Numerical modelling of the effect of using multi-explosives on the explosive forming of steel cones

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Abstract. Modelling and analysis of underwater explosive forming process by using FEM and SPH formulation is presented in this work. The explosive forming of a steel cone is studied. The model setup includes a low carbon steel plate, plate holder, forming die as well as water and C4 explosive.

The effect of multiple explosives on rate of targets deformation has been studied. Four different multi-explosives models have been developed and compared to the single explosive model. The formability of the steel plate based on forming limit failure criteria has been investigated. Aspects such as shape of plates deformation and thickness of the plate during the forming process have been examined.

The model results indicate that a multi-explosives model does not always guarantee a faster rate of target deformation without central explosive. On the other hand the model results indicate that the multi-explosives setup is capable of preventing crack failure of the steel plate during the forming process which would occur if a single explosive model was used.

1. Introduction

Explosive forming is based on releasing a high amount of energy in a short time into a surrounding environment, creating a shock wave which travels through an energy transfer medium and reaching the work piece, results in the deformation of the work piece. This process has been used in the aerospace industry since the $1960 - 70$s. For example, National Aeronautics and Space Administration (NASA) has carried production work for the skin of the Apollo space rockets [1]. The main elements involved in the explosive forming process are: the explosive charge, an energy transfer medium, a forming die and the workpiece. One can distinguish two main types of explosive forming: the contact technique and stand-off technique [1]. In this paper the stand-off technique will be considered, and particularly the application of the explosive forming process to the forming of a steel cone. Water will be used as the energy transfer medium, and a C4 explosive as explosive charge. The objective of the work presented in this paper is to
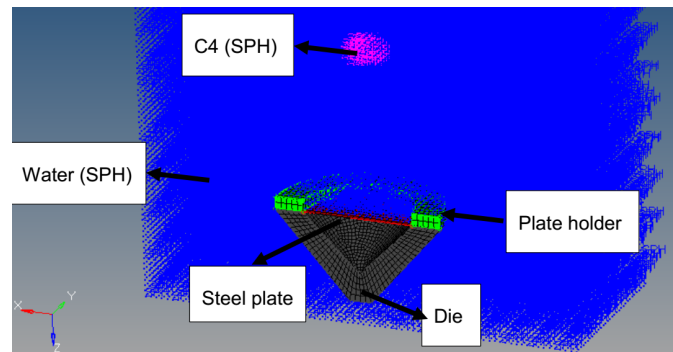
Figure 1. Overview of different parts in the numerical model

determine whether the use of multiple explosive charges offers potential benefits of the use of a single explosive charge.

2. Model Description

In Finite Element Analysis of the explosive forming process the Lagrangian, Eulerian and Arbitrary Lagrangian Eulerian spatial descriptions have been used in the past [2, 3, 4]. However, in this paper a different approach will be followed by using a coupled Finite Element - Smoothed Particle Hydrodynamics (FE-SPH) solver available in LS-Dyna [5]. This choice is based on the Lagrangian nature of the SPH method which makes tracking interfaces more straight forward than in Eulerian methods and is combined with the methods ability to deal with large deformations, hence avoiding numerical problems associated with element distortion/inversion. As stated in the previous section, the component to be formed will be a steel cone. The specific setup is based on the work presented in [6] and consists of a forming die with a base diameter of $200mm$ and angle of 90degrees, and a plate holder. The die and plate holder are modelled as a rigid body and discretised using hexahedral elements. The workpiece is a $1.6mm$ thick low carbon steel plate with a diameter of $200mm$. The plate was modelled with shell elements. Since the objective of this work is focussed on studying the potential benefit of using multiple explosive charges the material behaviour was approximated as elastic-perfectly plastic (yield stress $250MPa$). Finally to contain the water a rigid tank is defined using shell elements. The other parts in the model, the water and explosive are modelled with SPH particles. A spherical 19 gram C4 explosive charge is used throughout the paper. The water domain is modelled as a cube with dimensions $400 \times 160 \times 550mm$. The explosive is modelled using a high explosive burn model and a Jones-Wilkins-Lee equation of state (JWL EOS). The water is modelled as an inviscid fluid with a Gruneisen equation of state. The parameters for the C4 explosive and the water model were taken from [6]. The interaction between the different parts is achieved using the definition of three contact algorithms. The water particles interact with the workpiece, die and plate holder through a node to surface contact algorithm, the plate and forming die interact through a surface to surface contact algorithm, and finally the clamping of the workpiece by the plate holder is handled through a tied surface to surface contact.

Using this model five different explosive charge configurations (see Figure 2) were evaluated. Firstly one single explosive charge is placed centrally and at a distance of $150mm$ above the workpiece, secondly on top of the centrally located charge, a second charge is placed at the same distance from the workpiece, but offset laterally by $50mm$, thirdly on top of the centrally located charge, a second charge is placed at the same distance from the workpiece, but offset by $50mm$ at angle of 45degrees, fourthly on top of the centrally located charge, a second charge
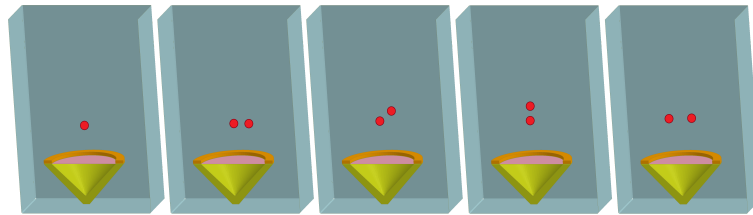
Figure 2. Overview of explosive charge configurations: from left to right configuration 1, 2, 3, 4, 5
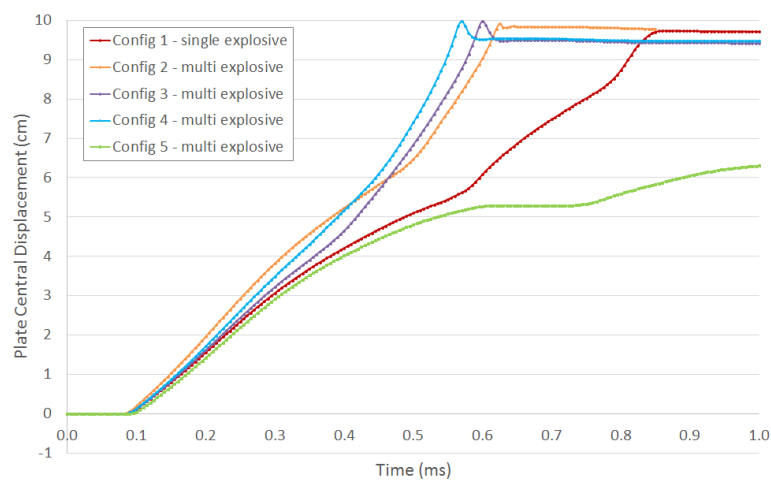

Figure 3. Comparison of displacement time histories at the plate center for the five configurations

is placed at the same distance from the workpiece, but offset vertically, $50mm$ above the first explosive, and finally two explosive charges are placed symmetrically at distance of $50mm$ from the symmetry axis and at a distance of $150mm$ from the plate. In order to assess the effect of these different explosive charge configurations on the formability of the plate, the model results are post processed based on forming limit failure criteria using a Forming Limit Diagram (FLD).

3. Results and discussion

It can be seen in Figure 3 that the multi-explosive configurations does not always result in a higher deformation rate than the single explosive charge. For the case where there is no axially located charge (configuration 5) this results in an incomplete forming operation despite the higher charge. This can be explained by the absence of a charge on the axis of symmetry which would deliver a more direct loading, and also interaction of the two pressure waves. The analysis of the FLD for the other cases shows a clear difference between the single explosive (Config. 1) and the multiple explosive (Config. 4) case, as shown in Figure 4. While the prediction for Config. 1 is one of cracks near the top of cone, Config. 4 the prediction is for wrinkling near the top of cone. In both cases the forming limit failure criteria predict cracking near the clamped area, but this could be due to the combination rigid constraints applied and the sharp corners. Considering a plot of the predicted sheet thickness (see Figure 5 the differences can be linked to different deformation patterns: the region where the sheet is thinnest in the single explosive
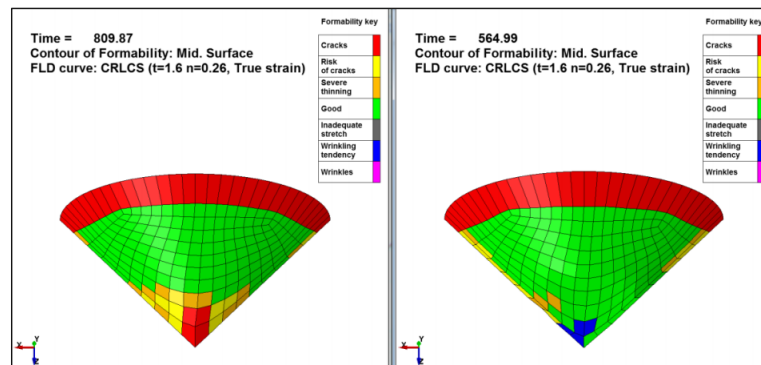
Figure 4. Comparison of Formability prediction for left: Config. 1 and right: Config. 4
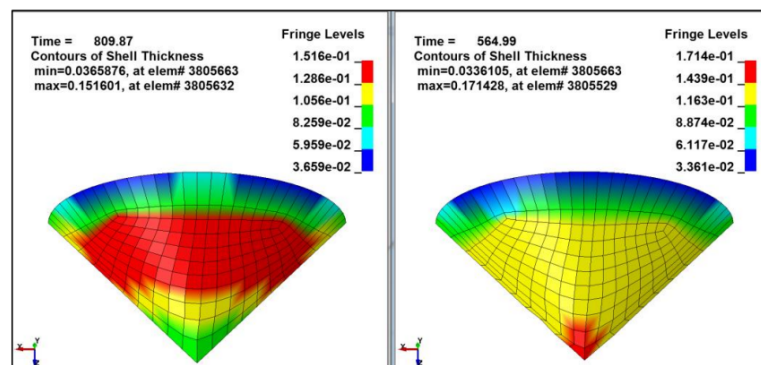

Figure 5. Comparison of predicted sheet thickness for left: Config. 1 and right: Config. 4

configuration is located near the tip of the cone, while in the multi explosive configuration (Config. 4) the thinning occurs along the flanks of the cone and the sheet is thicker near tip of the cone.

4. Conclusion

A coupled Finite Element - Smoothed Particle Hydrodynamics model has been developed to study the explosive forming process, and in particular effect of using multiple explosives on the formability of cones. The numerical results predict that a multi-explosives model does not always guarantee a faster rate of target deformation without central explosive. The model results also indicate that the multi-explosives setup is capable of preventing crack failure of the steel plate during the forming process a failure which would occur if a single explosive model was used.

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