DYNAMIC FAILURE IN METAL-POLYMER BILAYERS

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Summary. The problem of strain localization and failure in metallic specimens under high strain-rate loading is considered through experiments and simulations. Tubes of an aluminium alloy, either bare or coated with polymers such as polurea or polycarbonate, are expanded at strain rates on the order of 10000 per second until failure. The development of plastic strains, strain localization and eventual fracture are monitored using high speed photography. The results are interpreted in terms of dynamic forming limit diagrams. In addition, the influence of the polymer on the failure of the bilayer system is examined. Numerical simulations of the experiments are also reported.

INTRODUCTION

Blast protection has become an important problem in many military and civilian structures. In this regard, a rather interesting phenomenon has been observed experimentally – coating metallic structural components with a layer of a compliant polymer, typically an elastomer with a glass transition temperature significantly below the use temperature, decreases the propensity of the metallic structure to fracture and fragment [1,2]. The ability of the elastomer to withstand significant stress at high strain rates and elongations, and the consequent influence on the deformation of the metal are the key factors in the improved blast resistance of the polymer/metal system. Three main avenues of investigations have been pursued in this regard (see [3] for references to these efforts). The first is related to the failure of the metal; ductile failure in the underlying metallic structure is typically initiated through strain localization, followed by damage processes within this localized zone. Therefore, the role of the polymer layer in delaying or inhibiting the onset of strain localization has been pursued. The second avenue relates to the structural response of the metal-polymer bilayer systems. The last group of investigations is related to the constitutive characterization of the polymer; a number of investigators have explored the dependence of the mechanical response of the polymer on stoichiometry, on the strain rate, and on the effect of confinement and pressure. In this paper, we focus on the results of experiments that reveal the underlying deformation of the metallic specimen without and with a polymer coating. Considerations of the design of metal-polymer bilayers for optimal energy dissipation will also be presented.

EXPERIMENTS

An electromagnetic loading device was used for expanding bare Al 6061-O tubes and tubes coated with a layer of polyurea or polycarbonate. The interaction between the current in the coil and in the sample is used to generate repulsive Lorentz forces that apply a radial body force, causing high speed radial expansion of the sample. This expansion corresponds typically to strain rates in the range of ~3600 – 9200 s^{-1}. A Cordin Model 550 high-speed camera is used to monitor the expansion of the samples. The camera is synchronized with the experiment to record the event at a framing rate of ~150,000 frames per second; the expansion of the specimen can be followed for about 200 μs. Two xenon flash lamps are used to illuminate the sample. In order to facilitate viewing the entire cylindrical surface of the specimen, a conical mirror arrangement is used; this allows for real-time measurements of strain on the entire cylindrical surface of the sample. In order to measure the local strain, the tube surfaces were electrolytically etched with a pattern of circles. Details of this method have been discussed by Zhang et al., [3,4].

EXPERIMENTAL RESULTS

The main experimental observations are listed here: the aluminum tube specimens, either bare or with the polymer coating, experience uniform expansion until a critical strain is achieved; an approximately uniaxial stress condition is achieved in the short tube specimens before the onset of localization. This is followed by the nearly simultaneous nucleation of shear band localization at numerous locations in the specimen. Localization develops in the form of multiple crossing shear bands at angle of about 54° to the tensile loading direction. The forming limit diagram obtained from these measurements indicates that the localization criterion developed from quasi-static considerations continue to apply in the dynamic problem. Eventually the specimen fails by generating fractures at the intersections of many of the shear bands. The response of the polymer coated specimens is quite similar to that of the bare aluminum tubes; there appear to be two important quantitative effects of the polymer coating on the response. First, the additional mass of the coating material results in an inertial effect; therefore, for the same applied loading, specimens with the thicker coatings result in a slower overall expansion, and hence for a limited impulse loading, less overall straining of the metallic specimen. Second, the flow resistance of the polymer results in dissipation of additional energy and can prevent or delay the failure in the metallic specimen. This effect is much more pronounced in polycarbonate, the material with a larger strength than in the polyurea. Parametric studies have been conducted and the results will be reported.

NUMERICAL SIMULATION OF THE BILAYER TUBE

While reduced models such as plane-strain or shell elements may be computationally cheaper, they cannot be used to represent the deformations experienced by the expanding tubular specimen. Therefore, a three-dimensional model which resembles the geometry of the tube specimens is used. On the other hand, for simplicity, we consider only a quarter segment of the tube and impose symmetry boundary conditions; this model reduction does not limit the possible deformation and localization modes observed in the experiments. The model is discretized with eight-node linear brick elements with reduced integration and hourglass control in ABAQUS (C8D8R); a small percent of the total elements are randomly selected as material defects to trigger localization. The tube material is taken to obey the power-law hardening model with a J_2 flow theory for 3D generalization. A pulse pressure loading is used to simulate the electro-magnetic driving force experienced by the tube specimen in the experiments. The resulting expanding velocity of the tube is about 215 m/s in the first 40 μs, and corresponds to a strain rate of about 10^4 s^{-1}. In order to continue the simulation properly beyond the level of localization, a critical strain based criterion and element deletion technique is used to mimic material failure. An example of the results of the numerical simulation is shown in Fig.1. The response has been shown to be quite representative of the experimental measurements, both in the coated and uncoated tubes.

CONCLUSIONS

In this paper, we consider the deformation and failure of metallic cylinders under high strain rate loading, both with and without a polymer coating through experiments and simulations. The experiments clearly indicate that the key precursor to failure in the metallic specimens is the onset of strain-localization and is influenced significantly by material defects. The underlying mechanics is explored through numerical simulations. Some guidelines for design of blast resistant coatings will also be discussed.

References

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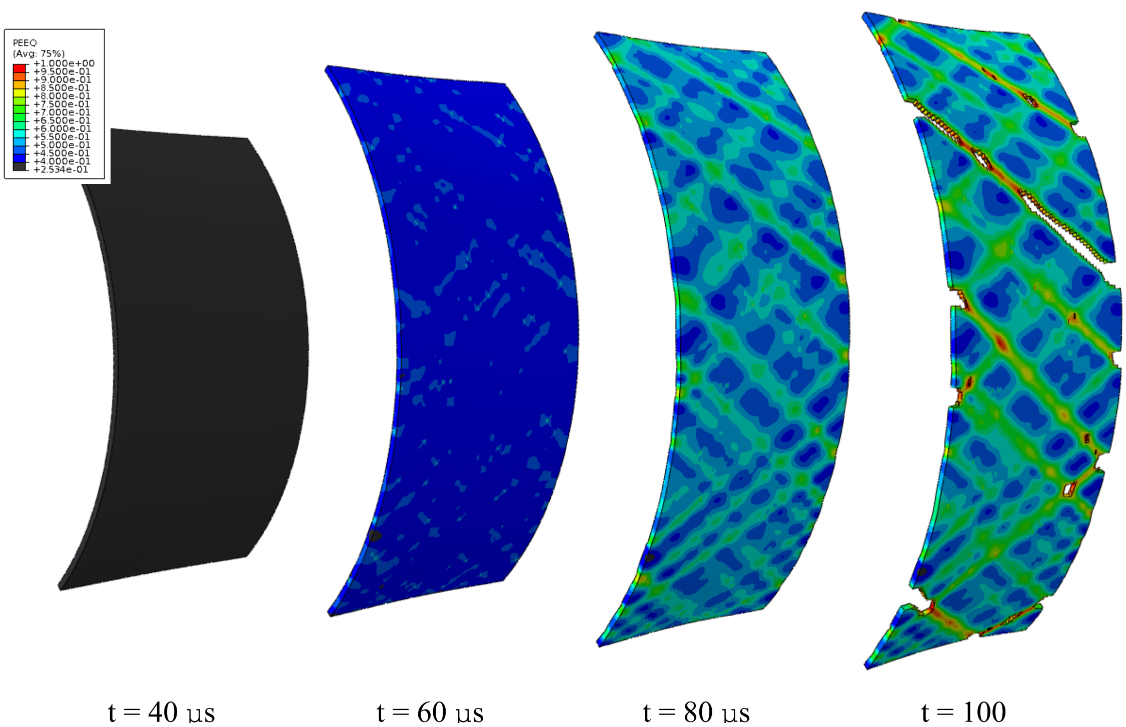

Fig. 1. Contour plots of equivalent plastic strain from one simulation. Bare Al 6061-O specimen, with $t_{AL} = 0.5$ mm. Similar results have been obtained in the case of Al 6061-O specimens coated with polyurea or polycarbonate.