

An Experimental Investigation on Composition 4 Linear Shaped Charges for Structural Steel Cutting

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Received: 25 August 2025 | Revised: 24 September 2025 and 7 October 2025 | Accepted: 12 October 2025

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ABSTRACT

Linear Shaped Charges (LSCs) are widely used for cutting structural steel in building demolition due to their high efficiency, speed, and minimal environmental impact. However, commercial LSCs are often expensive and require considerable time and cost for importation, especially in regions with limited access to such specialized tools. Therefore, this study explored the cutting performance of prototype LSCs using Composition 4 (C-4) explosives on structural steel plates. Three charge weights (42, 74, and 114 g) were tested using copper liners and acrylic casings. The cutting performance was evaluated through measurements of minimum and maximum cutting depths. The results showed a statistically significant increase in the cutting depth with a greater explosive mass. ANOVA confirmed that the charge weight is a critical factor affecting cutting efficiency. Regression models were developed to quantify the relationship between explosive mass and cutting depth, yielding R^2 values of 0.81 and 0.79 for the minimum and maximum depths, respectively. A design equation was derived for estimating the required C-4 charge per unit length. The comparative evaluation with previously published ribbon charge data revealed that the regression-based model required less than half the explosive mass to achieve equivalent performance. These findings suggest that C-4 can serve as an effective alternative for precision steel cutting, especially in resource-limited or emergency demolition scenarios.

Keywords-blasting demolition; linear shaped charge; composition 4 explosive; structural steel cutting; high-velocity jetting

I. INTRODUCTION

The demand for building and infrastructure demolition is expected to increase in various regions, particularly in urban redevelopment and disaster response contexts. Among the available demolition methods, blasting demolition offers several key advantages, including reduced vibration, noise, dust, and significantly lower risks associated with falling debris during dismantling operations [1]. Structural steel, recognized as one of the most challenging structures to demolish due to its high strength and ductility, can be effectively severed using LSCs [2]. These charges can produce precise, high-velocity jetting effects that can cut steel members and penetrate reinforcing bars embedded in concrete [3].

The performance of shaped charges is governed by multiple interacting factors, including explosive characteristics, liner material properties, liner geometry, initiation method, and

operational conditions. Explosive parameters, such as mass, grain size, explosive type, detonation velocity, and loading density, directly influence the detonation pressure and available energy [4-7]. Liner material attributes, including material type, density, thickness, hardness, ductility, and microstructure, determine the jet mass, velocity, stability, and penetration capability [4, 5, 8-15]. The liner geometry, including the cone profile, fill, thickness gradient, and multilayer construction, affects the collapse dynamics and jet coherence, and thus modulates the overall shaped charge performance [4, 16-20]. Similarly, the choice of standoff distance and the initiation scheme must be balanced to control jet elongation and breakup, thereby maximizing penetration for a given charge design [10, 14, 20-23]. Manufacturing quality, the surrounding medium (air versus water), and target characteristics (hardness, obliquity, multi-layered or reactive armor) can further alter the penetration outcome [7, 12].

Most experimental and numerical studies have focused on conical-shaped charges. Consequently, additional data specific to LSCs are required to establish reliable design guidelines for precision cutting of structural steel. Moreover, in some regions, LSCs are rarely accessible and extremely expensive, which limits their practical application in domestic demolition projects. Importing LSCs from overseas further elevates the cost due to high unit prices and shipping fees. In emergency scenarios such as post-disaster search and rescue, the lack of timely access to LSCs can hinder operations that require immediate and precise structural cutting.

In response to these constraints, this study explores the use of Composition 4 (C-4), a stable and widely available explosive, as a material for LSCs. The primary aim of this work was to evaluate the cutting performance of C-4-based LSCs when applied to structural steel and to compare their effectiveness and material efficiency with the ribbon charge configuration reported in previous studies.

II. EXPERIMENTAL PART

A. Test Specimens

To evaluate the steel-cutting performance of the C-4 LSCs, test specimens were prepared from SS400 structural steel plates, each measuring 300 mm × 300 mm with a thickness of 19 mm. These specimens represent typical flanges or webs found in wide-flange steel structural members.

B. Explosives

Although Pentolite and Composition B are widely used in conventional LSCs, the current study selected C-4 to investigate its performance in a linear cutting configuration due to its well-established safety characteristics. The key physical and performance properties of C-4 are compared with those of Pentolite and Composition B in Table I [4, 24]. To examine the influence of the explosive mass on the cutting performance, three C-4 charge weights of 42, 74, and 114 g were selected, denoted as Test Cases S, M, and L, respectively.

TABLE I. COMPARISON OF KEY PROPERTIES BETWEEN PENTOLITE, C-4, AND COMPOSITION B

Property	Pentolite	C-4	Composition B
Main components	PETN + TNT	RDX + plasticizer	RDX + TNT
Typical composition ratio	50:50 or 70:30	91% RDX, 9% binder	60% RDX, 40% TNT
Detonation velocity (m/s)	7,520 - 8,300	8,000-8,370	7,890 - 8,050
Relative Effectiveness (RE) Factor	1.27 - 1.33	1.34	1.25 - 1.33
Density (g/cm ³)	1.57 - 1.70	1.52 - 1.60	1.65 - 1.72

C. Linear Shaped Charge

A conventional LSC consists of an explosive filler, a metallic liner, a casing, a booster, and a detonator, as depicted in Figure 1. Upon detonation, the explosive collapses the liner material into a focused, high-velocity jet, capable of cutting through metallic targets. The effectiveness of the jet depends significantly on the density of the liner material [12].

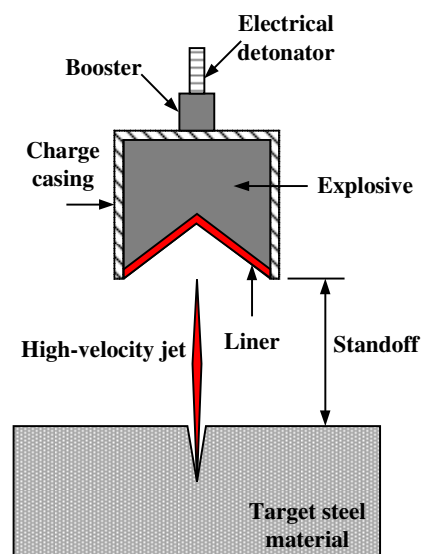


Fig. 1. Typical LSC configuration over a steel target.

Although several metals, such as copper, zinc, aluminum, tungsten, and molybdenum, can be employed as liner materials for LSCs, copper was selected in this study because it is readily available during emergency situations, possesses a relatively high density, and demonstrates well-documented penetration performance compared with alternatives such as zinc or aluminum. The liner was fabricated to a thickness of 0.8 mm and an apex angle of 90°, in accordance with previous studies [25].

The C-4 explosive was encased in a transparent acrylic casing with a thickness of 3 mm, as shown in Figure 2. The shape factor ($K = H/W$) was set to 0.75, and the standoff distance was maintained at 0.5 W, following the proposed configurations for optimal penetration efficiency [26]. The dimensional parameters of each test case are summarized in Table II.

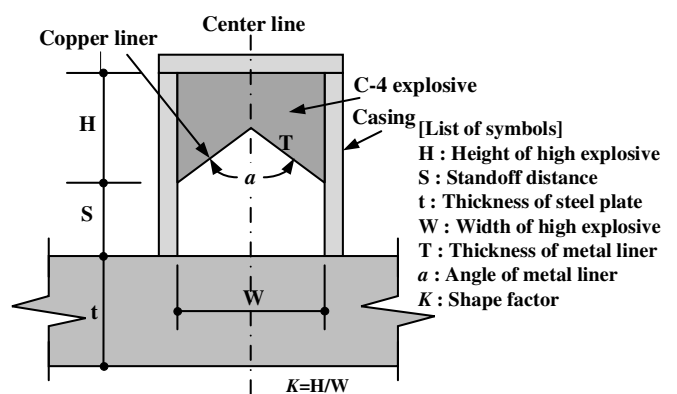


Fig. 2. C-4 LSCs parameters.

TABLE II. TEST CASE DIMENSIONAL PARAMETERS

Test case	C-4 amount (g)	Case	Liner	Steel grade	Apex angle	K (=H/W)	L (mm)	S (mm)	W (mm)	H (mm)
S	42	Acrylic	Copper	SS400	90°	0.75	370	6	12	9
M	74							8	16	12
L	114							10	20	15

D. Blasting Test Procedure

After filling the explosive into the shaped charge casings, each unit was secured directly to the steel plate surface using two strips of adhesive tape (duct tape) to maintain positioning. An electric detonator was inserted at one end of the charge and aligned with the detonation direction. The test setup is displayed in Figure 3.

Each test was conducted in triplicate to ensure repeatability and statistical reliability. Following each detonation, the minimum and maximum cutting depths were measured along the cut surface using a vernier caliper, and the results were recorded for further analysis.

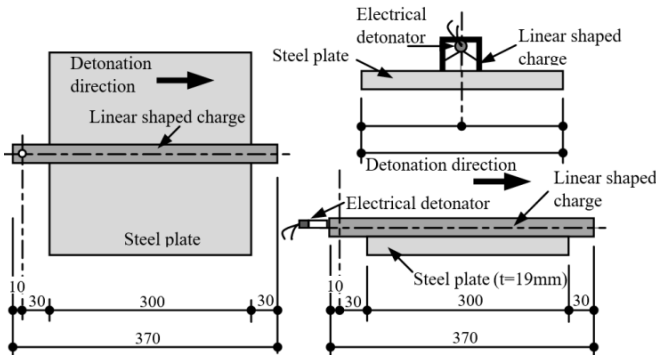


Fig. 3. Blasting test setup (units: mm).

III. RESULTS AND DISCUSSION

A. Damage on Test Specimen

Figure 4 presents the typical damage observed on the tested steel plates. Although the plates exhibited permanent bending, the LSCs consistently produced sharp, localized cuts, indicating that a high impulsive pressure and concentrated jet momentum were transmitted to the steel surface. This behavior is consistent with classical shaped-charge collapse and jet-formation physics (Munroe effect and collapse dynamics), whereby the liner collapses to form a high-velocity jet whose penetration capability is governed by its mass, velocity, and coherence. The observed increase in cut depth with larger explosive charges is generated by the greater available detonation energy and higher detonation pressure, which enhance the jet kinetic energy and tend to increase the jet length and tip velocity.

However, complete severance was not achieved in any of the tests. Mechanistically, this can be attributed to a combination of factors: (1) the jet may lack sufficient tip mass or sustained velocity to travel through the full plate thickness [4, 27], (2) jet breakup or loss of coherence prior to complete

penetration, which can be promoted by improper standoff, non-ideal liner geometry, or heterogeneities in the liner [28], and (3) target response under high strain-rate loading, including strain hardening, adiabatic shear formation, and bending dominated failure, which can absorb energy through plastic deformation rather than allowing a clean through-cut [29, 30]. Boundary conditions (clamping and plate support), multi-mode failure, and possible fabrication defects in the liner (porosity and asymmetry) would further reduce the probability of full severance [31, 32].

B. Cutting Depth

Table III lists the minimum and maximum cutting depths measured for each test case. The average minimum cutting depths for test cases S, M, and L were 1.40, 3.53, and 6.19 mm, respectively, representing an increase of about 152% from S to M and 75% from M to L. The corresponding average maximum cutting depths were 3.33, 5.18, and 11.45 mm for S, M, and L, respectively, which equate to increases of approximately 56% (S to M) and 121% (M to L). The results demonstrate that both the minimum and maximum cutting depths increase with increasing explosive charge. Nonetheless, some variations were observed between the minimum and maximum values for some samples. This variability requires further investigation to identify the underlying causes.

C. Cutting Depth Analysis

An Analysis of Variance (ANOVA) was conducted to examine the effect of C-4 explosive charge amount (in g) on both the minimum and maximum cutting depths during controlled explosive cutting of the structural steel plates, as shown in Table IV. For both cases, the ANOVA results yielded statistically significant differences in cutting depth across the three groups of explosive amounts (S, M, and L), with p-values well below the 0.05 threshold and an F-statistic significantly larger than the F-critical. This indicates that the explosive weight influences cutting performance significantly. Specifically, for the minimum cutting depth, the data suggest that increasing the amount of the explosive leads to greater baseline penetration, representing the least cutting depth achieved in a test. For the maximum cutting depth, a stronger relationship was observed. It was demonstrated that higher explosive amounts tend to result in greater peak penetration, indicating more effective material separation.

These results validate the positive correlation between the explosive amount and cutting depth, supporting the notion that an increased energy input leads to a deeper material response up to practical limits. This insight is valuable for optimizing explosive charges in structural demolition, where precise cutting performance is critical for minimizing the negative effects on the surroundings.

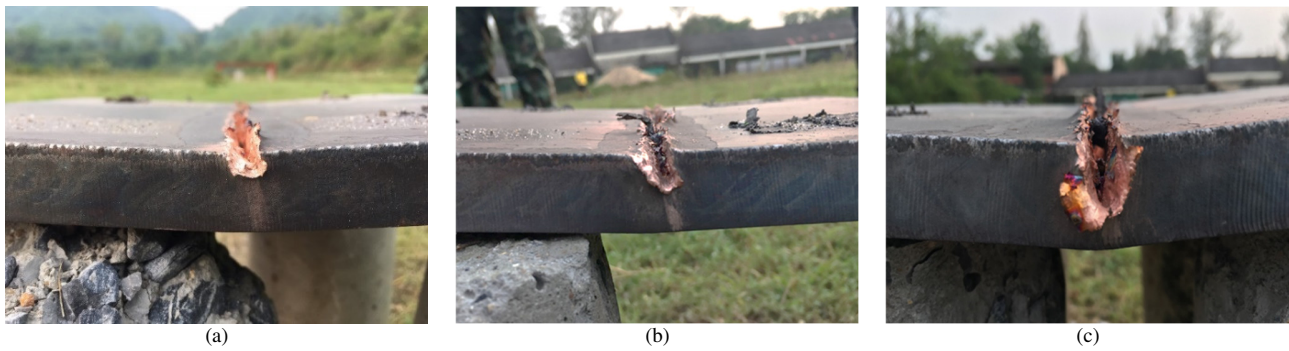


Fig. 4. Damage to the steel plates: (a) test case S, (b) test case M, (c) test case L.

TABLE III. MINIMUM AND MAXIMUM CUTTING DEPTHS OF EACH TEST CASE

Test specimen	C-4 amount (g)	W (mm)	H (mm)	K	L (mm)	Min. cutting depth (mm)	Max. cutting depth (mm)
S-1	42.06	12	9	0.75	370	1.00	2.50
S-2	42.06					1.40	3.50
S-3	42.08					1.80	4.00
M-1	74.05	16	12			2.25	2.85
M-2	74.08					3.60	5.40
M-3	74.09					4.75	7.30
L-1	114.09	20	15			4.50	8.90
L-2	114.09					7.45	12.60
L-3	114.09					6.63	12.85

TABLE IV. ANOVA RESULTS

Relationship	F-statistic	p-value	F-critical
Explosive amount VS minimum depth	12.83	0.0068	5.14
Explosive amount VS maximum depth	15.57	0.0042	5.14

D. Regression Analysis and Explosive Effect

Figure 5 presents the regression analysis of the cutting performance of the C-4 charges applied to structural steel plates, quantified by both minimum and maximum cutting depths as functions of the explosive mass. The results demonstrate a statistically significant linear dependency between the cutting depth and explosive weight over the tested range (42–114 g).

The linear regression models fitted to the experimental data yielded (1) for the maximum cutting depth:

$$y = 0.1145x - 2.1323, R^2 = 0.7911 \quad (1)$$

and for the minimum cutting depth, we have:

$$y = 0.0666x - 1.3989, R^2 = 0.8107 \quad (2)$$

The positive slope coefficients in both models indicate that the cutting depth increases proportionally with the explosive charge, confirming a direct energy-to-material penetration correlation under high strain-rate loading. Notably, the steeper gradient of the maximum cutting depth curve suggests an enhanced sensitivity of the localized peak failure zones to explosive impulse compared to the bulk average depth.

The coefficient of determination (R^2) values for both fits ($\approx 0.79-0.81$) reflect a strong degree of linear association, indicating that the explosive charge accounts for over 79% of

the observed variance in the cutting depth under controlled conditions.

The presence of negative intercepts in both regression lines implies the existence of a critical initiation threshold, below which the charge mass is insufficient to produce effective material severance. This is consistent with the principles of dynamic fracture mechanics, which state that a minimum specific energy density is required to initiate ductile fracture in high-strength structural steel.

These findings contribute to the predictive modeling of LSC-based steel cutting, offering valuable empirical relationships for determining the charge requirements in practical scenarios of structural steel structure demolition.

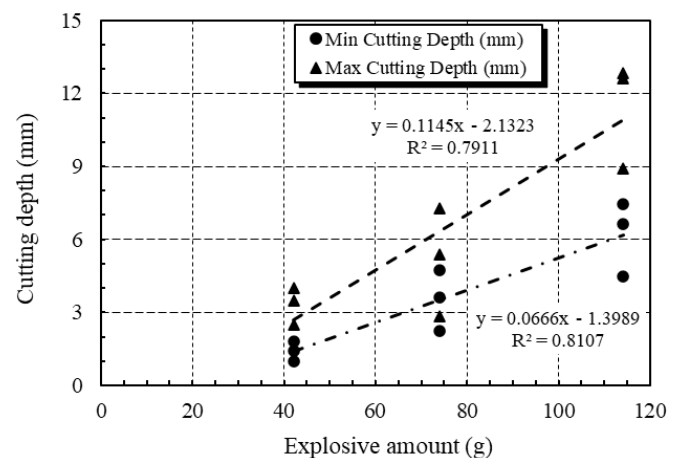


Fig. 5. Relationship between explosive amount and cutting depth.

To ensure the adequacy of the models, an examination through residual analysis was conducted, as illustrated in Figure 6. The residuals from both the minimum and maximum cutting depths were generally scattered around the zero-residual line without a pronounced systematic pattern, indicating linearity between the explosive mass and cutting depth across the tested range. However, non-linear behavior may occur under certain conditions. Accordingly, further investigations are necessary to refine the results.

Moreover, larger residuals were observed at higher predicted depths, suggesting mild heteroscedasticity, possibly arising from experimental variability, such as explosive density heterogeneity or standoff alignment. Nonetheless, the absence of pronounced patterns or clustering in the residual distribution confirms that the linear regression models provide an adequate fit and retain predictive validity within the experimental range tested.

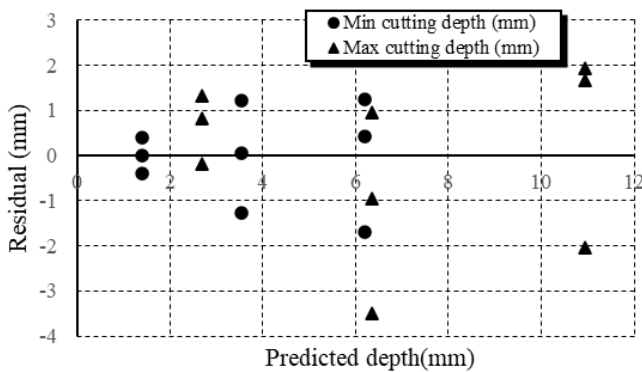


Fig. 6. Residual plot.

E. Application of the Regression Model

The regression equation developed for the minimum cutting depth provides a useful predictive tool for estimating the required explosive charge to achieve a target depth of penetration in structural steel cutting. Rearranging the equation to solve for the required explosive charge per unit length yields:

$$W_{C-4} = 0.4t + 0.0568 \tag{3}$$

where W_{C-4} is the amount of the C-4 explosive (g/cm) and t is the target steel thickness (mm).

This model enables practitioners to determine the appropriate mass of the C-4 explosive required to achieve a specified cutting depth with reasonable accuracy based on the observed linear correlation between charge weight and cutting performance. This relationship is particularly useful for preliminary planning in controlled demolition, precision cutting of steel components, and blast modeling, where charge optimization is essential for both safety and material efficiency. However, it is important to note that the validity of the regression model is constrained to the experimentally tested range of cutting depths (approximately 1–6 mm). Applications outside this range may require further calibration or nonlinear

modeling approaches to account for material failure thresholds and detonation dynamics.

In addition, because the equation was derived from a limited experimental dataset, its predictions should be regarded as preliminary estimates rather than definitive prescriptions. For safety, practical implementation requires the use of conservative safety factors and calibration trials. Moreover, the possibility of residual structural steel fragments or unconsumed jet material after detonation exists. Therefore, appropriate mitigations, such as protective backstops, sacrificial catcher layers, and sufficient spatial separation, are essential in practical applications to provide safety, particularly in disaster relief scenarios where victims may be trapped beneath the structure.

F. Comparative Evaluation against Ribbon Charge Method

To assess the efficiency of the regression model developed in this study, a comparative analysis was conducted against a previously reported explosive cutting configuration with ribbon charges. According to [33], a ribbon charge requires at least approximately 5.20 g/cm of C-4 to achieve complete severance in structural steel of equivalent grade and of 5.0 mm thickness. Using the regression model proposed in the previous section, the estimated C-4 requirement for achieving a minimum cutting depth of 5.0 mm is 2.06 g/cm, representing a 152% lower explosive consumption than the ribbon charge setup for equivalent cutting performance. A comparison of both methods is provided in Table V.

TABLE V. COMPARISON OF C-4 REQUIREMENTS BETWEEN THE REGRESSION-BASED MODEL AND THE RIBBON CHARGE METHOD

Method	Required C-4 (g/cm)	Cutting depth (mm)	Relative difference
Regression model (this study)	2.06	5	-
Ribbon charge [33]	5.20	5	+152%

The ribbon charge method requires over twice the explosive mass compared to the regression-based prediction for the same cutting depth. The results highlight the efficiency advantages of well-optimized linear cutting charges. The regression model not only predicts the cutting depth performance, which can improve precision, but also provides a basis for reducing explosive consumption in precision demolition or breaching operations.

IV. CONCLUSIONS

In this study, the cutting performance of improvised Linear Shaped Charges (LSCs) using Composition 4 (C-4) explosive on structural steel plates was investigated. The experimental results demonstrated that C-4 charges, when configured with copper liners and acrylic casings, were capable of generating sharp, localized cuts.

The quantitative measurements of the minimum and maximum cutting depths revealed a clear and statistically significant relationship with the explosive mass. The Analysis of Variance (ANOVA) confirmed that increases in charge weight resulted in deeper cutting performance across all

specimens. The maximum cutting depth showed greater sensitivity to explosive mass than the minimum, suggesting that localized failure zones respond more strongly to high-intensity impulse effects.

Linear regression models developed from the experimental data exhibited strong correlations (≈ 0.79 - 0.81), validating the predictability of the cutting depth based on the explosive quantity. The regression model for the minimum cutting depth was further formulated into a design equation to estimate the required explosive mass per unit length, offering a practical tool for demolition planning and charge optimization. However, since the model was based on a limited dataset, for safety, practical use requires conservative safety factors, calibration trials, and appropriate protective measures to control the residual jet fragments and safeguard personnel and structures.

A comparative evaluation with previously published data on ribbon charge configurations revealed that the regression-based model required less than half the C-4 mass to achieve an equivalent cutting performance within the tested range. This highlights the superior efficiency and material utilization of well-designed LSCs using C-4, especially in controlled blasting demolition or emergency applications.

Overall, the study provides valuable empirical insights into the feasibility and effectiveness of C-4 LSCs for precision cutting of structural steel. The findings support further exploration and refinement of improvised linear shaped charge systems for emergency-controlled demolition and specialized engineering operations.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support provided by the Royal Thai Army, Thailand. The blasting experiments were conducted at the Chulachomklao Royal Military Academy, whose assistance and facilities are sincerely appreciated.

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