Deformation, fragmentation and acceleration of a controlled fragmentation charge casing

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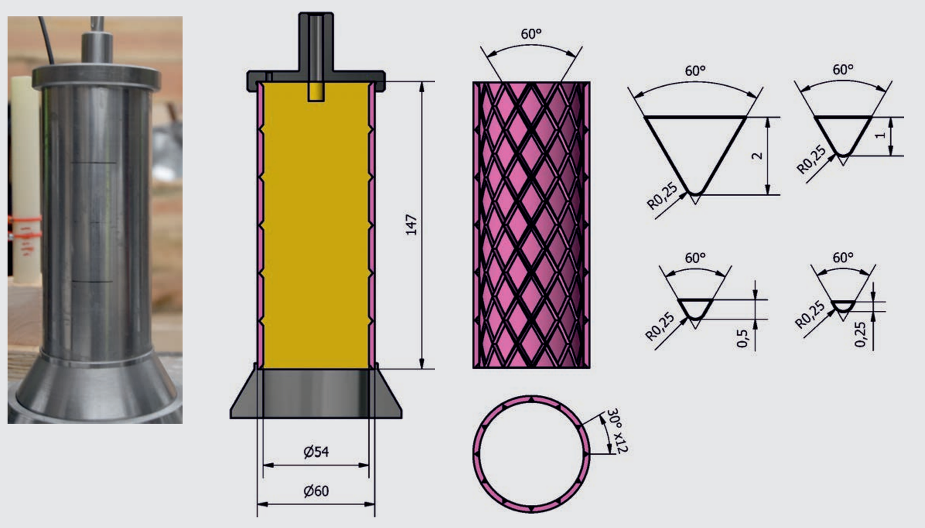
Introduction

Two different finite element software, LS-DYNA and Impetus, have been evaluated to test their ability to predict the deformation, fragmentation and acceleration of a controlled fragmentation charge casing. In order to acquire data to validate our computational tools and constitutive models, a series of experiments have been performed using a laboratory charge with an internal grooved casing. In the test series, the charge geometry was fixed except that the groove depth were varied from very shallow to very deep resulting in different deformation patterns, fracture modes and terminal velocities. Various diagnostic tools captured the different stages of the expansion and fragmentation of the casing. In addition, the fragments were soft recovered in a set of sawdust pit tests and their final shape and weight were measured. A SEM was used to characterise the fracture surfaces and to determine the modus of fracture.

Method

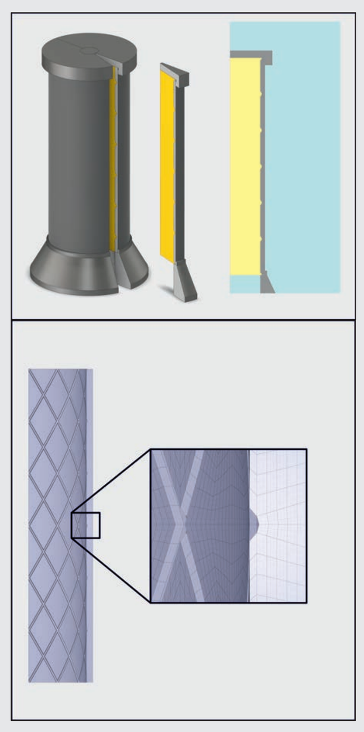
Test charge

Four casing types with different grove depths were studied. The casing material was S355J2H. Melt cast hexotol (Comp-B) was used as HE filler with obtained density 1.67 g/cm^3. A 5 mm thick steel cover with a concentric hole was positioned on top of the charge to provide confinement and for positioning the detonator.



Simulations

The general-purpose program LS-DYNA was used with a multi-material ALE formulation and a mass-preserving erosion criterion coupled to a Johnson-Cook fracture criterion. The rotational symmetry of the charge was fully utilized and only a small sector (a half fragment column with a 15-degree opening angle) was included in the model. A small core of the HE around the axis was replaced by a rigid boundary to avoid very small tetragonal elements at the charge axis. Symmetry boundary conditions were used at the sector planes. Typical element lengths were 0.25 mm and the complete model consisted of 3.5 million solid elements.
In the Impetus simulations, a third order Lagrangian element formulation was used for the casing and a node-splitting element erosion treatment coupled to a Cockcroft-Latham failure criterion was used to describe casing fracture. The high-explosive gases were described by a discrete particle formalism using a modified ideal gas EOS with co-volume corrections. A quarter sector of the geometry was included in the model. The model consisted of 90 000 solid elements and 10 million particles.

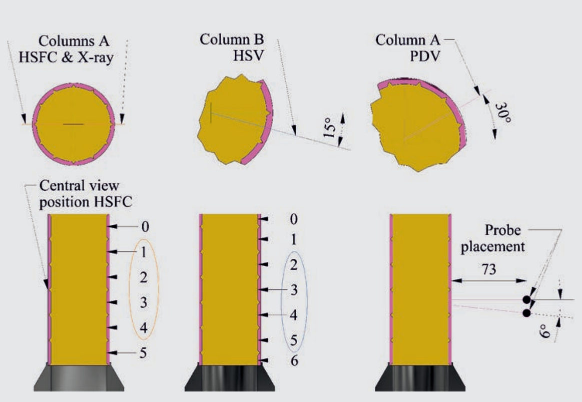


Computational geometries, LS-Dyna top, Impetus bottom

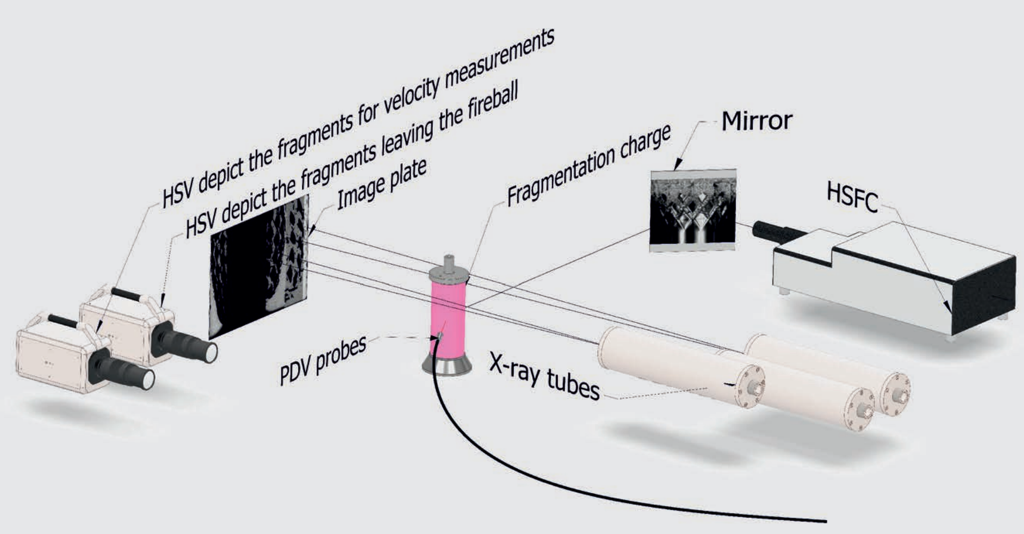
Time resolved fragmentation and acceleration diagnostics

The casing deformation and approximate breakup time was captured by a high-speed framing camera (HSFC). Three different techniques were used to measure the velocity of the casing and the final fragments; Photon Doppler velocimetry (PDV) to determine the initial acceleration of the casing, double exposed radiographs (X-ray) to estimate fragment velocity after breakup and a high-speed video (HSV) to determine the terminal velocity of the fragment after leaving the fireball.

There are two alternating fragment columns where one, denoted A, contains six full diamonds and one, denoted B, contains five full and two half diamonds. The different diagnostic tools were tracking slightly different fragments.

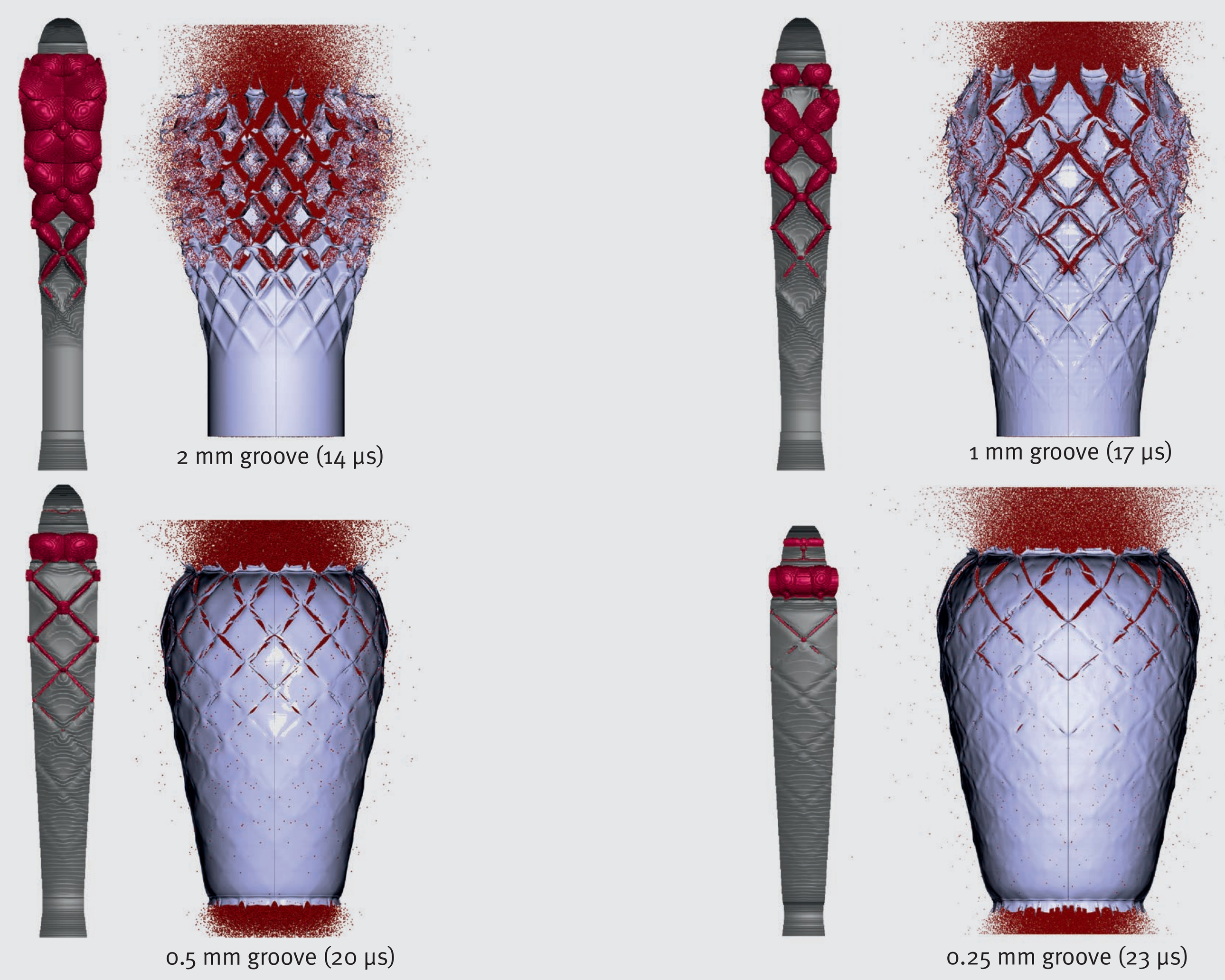


Position of fragments used for registration by:
(a) HSFC and X-ray, (b) HSV and (c) PDV.



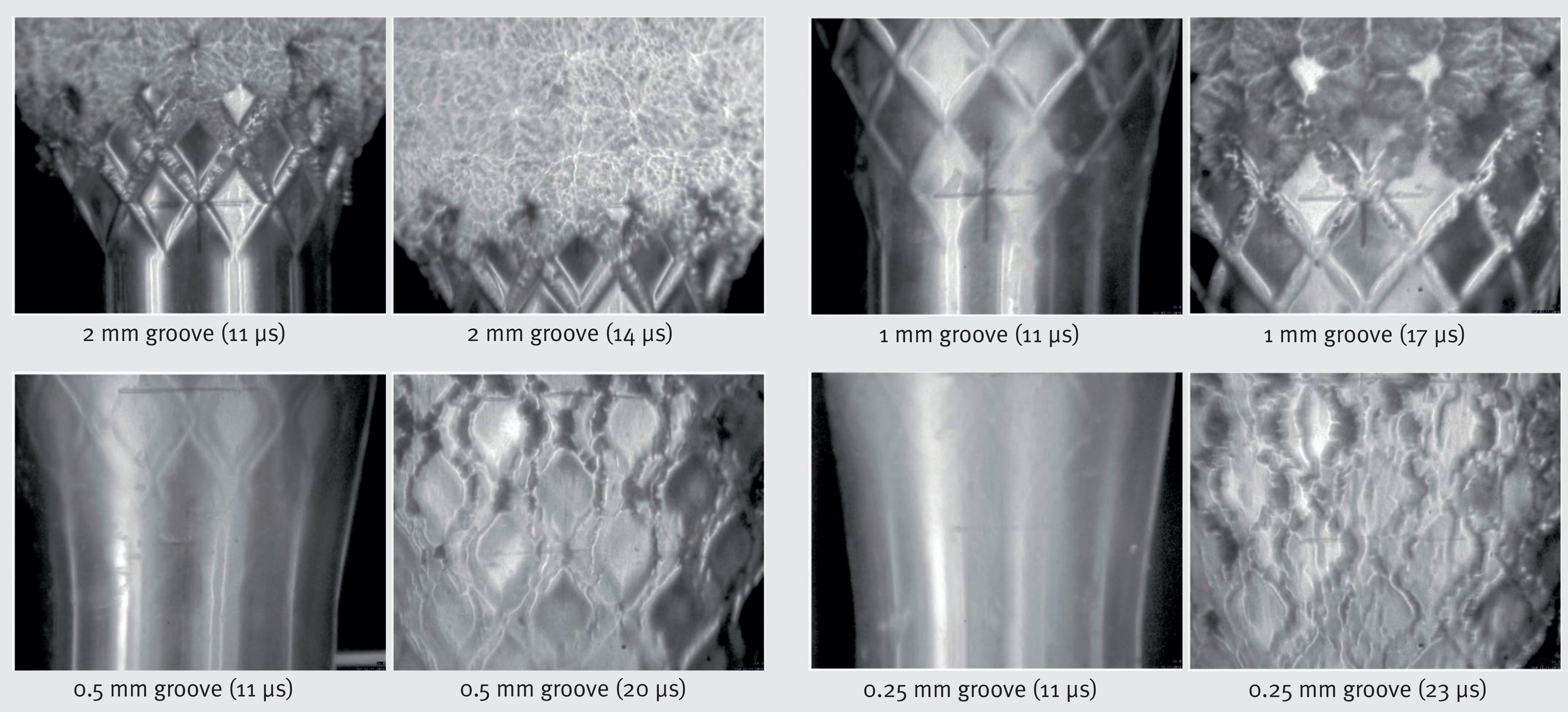
Results

Numerical simulation

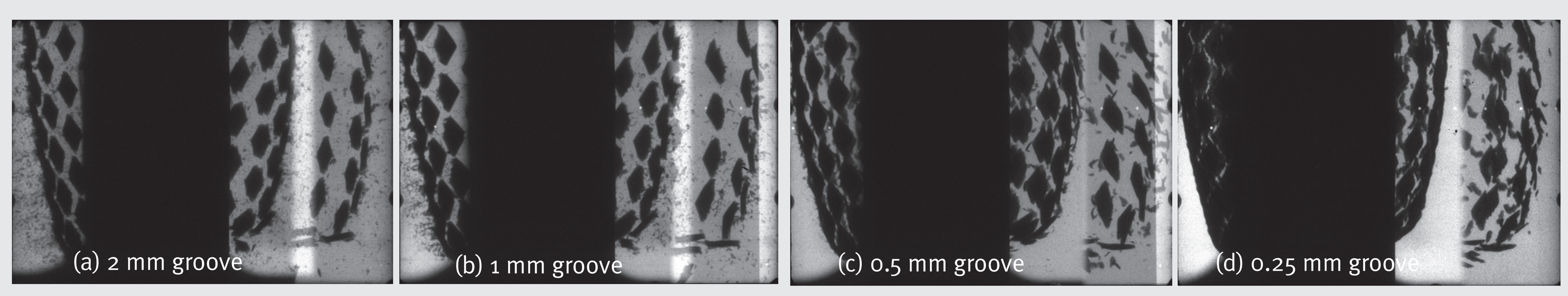


Numerical simulation of the deformation and breakup of the casing. For each groove depth, LS-Dyna to the left and Impetus to the right

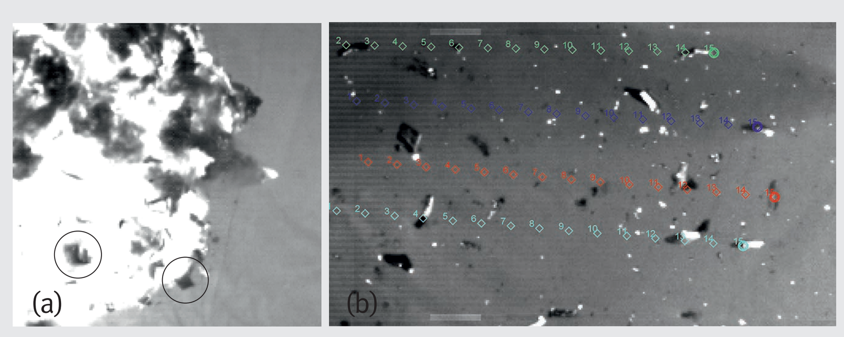
Experiments



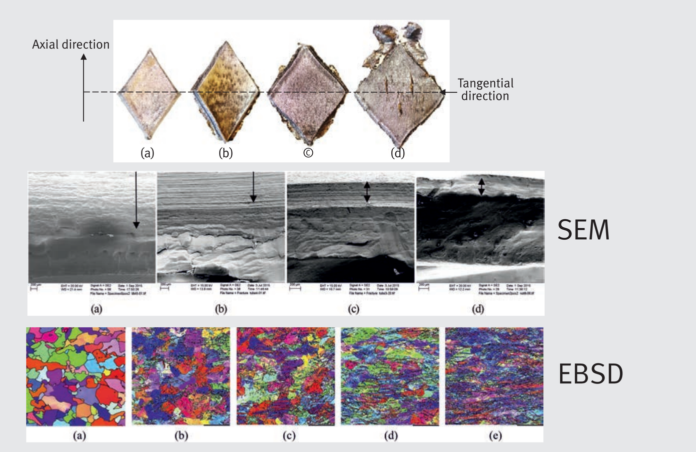
HSFC-pictures showing the initial deformation pattern of the casing at two different times. Left, arrival of detonation front. Right, start of fragmentation (matching the times of the numerical simulation snapshots shown above).



Radiographs of the fragmentation process for different groove depth: (a) 2.0 mm, (b) 1.0 mm, (c) 0.5 mm and (d) 0.25 mm, respectively.



HSV-picture at two different positions from the charge: (a) at the position when the fragments leave the expanding fire ball (two fragments are marked with circles) and (b) at 1.2-1.5 m from the charge were the terminal velocity of the four leading fragments are evaluated. The direction of flight is to the right in the pictures.

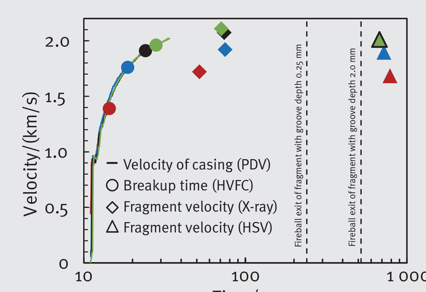


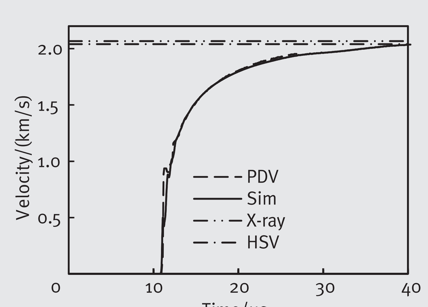
Fragments were soft-caught and analysed with regard to the fracture surfaces and deformation using SEM and electron backscatter diffraction (EBSD).

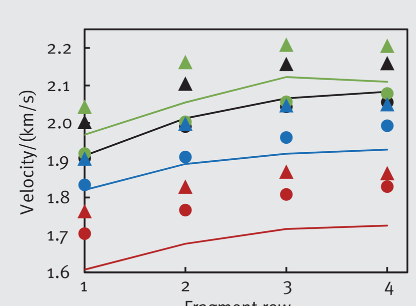
Analysis

The deformation of the casing depends strongly on the groove depth. For deep grooves, the case material is rapidly punched out from the bottom of the grooves. This material forms a fast expanding cloud of small fragments ahead of the main fragments. The fracture mode is in this case dominantly tensile as seen in the SEM-picture. For shallow grooves, the deformation is less localized with a tendency of necking in the region of the groove. This is most pronounced for groove depth 0.5 mm. The fracture mode is in this case mainly shear controlled. The post breakup velocity increase are largest for the casing with the 2.0 mm grooves, a nearly 20 % increase was observed after the breakup of the casing. The post breakup acceleration decreases rapidly for shallower grooves, and the velocity increase is only around 8 % or less for 0.5 and 0.25 mm deep grooves. On the other hand, the premature fracturing of the casing with deep grooves result in markedly reduced terminal velocity of the fragments.

Comparing the results from the numerical simulations and the experiments show that both software can predict the change in deformation behaviour when the groove depth increases, from tangential necking for shallow grooves to radial punching for deep grooves. Both software could also reasonable well predict the acceleration of the fragments, though both overestimates the terminal velocity for the charge with the deepest grooves.







Conclusions

The study shows that detailed numerical simulations using relevant material models and calibrated material parameters can predict both the fragment shape and the velocity of a controlled fragmenting charge with high fidelity. Fast running models often lacks the ability to resolve the influence of grooves on the terminal velocity of the fragments and the fragment distribution. The presented experimental data can be used for benchmarking numerical simulation tools and for developing simplified acceleration models for fast running semi-analytical lethality software

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