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Lagrangian analysis led design of a shock recovery plate impact experiment

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ABSTRACT

Shock recovery techniques, such as the flyer-plate impact test, are used to examine a material that has been subjected to a single well-defined shock, followed by a single release wave. One of the key requirements of this type of technique is that the process should be such that any change found in the sample after recovery, can only be attributed to the shock process alone. Therefore, the principal problem for a test specimen-fixture assembly is that it is designed such that the loading history of the recovered specimen is known. This has motivated this research through the analysis led design of a shock recovery experiment. The choice of Lagrangian Finite Element Analysis for this design work was driven by the method's ability to accurately track history variables (for plastic deformation) and treat contact interactions which are crucial in this problem.

Starting from an initial configuration, LS-Dyna has been used to analyse in detail the resulting wave propagation to ensure the generation of a uniaxial strain state in the specimen through Lagrangian distance-time diagrams. These iso-maps enabled the identification of potential shortcomings with the initial design, in terms of the transmission of contact and the influence of radial release waves at the different boundaries between specimen and supporting fixture rings.

The benefits of using Lagrangian Finite Element Analysis for this design work are its ability to track history variables (for plastic deformation) and contact treatment. Based on these findings, a new configuration was developed, which consists of an array of concentric rings that support the specimen. During shock formation in the specimen, these rings progressively transfer the loading in the impact direction and radially away from the specimen, acting as momentum traps and preventing unwanted release waves from affecting the strain state experienced by the specimen.

Comparing distance time diagrams between original and proposed configurations, a design sensitivity analysis was performed, where the new geometry resulted in a decrease of both the residual velocity (−38%) and radial displacement (−27%) of the target when compared to the original setup.

1. Introduction

The plate impact experiment [1–3] is a fundamental tool in the experimental investigation of material behaviour at high strain rates. In addition to providing Hugoniot data it is increasingly used, combined with soft recovery techniques, to investigate the response of materials to shock loading [4–7]. Proper understanding of the recovered sample requires knowledge of the shock history experienced by the sample. Ideally the sample is exposed to a single shock compression, followed by a single release, while remaining in a state of uniaxial strain. In practice reflected waves generated at the free surfaces of the specimen and flyer plate interact and influence the strain history of the material, shown schematically in Fig. 1 making it impossible to separate from the effects of the desired single shock release [8]. This lead to the development of the concept of the momentum trap [9], which in its simplest form is the addition of an additional block of material, impedance matched to

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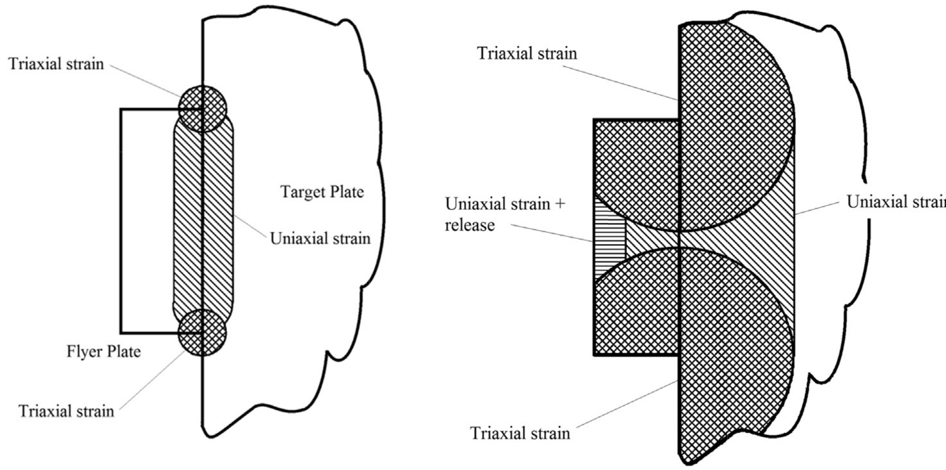

Fig. 1. Impact of a finite flyer plate onto a semi-infinite target, a few moments after impact (left) and at a later time (right).

the sample, that allows the transmission of the initial compressive wave from the sample without reflection but separates from the sample before undesired release waves reach the contact interface.

Due to the complexity of understanding what is going on during a shock recovery test, several researchers have adopted the use of numerical analysis. An early investigation by Stevens and Jones [10] analysed the effects of radial release phenomena and the beneficial influence of incorporating guard rings using a two-dimensional Lagrangian finite difference code. Rabie and Vorthman [8] who performed three-dimensional computer modelling in order to prove that the mid-section of star shaped samples were protected from the effects of the radial release and were in a state of uniaxial strain. More recently studies by Stojkovic [15], Bourne and Gray [12] and d'Almeida et al. [6] have applied hydrocode analysis to the design of a shock-recovery target fixture.

This paper presents an analysis methodology for shock recovery fixtures based on the use of Lagrangian finite element analysis. The use of Lagrangian methods allows for natural treatment of material interfaces, including contact interfaces. The accurate treatment of the interaction of the separate components of the target fixture is critical to the accuracy of the numerical model. Additionally Lagrangian methods naturally track material history parameters, an advantage when more complex constitutive models are used. This analysis methodology is described in section 3 and is then applied to the optimisation of an improved fixture design in section 4.

2. Baseline experimental layout

An initial configuration was investigated (Fig. 2), which consists of nine different parts, whereby the specimen/target is surrounded by inner and outer rings, together with four spall plates and a cover plate.

With this configuration, a flyer plate whose diameter is large compared to its thickness allows planar, high amplitude waves of uniaxial strain to be generated in the central portion of the specimen, before the arrival of any release waves from the edges of the specimen. This is made possible by allowing the specimen to separate from the fixture plates and surrounding materials through the incorporation of lateral release, resulting in the trapping of tensile release waves in the surrounding components, which cannot re-enter the specimen.

The separation between parts plays a critical role, since it directly influences the propagation of a shock wave across an interface. Tolerances have to be tight in order to provide shock continuity and to prevent any reflections occurring at the interfaces between parts. Bourne and Gray [11] state their assemblies are manufactured to machining tolerances of 25.4 μm. In this study, the effect of machining tolerances was taken into account in the numerical analysis by introducing a 10.0 μm gap between all components which is considered as an average value.

A momentum trap behind the target (which consists of four spall plates in Fig. 2) has two purposes. Firstly, it prevents any unwanted reloading, except for the initial compressive and tensile wave reflected from the backside of the flyer plate, and secondly, is used to trap part of the momentum in order to decrease the residual velocity of the specimen.

The function of the inner and outer ring (lateral momentum trap) is to constrain the target in the radial direction and reduce lateral loading of the sample. These rings have to be sufficiently sized to provide enough time for the release wave coming from the back of the flyer plate to unload the specimen and allow its separation from the fixture, before any radial release waves arrive. In addition, these rings also serve to absorb part of the impact energy.

The flyer plate for the given test set-up has a diameter of 25 mm and a thickness of 3 mm and an initial velocity of 300 ms^{-1}. The

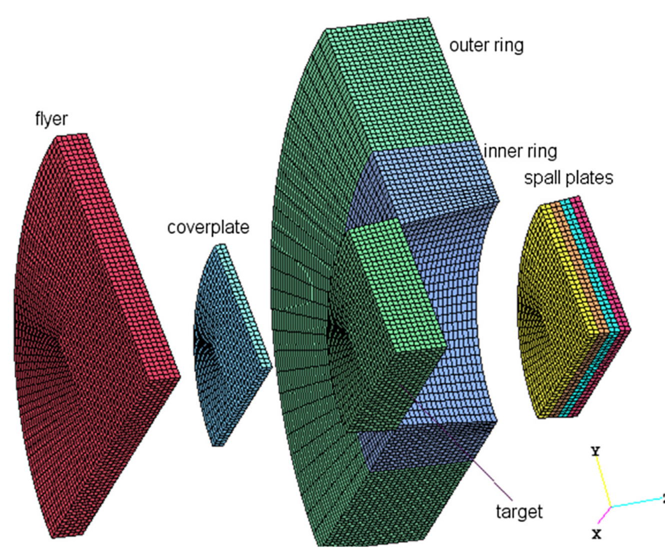

Fig. 2. Finite element discretisation of baseline configuration — low resolution model shown for clarity.