Numerical Simulation on Conical Shaped Charge with Copper Liner in Several Typical Shapes

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Abstract. Conical shaped charges with five types of liner geometries: (1) cone, (2) round-tipped cone (3) hemisphere, (4) ellipsoid, and (5) trumpet, have numerically been simulated to investigate jet formation and target penetration capabilities via LS-DYNA Multi-Materials Arbitrary Lagrangian Eulerian (MMALE) technique. The purpose is to observe the influences of liner shapes on performance of shaped charge setup and, the final behavior of such shaped charge devices. The explosive filling and the liner material are kept to be identical in the study. Simulation results show that the hemispherical liner brings out the lowest penetration performance, while the cone and round-tipped cone shaped liners result in highest performance, and, ellipsoid and trumpet liners are of middle performance, in comparison. Especially, shaped charges with both ellipsoid and trumpet liners present no remarkable discrepancy on penetration depth, but the entrance craters are of dramatically geometrical difference. Such penetration features are anticipated to be applicable in technical design of shaped charges for various specific applications.

Introduction

Jet from shaped charge device is of important role in penetration, cutting, perforation, and other applications [1]. Device of shaped charge is composed of two main parts: explosive filling and metallic liner. Traditionally, the conical shaped charge with conical copper liner has been utilized broadly. In the development of shaped charge skill, people pursued other geometrically shaped liners. Fedorov et al. [2] once proposed a liner with shape of hemisphere-cylinder combination for a shaped charge setup. Cao et al. [3] made numerical simulation on several shaped charges with different liner shapes and gained the conclusion that liner with hemisphere shape has worst penetration ability and hence limited application based on the simulated results of lowest jet tip velocity. In this paper, instead of experimental investigations, numerical technique is employed to study the performance of shaped charges with five kinds of geometrically shaped liners on the penetration abilities. The liners are of (1) cone, (2) round-tipped cone, (3) hemisphere, (4) ellipsoid, and (5) trumpet shapes, respectively. Multi-Materials Arbitrary Lagrangian Eulerian (MMALE) numerical technique in LS-DYNA software [4] is used to perform all numerical simulations. The focuses are made on the penetration depths on the target block and the sizes of the craters left by jet entrance. Such features may provide the useful support for the design of charges with suitable liner shape for specific application.

Simulation Procedures

Computational models. Shaped charge with cone liner is a commonest set-up in use. It is firstly selected for consideration. As depicted in Fig.1, it basically consists of a liner, an explosive filling, and an outer case [5]. The dimensions and materials relevant to the device are given in Table 1. A steel target, 15.24 cm diameater and 62.87 cm length, is set off the bottom of shaped

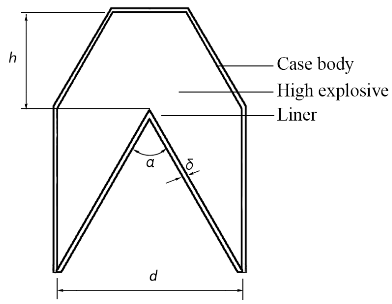
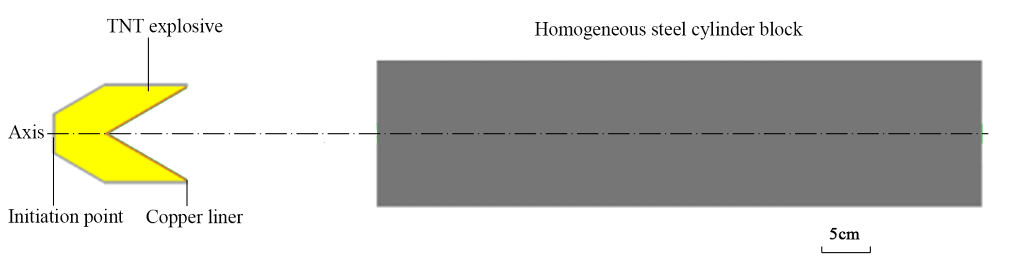


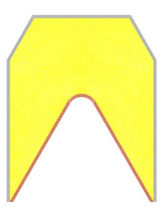
Fig. 1 Basic configuration of conical shaped charge considered for numerical simulation.

Table 1 Basic geometrical parameters of shaped charge model.

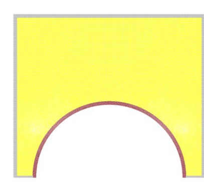
Liner thickness δ(cm)	Height of expl. filling h(cm)	Diameter d(cm)	Apex angle α(°)
0.20	5.29	10.00	60



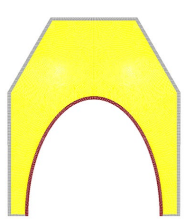
(a) Cone liner case



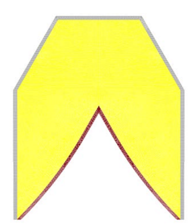
(b) Round-tipped cone liner case



(c) Hemisphere liner case



(d) Ellipsoid liner case



(e) Trumpet liner case

Fig.2 Assembly of shaped charge and witness steel block (a), and shaped charge devices possessing respective liner shapes (b-e).

charge with 20cm stand-off distance. The computational models for all five cases are illustrated in in Fig. 2.

Computational tools. Multiple Materials Arbitrary Lagrangian Eulerian (MMALE) solver in LS-DYNA software is used to for the whole computations.The characteristic size of mesh is set to be 0.05cm, and such size is used for all models. Quadrilateral meshes are utilized.

Equations of state and material models. For the high explosive, Jones-Wilkins-Lee (JWL) form equation of state is employed. The property parameters for TNT is found from Ref. [6]. For copper and aluminum, Steinberg strength model [7] is used for strength criterion, and Gruneisen equation of state is used under high pressure. The relevant parameters for copper and steel is obtained from Ref. [8]. Target is treated as dual-linear elastic-plastic material containing the criterion for failure. The relevant parameters used is from Ref. [5].

Results and discussion

Fig. 3 presents the computational results for the cone liner case, including jet formation, jet impinging onto target, as well as initial, middle, final penetrations in target block. Once the charge initiated, at 15μs, liner begins to collapse forming an initial jet shape. Utill the time of 62μs, the jet touches the target block as shown in Fig. 3(b). Fig. 3(c) displays the initial penetration of jets. With the later progress of penetration, jet velocity drops down and, jet mass is consumed by dispersion on the surface of the penetrated hole. At later phase, jet becomes slow, losing penetration ability just as Fig. 3(e) shows.

Similarly, simulation has also been performed for the cases with the other four liner shapes on jet formation and penetration. The detailed computational results are not further illustrated, only are typical features compared for those models. Firstly, jet tip velocities before striking the target are chosen for comparison and shown in Fig. 4. Among the five cases, shaped charge with round-tipped cone liner may provide the maximum jet velocity, following by the case with cone

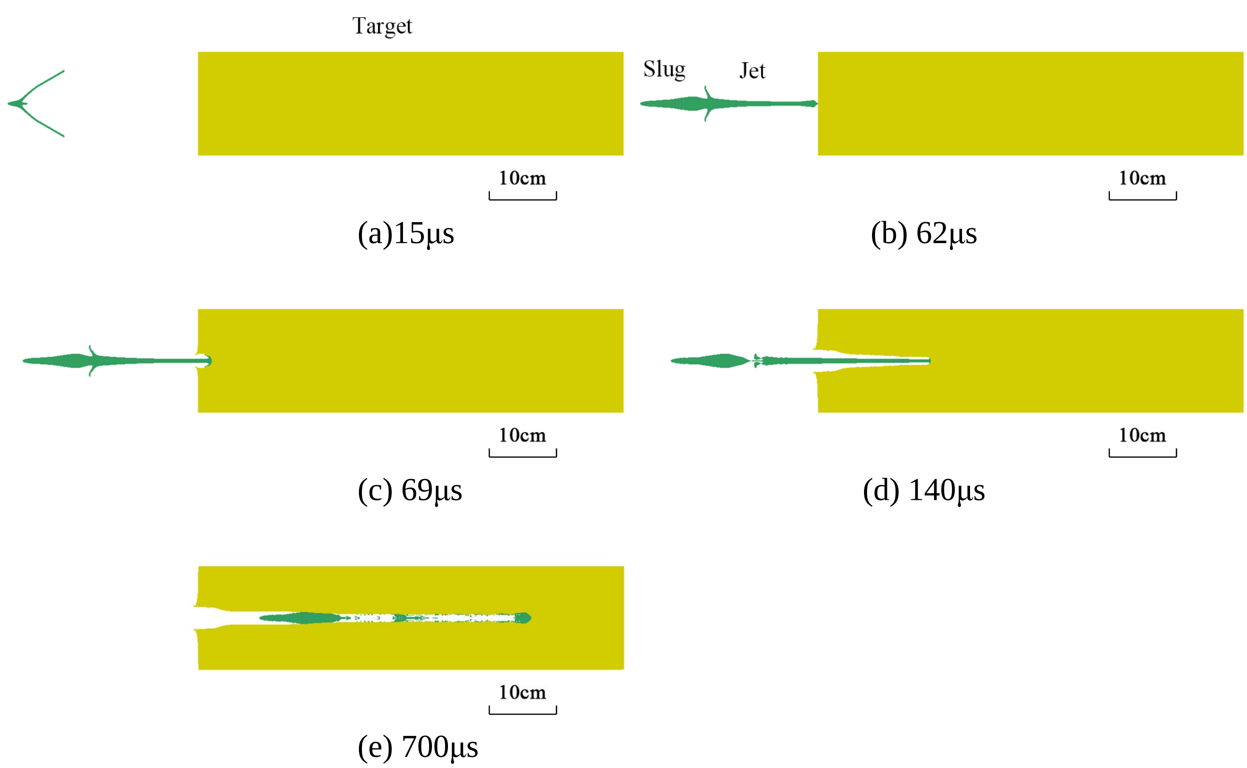


Fig. 3 Jet formation and penetration into target by shaped charge with cone liner by simulation.

shape liner. Relatively, trumpet shape liner is also able to provide a higher jet velocity. However, ellipsoid shape liner brings out a slower jet velocity, and hemisphere shape liner produces the lowest jet velocity, only being higher than the half value of jet velocity from the round-tipped shape liner. In addition, with respect to the arrival time for the jet striking the target, trumpet shape liner is of the shortest one, then, followed by round-tipped cone liner; however, ellipsoid and

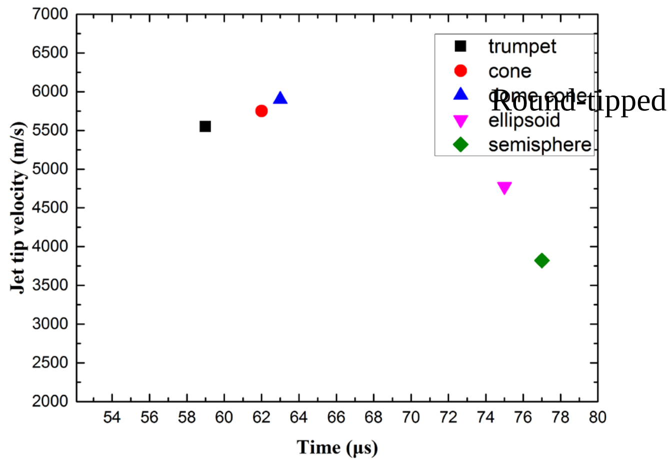


Fig. 4 Jet tip velocities just before striking the target by charges with various liners.

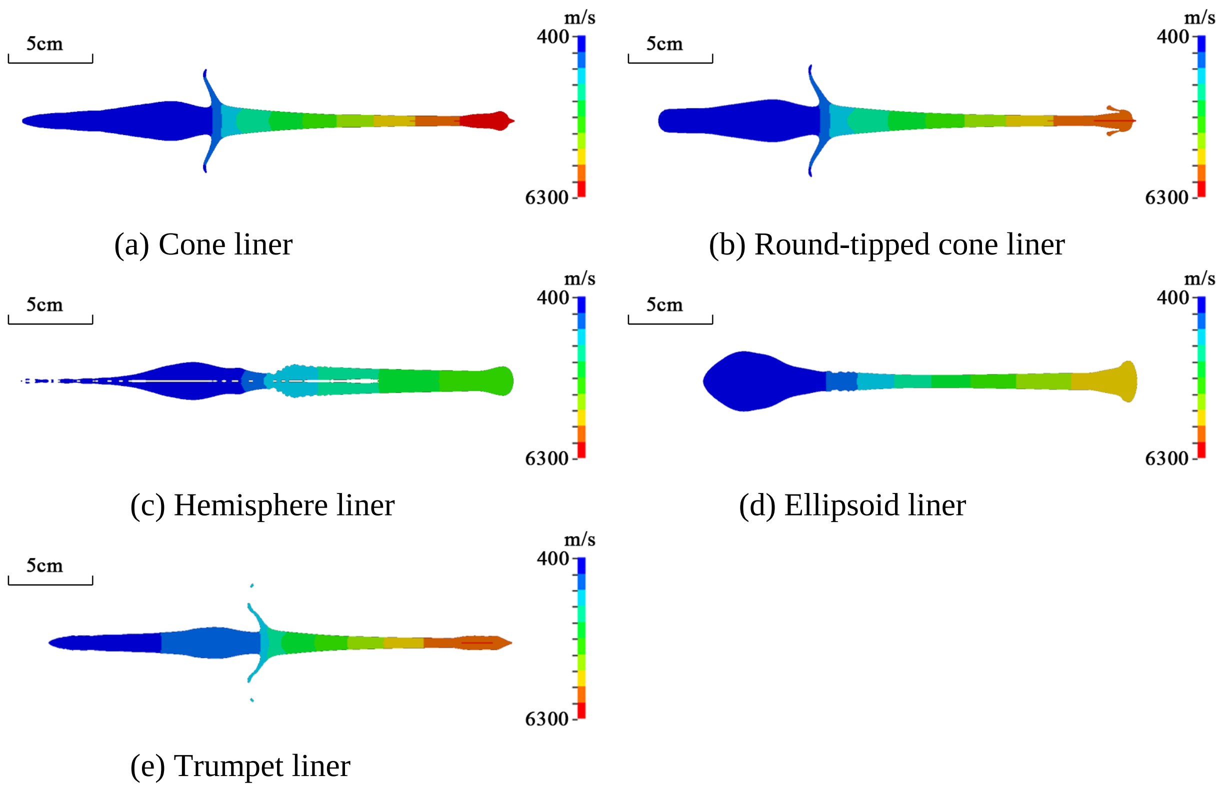


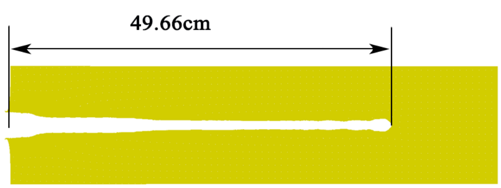
Fig. 5 Configurations of jet and its velocity variation before striking the target from five charge models.

hemisphere liners exhibit much slower arrival time. The lag on the arrival time is due to a longer time for the collapse of liner to form jet for the cases of the ellipsoid and hemisphere liners.

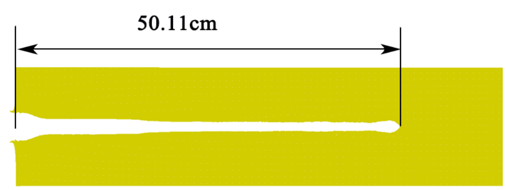
To the penetration process, jet tip velocity is not the sole parameter to determine the depth of penetration. The important factor is kinematic energy of jet which completely determines the penetration depth. Kinematic energy of jet is related to mass distribution of jet as well as its velocity gradient. Fig. 5 shows the computed jet configurations for five charges with each liner shape in each charge before striking the target. The color variations in the figure denote the velocity magnitudes from 0.4km/s by blue to 6.3km/s by red. It clearly exhibits the velocity gradients in jet and slug during jet motion. The existence of velocity gradient would stretch the jet and force it to become slimmer. From Fig. 5 it is intuitively illustrated the jet tip velocities in all charge models. Charges with cone, round-tipped cone and trumpet liners produce a relatively higher tip velocity, and the cases with hemisphere and ellipsoid liners are of lower jet velocity distribution. However, in two charge models with hemisphere and ellipsoid liners, the jet diameter is extremely large, implying more mass distribution in jet portion.

Table 2 Calculated results of penetration depth by charges with different liner shapes.

Liner shape	Cone	Round-tipped cone	Hemisphere	Ellipsoid	Trumpet
Penetration depth (cm)	49.66	50.11	18.11	32.21	32.11

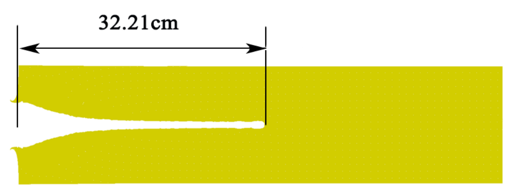


(a)Cone liner case

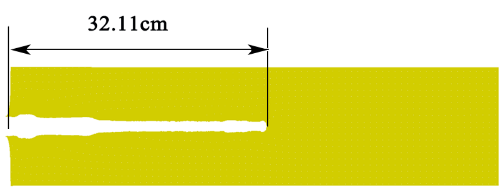


(b) Round-tipped cone liner case

(c) Hemisphere liner case



(d) Ellipsoid liner case



(e) Trumpet liner case

Fig. 6 Final penetration depths by jets from shaped charges with respective shape liners.

The total penetration depths are tabulated in Table 2 for all five charge models. Charge with hemisphere liner generates the lowest penetration depth of 18.11cm, however, both charges with cone and round-tipped cone liners even achieve the depth of around 50cm. Charges with ellipsoid and trumpet liners can produce the very similar penetration depth of 32.21cm and 32.11cm, respectively.

Fig. 6 shows the distributions of penetration holes by jets from five shaped charges as well as the graphical presentation of holes depths. Charges with cone and round-tipped cone liners produce holes with similar geometrical appearance and further, the penetration depths are very close. Charge with ellipsoid liner generates the very similar penetration depth, but the entrance craters are remarkably different. It implies that if large crater at entrance of jet is desired in the engineering application, charge with ellipsoid liner is a recommendable device. Moreover, charge with hemisphere liner produce the shortest penetration depth, however, the hole's diameter is large in total. It means if a larger and a uniform hole is required, this device is an ideal choice.

Conclusions

Jet formation and characteristics of target penetration from conical shaped charges with varied liner shapes have been simulated numerically via LS-DYNA dynamic software. The following conclusions can be achieved.

(1) Under the same mass of explosive charge, the traditional charge design with cone shape liner is able to produce the ideal penetration depth for targets. Other varied designs do not provide better penetration capability.

(2) Charge with ellipsoid shape liner may cause a larger crater at the entrance, and charge with hemisphere shape liner is able to produce a large and a uniform hole. Those designs provide enlarged opportunities for possible engineering applications.

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