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FINITE ELEMENT ANALYSIS OF HIGH SPEED IMPACT ON ALUMINIUM PLATE

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ABSTRACT

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This work investigates a basic problem in crashworthiness by finite element modelling. A circular plate in aluminium alloy is the material used as a target. Different impact conditions are simulated. The projectile is modelled as a rigid body, as a harder body compared to the target, and a softer as well. An Arbitrary Lagrangian Eulerian formulation, coupled to a Cockroft and Latham element deletion model is used for simulating the transition from ductile to brittle fracture. Results by finite elements are compared to experimental tests and analytical models based on the energy of the impact.

Keywords: high strain rate, aluminium plate, finite elements, fracture.

INTRODUCTION

Crashworthiness is an area of ongoing research and the comprehension of phenomena involving high and low energy impacts are relevant to a wide range of engineering applications, first of all safety in transport. The core of research in crashworthiness is essentially based on crash test. However, the main problems in the experimental approach are the high cost of test, the non-repeatability, and the difficulty in having a deep insight in the problem. Numerical simulation of dynamic impact events has reached a level of maturity at which it is often used as a design tool for a wide variety of transport structures in aerospace and automotive industry. Explicit transient finite element modelling of even the simplest of problems, such as a regularly shaped projectile impacting a flat plate can result in widely varying results, depending on the material and failure models, available material properties, the contact models, the mesh density, and a number of different numerical parameters that must be specified in the computer codes. Accurate impact models includes high strain rate material properties, failure modes, and static properties: a comparison with impact test measurement is necessary to validate the impact model. However the difficulties in obtaining quantitative measurement lead to considerate the role of finite element simulations as the main design method in crashworthiness, if simple models are supported by experimental analysis [1].

From a mechanics viewpoint, the consequences of an impact are threefold. First, stress waves or shock waves are propagated inside the impacted bodies, and the propagation of these waves must be understood. Second, large inelastic deformations might be developed, typically at high rates of deformation. Third, the entire impacted structure might be excited by the impact, leading to structural dynamics and vibration problems. This research work will not consider the third of these consequences. From a velocity point of view, ballistics impacts occurs within 1-2 km/s and vehicle impacts within 0.2-1 km/s, with the peak strain rates within the order of 10^5 s^{-1} to 10^6 s^{-1} [2].

However, the solution is strongly dependent on material model. This work investigates the problem of impact on a circular plate in Al2024 T3, a material widely used in aerospace and automotive industry.

FINITE ELEMENTS APPROACH

Simulations were carried out on the commercial software DEFORM-3D v6.1, with an Arbitrary Lagrangian Eulerian formulation and automatic remeshing. Remeshing parameters were set in order to obtain the finest mesh were high speed deformation occurs. Remeshing triggers are listed here: interference depth, strain intensity, strain rate intensity, quality of the tetrahedral elements (overall deformation of the elements). The simulation represents a rigid cylindrical projectile impacting at 200 m/s and passing through a Al2024 T3 round plate with a radius of 100 mm and a thickness of 3 mm. In order to save computational resources, symmetries were used, so that only a quarter of the plate was simulated. The plate was meshed by a mainly tetrahedral mesh with 58527 elements (13711 nodes). Figure 1 shows an overview of the FE model with the elasto-plastic model of plate with the rigid bullet impacting on the centre of the plate.

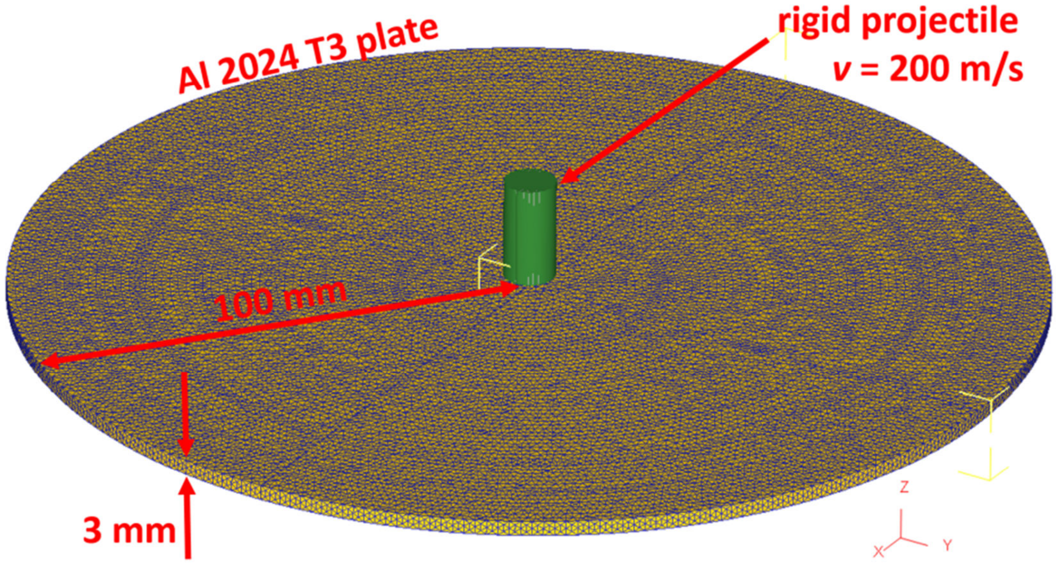

Fig. 1 - Overview of the finite element simulation geometrical setup with symmetries

An adaptive remeshing algorithm activate by a relative interference depth of 0.7 allows the recalculation of the mesh when the deformation of elements exceed the 70% of their length. The initial mean element length is 1.5 mm, however, as mesh deformation occurs due to the impact of the cylindrical bullet, the element size in the remeshing is inversely proportional to strain and strain rate, in order to capture strain and strain rate dependent phenomena in the region of interest (ROI). The mesh size ratio between the largest and the smallest element was set to 15, so that the smallest element in the mesh has a size of 0.1 mm. Figure 2 illustrates

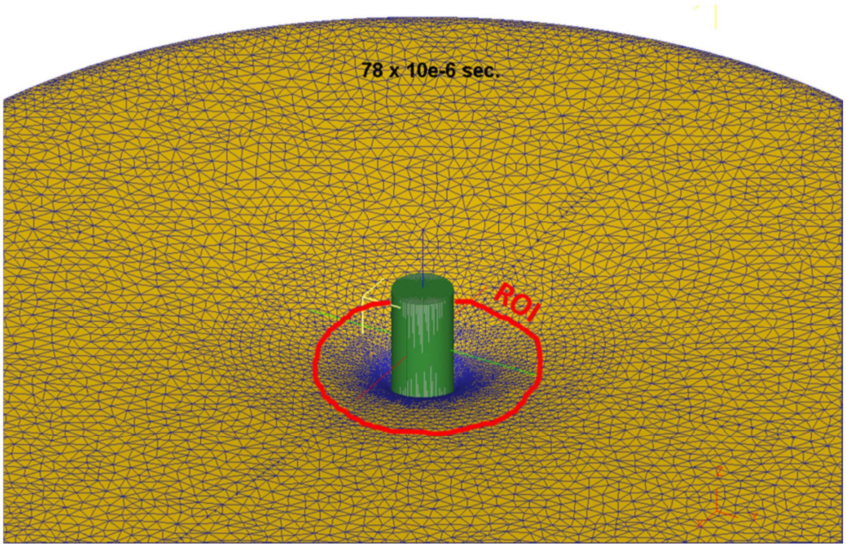

Fig. 2 - As the bullet deeply impact into the plate, adaptive remeshing is activated and a new mesh is generated with the smallest elements concentrated in the region of interest (ROI)

FLOW STRESS AND DAMAGE MODEL

In order to account strain hardening, flow stress models as a function of the strain rate have to be were used in the finite element simulations. Flow stress models set the relation between the plastic flow stress $\bar{\sigma}$, the effective strain $\bar{\varepsilon}$ and the strain rate $\dot{\bar{\varepsilon}}$. More complex models involves the temperature rise during deformation. Various analytical equations have been used to fit the flow stress data obtained from tension, compression, and torsion tests. The specific form of the equation usually depends on the test temperature and on the strain rate [5]. The use of two different flow stress models [6] was used in this research work:

$$\bar{\sigma} = c\ \bar{\varepsilon}^{n} \dot{\bar{\varepsilon}}^{m} + y$$

(Eq. 1 - Power Law flow stress model)

$$\bar{\sigma} = \left(A + B\bar{\varepsilon}^{n}\right)\left[1 + C\ln\left(\dot{\bar{\varepsilon}}\right)\right]\left(1 - T^{*m}\right) \quad where\ T^{*} = \frac{T - T_{room}}{T_{melt} - T_{room}}$$

(Eq. 2 - Johnson - Cook flow stress model)

Flow stress data by Rodriguez-Martinez et al. [7] was used for model fitting:

Table 1 - values for Power Law flow stress model

C	N	m	y
84.0972	0.419404	0.0140737	270

Table 2 - values for Johnson-Cook flow stress model

A	B	C	N	m	T_{room}	T_{melt}
2670.18	-2307.27	0.000745645	-0.0161982	3.44782	20	1500

In finite elements simulations the Power Law was chosen since this flow stress model allowed a better agreement with the results obtained by Pereira [1].

In order to model the transition from ductile to brittle behaviour, the normalized Cockroft-Latham element deletion approach was used. The Cockcroft-Latham damage model has been shown to be a good indicator of certain types of tensile ductile fracture in cold parts and high strain rate deformations [8]. The normalized Cockroft-Latham failure model is a criterion on the maximum deformation work a material can support before cracking (in the case of a homogeneous material) or unbounding (in the case of heterogeneous material).

$$\int_0^{\bar{\varepsilon}} \frac{\sigma^*}{\bar{\sigma}} d\bar{\varepsilon} = const. = 0.45$$

(Eq. 3 - The normalized Cockroft-Latham coefficient used in this research work)

The ratio between the maximum stress (in any direction) σ^* and the effective stress $\bar{\sigma}$ integrated along the effective strain $\bar{\varepsilon}$ should be lower than a constant value, otherwise the element deletion occurs. If the mesh is extremely fine, the normalized Cockroft-Latham model shows a good correlation with experimental data obtained by Digital Imaging Correlation. The value of the Cockroft-Latham coefficient of CL = 0.45 shows a good correlation with the measurements taken by Pereira et al. [1].

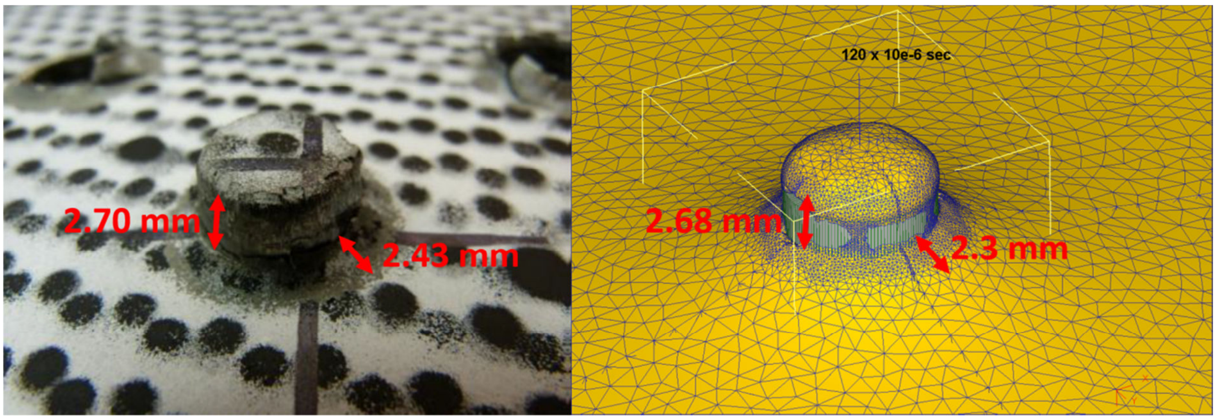

Fig. 3- Comparison between the experimental tests and finite element model with CL = 0.45

Figure 3 shows the experimental tests reported by Pereira et al. [1]. The bullet crashes into the Al 2024 T3 plate and the penetration depth is 2.70 mm for a local deformation zone with 2.43 mm of thickness. On the right side of the image the finite element simulation carried out with the damage model by Cockroft - Latham shows similar dimensions. Also, both of the images show a built-up layer on the plug, with similar thickness.

RESULTS

Simulation results shows the bullet impact the plate after 13x10^{-6} sec. The elastic behaviour of the material propagate the stress wave at a speed of 2.5 km/s.

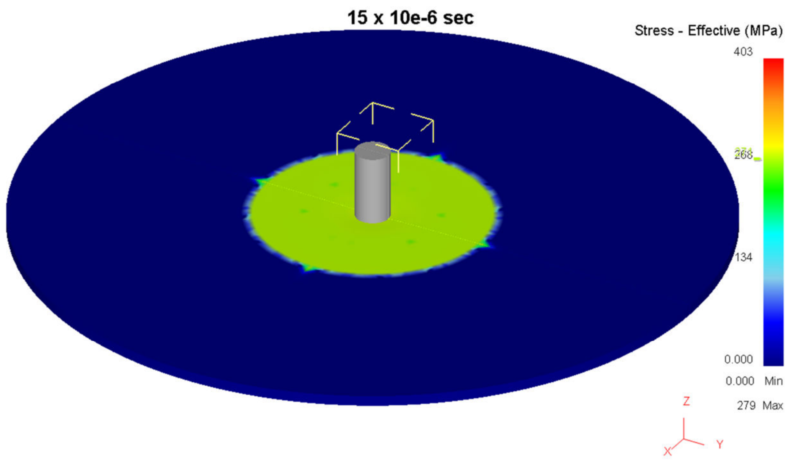

Fig. 4 - Propagation of a stress wave within the plate

CONCLUSION

The finite element simulation of low ballistic rigid plug against Al 2024 T3 plate with flow stress model by power law and Cockroft-Latham damage model show a good agrements in terms of digital imaging correlation with the experimental tests. This lead to a better understanding of the stress wave propagation within the material during impact.

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