Effect of variation of conical liner apex angle on shaped charge performance

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Abstract

The efficiency of conical linear shaped charge is estimated based on the penetration depth in a target material. Taking into consideration a significant number of parameters that affect the penetration depth, the optimization of the conical linear shaped charge parameters is a complex process.. In this study, the effect of varying conical liner apex angle is investigated using the SHARP code. A shaped charge with 29 mm charge caliber, conical liner base radius (cone base) is 28.3 mm and charge

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length is 72.5 mm. The study is carried out for cone apex angle 2α with values: 36°,40°,44°,48°,52°,56°,60° and 64°. The density law is used for estimating the penetration value. It was found that, as long as cone apex angle is increased, the value of target penetration is increased as well. This because the jet length is increased which is really the main factor in density law approach. But the behavior of jet length and penetration value is changing beyond the cone apex angle having the value of 53°, they start decreasing as cone apex angle is increased. This is because the distance travelled by the collapse liner element is increased so the jet velocity and its length are decreased and also because the decrease in the overall liner mass starts influence the jet formation in such a way that the jet mass decreases.

Keywords: *shaped charge, standoff distance, jet breakup, penetration, warhead design.*

1. Introduction

The efficiency of linear shaped charges is determined based on the achieved penetration depth in a target material. Due to a significant number of factors that affect the efficiency of the linear shaped charges the optimization is very complex. In order to determine the effect of a single factor, it is necessary to conduct measurements with other factors that do not vary. Since that increases the number of measurements, the research is usually directed towards the effect of a single factor [1]. Liner is considered as the most critical element affecting the dynamic characteristics of the shaped charge jet and its penetration capability into target materials. There are many liner shapes, which could produce different jet characteristics. These shapes include conical, Hemispherical, Tulip, trumpet (or bell shape) and bi-conical liners [2].The characteristics of the shaped charges jet mainly depend on the explosive to metal mass ratio and the liner geometry (i.e. wall thickness and its cone apex angle). The liner shape determines the characteristic of the produced jet. For example, the conical liner produces deeper penetration with small hole diameter. On the other hand, the bell shape liners produce shallow depth penetration with greater hole diameter [3]. In general, the geometry of the cone is determined by the cone apex angle. If this angle is small, the jet is long, thin and more penetrative. As the cone angle widens, the jet becomes shorter, thicker, and less penetrative [3], as illustrated in Figure (1).

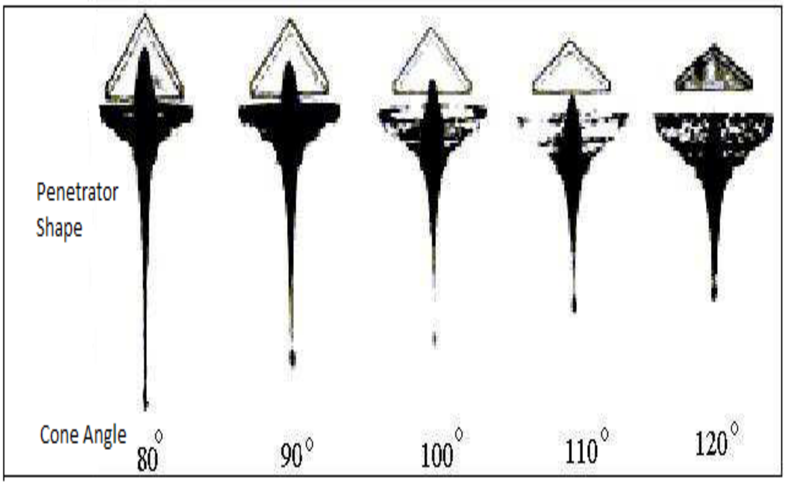

Figure (1) Shaped charge jet profile at different cone angle [2]

In this paper, a conical liner with different apex angles was considered to study the effect of cone apex angle on the shaped charge performance.

2. Shaped Charge Jet Formation

Upon the detonation of a shaped charge, three different phases are observed. These phases are jet formation, jet breakup and jet interaction with a target. For the first phase, Birkhoff et al. [4] proposed the steady state theory, which was developed into the well-known PER (Pugh, Eichelberger and Rostoker) theory, the most commonly used unsteady state model. Also, Godunov et al. in 1975 modified the steady state theory to include the strain-rate effect, which was further developed by Walters. In this paper we will focus on the PER theory. The steady state theory for the shaped charge jet formation was established by Birkhoff et al. [4], which had the following assumptions:

- The liner elements are accelerated instantaneously to the final collapse velocity at the liner axis with the same value V_o.
- A constant jet length equal to the slant cone height is assumed.
- Moreover, the pressure applied to the liner wall is assumed to be equal and the collapse angle 2β is greater than the original cone apex angle 2α.
- Both the velocities and the cross-sectional areas of jet and slug are constants. Figure (2) presents a schematic drawing of the steady state jet collapse process, in which β represents the collapse angle and α is the half cone angle. V_o is the collapse velocity, V_1 is the velocity of the moving coordinates (or stagnation velocity of point A), V_2 is the flow velocity, UD is the detonation wave speed of the explosive.

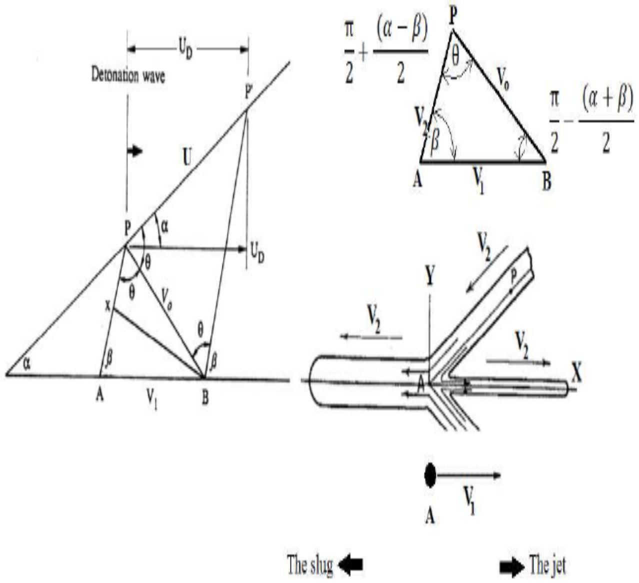

Figure (2) The nomenclature for steady state jet collapse process

From the trigonometric relations, the angles in triangle PAB can be calculated as a function of **β** and **α** as follow:

$$\angle PBA = \frac{\pi}{2} - \frac{(\alpha+\beta)}{2} \quad (1)$$

$$\angle BPA = \theta = \frac{\pi}{2} + \frac{(\alpha-\beta)}{2} \quad (2)$$

An observer at point A will feel point P approaches him by a velocity V_2, while point A itself moves towards right by a velocity V_1, therefore the velocities of both the jet and the slug can be calculated from:

$$V_{jet}=V_1+V_2 \quad (3)$$

$$V_{slug}=V_1-V_2 \quad (4)$$

Where V_1 and V_2 are the stagnation and the flow velocities, respectively. They can be estimated according to the sin rule from:

$$\frac{V_0}{\sin\beta} = \frac{V_1}{\sin(\frac{\pi}{2}+\frac{(\alpha-\beta)}{2})} = \frac{V_2}{\sin(\frac{\pi}{2}-\frac{(\alpha+\beta)}{2})}$$

Thus, V_1 and V_2 can be expressed as:

$$V_1 = V_0 \frac{cos\left[\frac{\beta-\alpha}{2}\right]}{sin\,\beta}$$

$$V_2 = V_0 \left\{ \frac{cos\left[\frac{\beta-\alpha}{2}\right]}{\tan\beta} + \sin\left[\frac{\beta-\alpha}{2}\right] \right\}$$

Normally, slug portion is not point of interest due to the fact that, the penetration is dependent only on jet portion; therefore, the jet velocity in term of U_D can be expressed as:

$$V_{jet} = \frac{U_D}{\cos\alpha}\sin(\beta-\alpha)\left[\csc\beta + ctn\,\beta + \tan\left(\frac{\beta-\alpha}{2}\right)\right]$$

From the previous equation, it is clear that, the cone apex angle 2αhas a great rule in jet formation phase. The velocity gradient along the jet is also exposed to the influence of the cone apex angle as well. As a result of that, the jet breakup phenomenon is affected.

3. Results and Discussion

In order to investigate the rule played by cone apex angle in jet formation and target penetration, a theoretical analysis using SHARP program was performed to carry out the results for a typical conical liner shaped charge with 29 mm as charge caliber, liner base radius (cone base) is 28.3 mm and charge length is 72.5 mm. The cone apex angle 2αvalues are: 36^o,40^o,44^o,48^o,52^o,56^o,60^o and 64^o. The liner collapse velocity is assumed to be gained from instantaneous acceleration. From figure (3), it can be seen that, the jet length is slightly increased (~ 14%) as cone apex angle increased. At small cone apex angles, the liner is at small distance from the charge center line, so, the collapsed liner element has a very short time to arrive to center line and to build the jet with proper length, also, a high percentage of the liner mass goes to the slug portion which is not contribute in target penetration. In other hand, the jet diameter is increased. This will create a penetrator with short length which is not desirable if a high penetration value is required. As long as cone apex angle is increased, the collapsed liner element will have a suitable distance to travel to the charge center line, and it's collapsed velocity still high (velocity does not have a chance to drop in high manner) , then the results is a high chance to build a jet with appropriate properties. But this is not always the case, from figure (3), as cone apex angle is greater than 53^{o}, the jet length is start decreasing because the decrease in the overall liner mass starts influencing the jet length obtained.

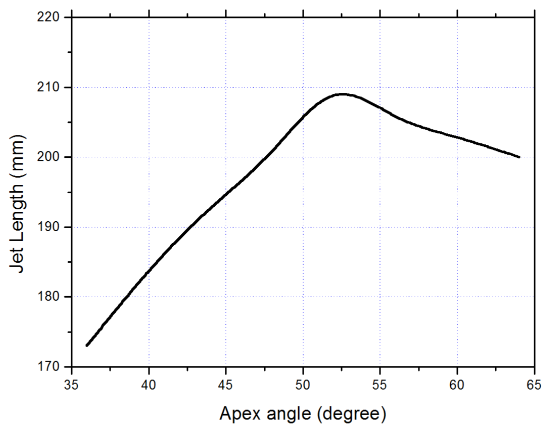

Figure (3) Jet length vs. cone apex angle

Concerning the breakup time, it is decreased while cone apex angle is increased, and, is starts increasing as cone apex angle is kept increasing beyond 53^{o}. This is clearly showed in figure (4) below.

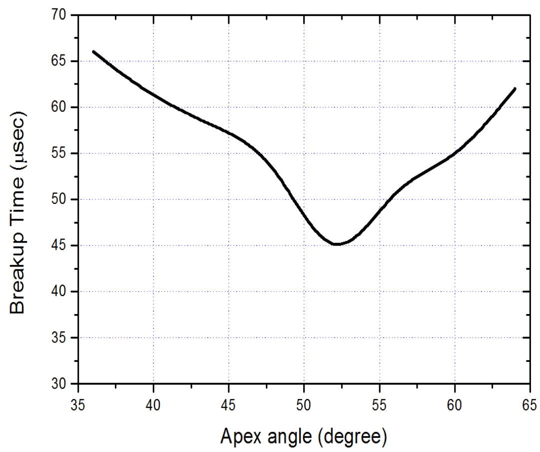

Figure (4) Jet breakup time vs. cone apex angle

At low cone apex angle the jet has small length but with big diameter which make the jet breakup a little bit hard this will increase the breakup time for small cone apex angles. The jet tip velocity is very important parameter especially when a high penetration value is required, but also, if tip velocity is high, this may have a disadvantage which is the phenomena of high velocity gradient along the jet axis. A high velocity gradient can accelerates the jet breakup which consequently leads to short jet length. Table (1) shows the tip velocity for different cone apex angles. It can be seen that, as cone apex angle increase the tip velocity decreases. As it has been mentioned before, the instantaneous acceleration behavior is considered, so, as long as the distance travelled by the collapsed liner element increases, the result of that decreasing in tip velocity is accomplished.

Table (1) Tip velocity for different cone apex angle

Con apex angle (deg.)	Tip velocity (Km/s)
36	10.21
40	9.29
44	8.56
48	7.96
52	7.45
56	7.0
60	6.6
64	6.24

Figure (5) shows particle velocity for different cone apex angles. Liner element number is indicating the element position (liner element) along the cone axis starting from cone head toward the cone base. From figure as cone apex angle increases, particle velocity decreases. This is due to increasing in the distances travelled by the collapsed liner element in order to reach the charge center line.

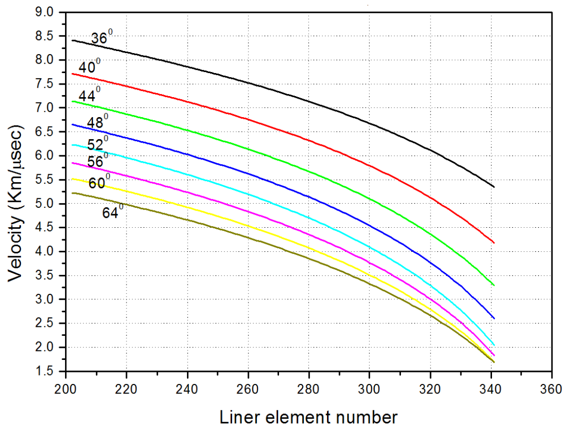

Figure (5) Particle velocity for different cone apex angles.

For penetration issue, as long as the "density low" is applied for penetration analysis, the penetration value versus cone apex angle variation is similar to jet length behavior. Figure (6) shows the variation of penetration values for different cone apex angles. Finally, it is important to say, that a homogenous target was implemented in analysis and standoff distance of 3CD value was applied in analysis.

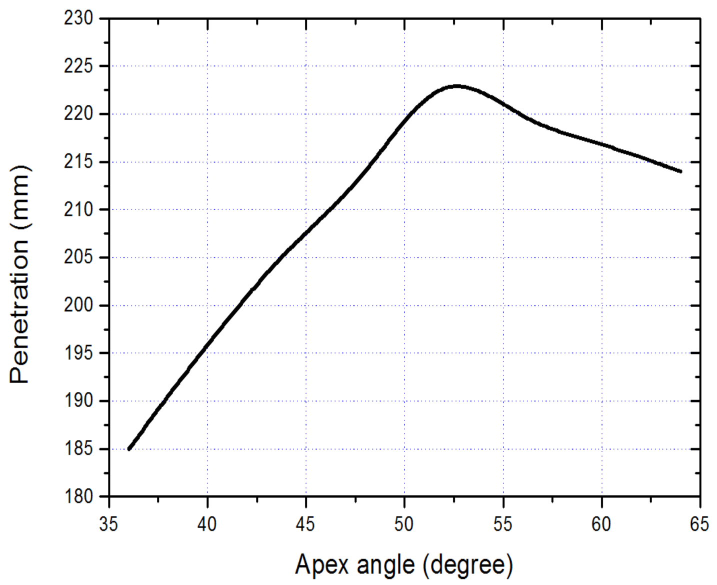

Figure (6) Penetration for different cone apex angles.

4. Conclusion:

Cone apex angle is considered as critical design parameter for shaped charge design. From the theoretical analysis and calculations carried in this study, it was found that, increasing cone apex angle, the jet length is increased and the breakup time is decreased. Penetration value is also increased if cone apex angle is increased. This behavior is changes when the cone apex angle is exceeding 53^{o}, the penetration is start decreasing which usually not desirable. This value of cone apex angle is considered as the maximum theoretical value can be used to get high value of penetration. For shaped charge design, the penetration value depended on many parameters. So, a compromise between all the design parameters should be considered. For further work a finite element technique can be used to study the jet penetration and the influence of changing cone apex angle on the shaped charge performance

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