figure 1(b). Figure 2 shows the experimental results of the multi-layered target plates compared with the computational model. The multi-layer simulations still require some validation, however the simulations are able to capture the basic damage of the plates. The EBAM targets are extremely challenging to model because of the microstructure, porosity, and quasi-static property differences and have not been included in this work.

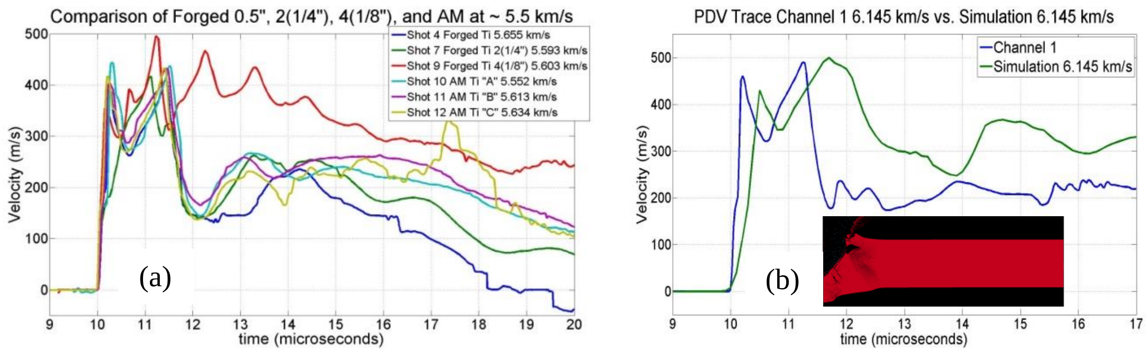

Figure 1. Velocity traces: (a) PDV data forged, layered, and AM material and (b) Experimental vs. simulation for forged titanium

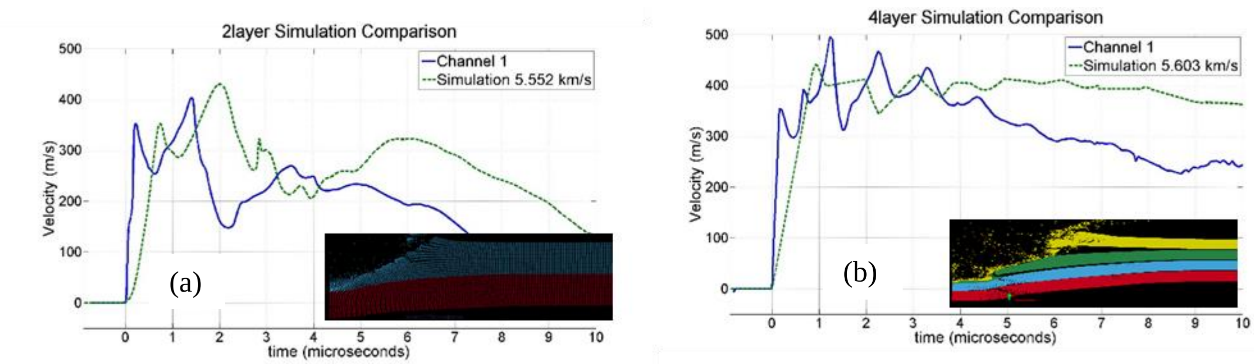

Figure 2. Experimental vs. simulation velocity traces: (a) two layers of forged titanium and (b) four-layers of forged titanium

CONCLUSIONS

The 4-channel PDV experiments were successfully completed to explore the dynamic behavior of forged titanium, stacked forged titanium, and AM titanium target plates. Differences in deformation and failure of six different types of titanium were documented for three different impact velocities. The AM material shows more damage than the forged plate for similar impact velocities and observations from these experiments indicate that the penetration velocity would be lower for the AM targets. Computational models were developed to simulate projectile-target interaction for the forged and multi-layered titanium plates. Reasonable agreement was found with experimental data. Additional microstructural geometry details and material property variations are needed in order to develop models for the AM titanium.

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