Numerical simulation of the forming characteristics of the circumferential MEFP with integrated shell and liner

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Abstract. To study the forming characteristics of the multiple explosively formed projectile (MEFP) warhead of the small-caliber grenade with the integrated design of the liner and shell, the liner thickness is less than the shell thickness as the research object, and LS-DYNA is used for numerical simulation. On this basis, the influence of the curvature radius and the center thickness of the liner on the forming results of the projectile is further studied, and the integrated design of the MEFP forming result and the separate design were compared and analyzed. The simulation results show that, when the liner thickness structure is smaller than the shell thickness, the projectile shape is better. The shape of MEFP with the integral design is better than the separate design, and the forming velocity of the integral design is slightly lower than the separate design with the curvature radius increase of the outer and inner wall. When the liner curvature radius is fixed, the shape of MEFP with the integral design is better than the separate design, and the forming velocity of MEFP with the integral design is slightly less than the separate design with the liner center thickness increase. The results show that the forming characteristics of circumferential MEFP of integrated design and separate design have a certain similarity. The shape of MEFP with the integrated design is better than that with separate design, however, the forming velocity of MEFP with the integrated design is slightly lower than that with separate design.

1. Introduction
During the Spanish Civil War from 1936 to 1939, High-Explosive Anti-Tank (HEAT) with gathering energy effect began to be used. As a kind of shaped charge, the explosively formed projectile (EFP) arises at the historic moment in the 1970s [1]. In wars since ancient times, the ability of defense and attack has been constantly increasing in one direction and the other. Since the emergence of armor weapons on the battlefield, with the continuous increase of armor protection ability, the offensive ability of anti-armor weapons has been continuously enhanced. Therefore, since the emergence of EFP, because of its excellent armor-breaking capabilities, it has gradually become one of the hotspots for researchers in various countries to study anti-armor weapons. At present, the research on EFP by researchers mainly focuses on the structural parameters of the liner [2-5], the material of the liner [6-8], the charge parameters [9, 10], the initiation mode [11], and the penetration of EFP to the target [12-15] and other aspects. Since the 1980s, in order to increase the probability of projectiles hitting and damaging armored
targets, Multiple Explosively Formed Projectile (MEFP) was proposed. MEFP is an efficient warhead developed on the basis of a single EFP warhead [1, 16]. MEFP warhead can be divided into three types according to its charge structure: integral type [17], combined type [18], and cutting type [19]. Among them, integral type MEFP has become the research focus of researchers because its simple structure makes the formed projectile obtain higher penetration performance. The research on integral MEFP mainly focuses on two aspects: the axial arrangement of the charge along with the warhead [16, 20-23], that is, the explosively shaped projectile flies along the axial direction; and the circumferential arrangement of the charge along with the warhead [24-29], that is, the explosively formed projectile flies in the radial direction. Liang, ZG et al. [24, 25] studied the influence of the structural parameters of the liner and warhead on the formation of MEFP by simplifying the model and carrying out the numerical simulation. When the charge structure is fixed, the liner thickness diameter jointly affect the kinetic energy of EFP, and the liner curvature radius affects the length diameter ratio of EFP. Li, P et al. [26] designed a rod-type circumferential MEFP warhead. Through numerical simulation, the influence of the liner with non-lined and the lined on the MEFP forming was analyzed respectively. It was concluded that the placement of patches on the outside of the liner can control the velocity gradient of the formed projectile, and then control the shape of the formed projectile. Yin, JP et al [27] discussed the influence of the parameters (, thickness, diameter and radius of curvature) of the liner on the MEFP forming by numerical simulation, and obtained the best matching relationship between the curvature radius and the diameter of the liner, the best matching relationship between the wall thickness and the liner diameter, and the best matching relationship between the liner diameter and the charge diameter. Li, P et al. [28] and Song, P et al. [29] analyzed the effect of the initiation mode on the characteristic of the MEFP warhead by combining the static explosion experiment with numerical simulation respectively. In literature [28], a MEFP warhead with eccentric initiation was designed. The static explosion experiment and numerical simulation were carried out by means of central initiation and eccentric initiation. The results show that the initiation mode of two-point eccentric initiation can effectively improve the comprehensive damage efficiency of MEFP warhead; Literature [29] studied the influence of the initiation point height during single point initiation, the initiation points number during multi-point initiation, and the initiation synchronization error on MEFP comprehensive damage performance through simulation. The results show that for the multi-layer MEFP warhead, the forming projectile with the minimum velocity difference of each layer can be obtained by the method of axis center detonation.

In the study of the literatures [24-29], the diameter of the MEFP warhead charge circumscribed in the literature [24,25] is 92 mm; the diameter of the MEFP warhead studied in the literature [26] is 120 mm; The MEFP warhead charge diameter studied in the literature [27] is 90 mm; the MEFP warhead charge diameter studied in reference [28] is 203 mm; the MEFP warhead charge diameter studied in the literature [29] is 48 mm. Based on the above analysis of the relevant literature, we found that in the existing research on the circumferential MEFP warhead, the main focus is on the medium and large caliber charges, and only literature [29] has studied the shape law of the small caliber grade. In the research of literature [24-29], that have two other characteristics, first, the liner wall thickness is equal; second, the liner and the shell adopt the separated design. For small-caliber ammunition, there is no more report on the research of the circumferential MEFP of the integration of the liner and the shell at domestic and overseas. In order to study the forming characteristics of the MEFP for the integrated design of the shell and the liner of small-caliber ammunition. Firstly, the shaped characteristics of the MEFP for the equal wall thickness design of the liner and shell, the variable wall thickness design of the liner and shell are studied numerically. Secondly, based on the above numerical simulation and analysis results, the structure with the thickness of the shell greater than the thickness of the center of the liner is selected as the object of further study on the MEFP forming characteristics. The forming characteristics of the MEFP with different center thickness and the curvature radius of liner were studied numerically, and the MEFP forming results and forming velocity of the integral design of the shell and liner and the separate design of the shell and liner were analyzed and compared.
In the numerical simulation, the structured mesh of the designed small-caliber MEFP warhead is firstly divided by the ANSYS/ICEM mesh generation tool, then the structured mesh generated by ANSYS/ICEM is imported into HyperMesh for LS-DYNA preprocessing, and finally, the LS-DYNA solver is submitted for calculation. The numerical simulation method is used to study the shaping raw of the small-caliber MEFP warhead, and the MEFP warhead is used to improve the comprehensive damage efficiency of the small-caliber ammunition, which provides certain technical support for the development of low-cost small-caliber MEFP warhead technology in the future.

2. Integral circumferential MEFP structure design

In the research of MEFP, the structure is mostly the separation design of liner and shell, and the liner wall thickness is constant. To study the shaping characteristics of the circumferential MEFP with variable wall thickness in the integrated design, three kinds of structures were designed, which is the thickness of the liner and the shell is equal, the shell thickness is greater than the liner and the shell thickness is less than the liner. Three different MEFP structures designed in this study are shown in Figure 1. The diameter of the MEFP is 40mm, the shell thickness is 1mm, the charge diameter is 38mm, and the charge height is 53mm.

![Figure 1](image)

*Figure 1. The structure design of forming projectile which integral circumferential MEFP for small-caliber shell and the liner integrated: (a) equal thickness of shell and liner; (b) the shell thickness is greater than the liner; (c) the shell thickness is less than the liner.*

In Figure 1, the diameter of the charging outer circle is 38mm, the diameter of the liner is 9mm, and there are 4 rows of liner along the axial direction, each row is 12. In Figure 1-a), R1=R2=12mm, and the thickness of the liner and the shell is 1mm ($\Delta t = 1.0\text{mm}$). In Figure 1-b), R2=9mm, R1=12mm, the thickness of the shell is 1mm, and the thickness of the thinnest part is 0.67mm ($\Delta t = 0.67\text{mm}$) in middle of the center of the liner. In figure 1-c), R2=14mm, R1=12mm, and the shell thickness is 1mm, and the thickness of the thickest part is 1.16mm ($\Delta t = 1.16\text{mm}$) in middle of the center of the liner.

3. Numerical calculation model

3.1. Finite-Element Model (FEM)

The joint simulation method of the ANSYS / ICEM-HyperMesh and LS-DYNA is used in the numerical calculation, the forming process of MEFP was simulated by multi-material ALE algorithm. Firstly, the designed integrated shell and liner structure was imported into ANSYS/ICEM for structured grid division, and the divided structured grid was converted into an unstructured grid. Secondly, unstructured mesh files are imported into HyperMesh for pre-processing of the LS-DYNA solution. Finally, numerical calculations are carried out by LS-DYNA. To reduce the amount of calculation in numerical simulation, a quarter FEM was established according to the symmetry of the MEFP warhead, the FEM is shown in Figure 2. (Because the structure designed in the second part has certain similarity, this part only takes the fem with the thickness of the liner less than the thickness of the shell as an example).
3.2. Material Model
The material model is the same as references [30,31].

3.3. Forming Results
The model of single point initiation is selected in the numerical simulation, and the unit used in the calculation is cm g μs. The shaping result of the MEFP warhead is shown in Figure 3.

![Figure 2. FEM of the MEFP warhead](image)

![Figure 3. The results of forming projectile which integral circumferential MEFP for small caliber shell and the liner integrated: (a) equal thickness of shell and liner;(b) the shell thickness is greater than the liner;(c) the shell thickness is less than the liner.](image)

The circumferential MEFP structure is centrosymmetric, and the detonation point is show in Figure 2, therefore, the forming results of the 12 rows of the designed liner are similar of the simulation results in Figure 3, so one row of them is selected as the research object. As can be seen from the Figure 3, where 1#EFP-4#EFP in Figure 3 (a), (b) and (c) represents the shaping results. In Figure 3(a), the liner outer wall is overturned to form the head of the projectile, while the liner inner wall is extruded along the radial inward direction to form the tail of the projectile, and the forming projectile is similar to W shape. In Figure 3(b), both the head and the tail of the projectile overturn, forming a overturned projectile. In Figure 3(c), the head of the projectile is formed after the slight overturning of the liner outer wall, and the projectile tail is formed by the extrusion of the liner inner wall along the radial inward direction, and the head of the final shaped projectile is slightly flat and the tail is ellipsoid shape.

3.4. Forming velocity
The speed of 1#EFP, 2#EFP, 3#EFP and 4#EFP shown in Figure 3 are shown in Figure 4.
Figure 4. Speed of the MEFP warhead (a) equal thickness of shell and liner; (b) the shell thickness is greater than the liner; (c) the shell thickness is less than the liner.

In Figure 4 (a), EFPs velocity are between 2250m/s and 2500m/s. In Figure 4 (b), EFPs speed are between 2500m/s and 2800m/s. In Figure 4 (c), EFPs speed are between 2100m/s and 2250m/s. According to the shape of the MEFP (as shown in Figure 3) and the forming velocity of the MEFP (as shown in Figure 4), for the MEFP studied in this paper, when the thickness of the liner is slightly less than the thickness of the shell, the shape is better and the projectile speed is larger.

To further study the influence of liner parameters on the forming characteristics of MEFP, on the basis of Part 2, Part 3 and Part 4, the scheme that liner thickness is less than shell thickness is selected, nine kinds of integral structures (integral type) of shell and liner are redesigned, and numerical simulation is carried out. In the literature [25-30] on the study of MEFP, the structure (separate type) in which the liner and the shell are separated is generally used, therefore, in this study, the numerical simulation of 9 kinds of structures (structural parameters are the same as that of the integral design) of the separation design of the liner and the shell is carried out, and the results of the integral design and the separation design are compared and analyzed.

4. Influence of the liner parameters

4.1. Structural parameter design and numerical calculation model

The 9 redesigned structural parameters are shown in Table 1.

| MEFP Warhead Parameters | design scheme | Liner Center Thickness (Δt)/mm | Liner Inner Wall Curvature Radius (R1)/mm | Liner Outer Wall Curvature Radius (R2)/mm |
|-------------------------|---------------|---------------------------------|------------------------------------------|------------------------------------------|
| Height of charging: 52 mm, charging diameter: 37 mm, shell thickness: 1.5 mm, liner diameter: 9 mm | 1 | 0.85 | 8 | 6 |
|                         | 2 | 1.18 | 10 | 8 |
|                         | 3 | 1.31 | 12 | 10 |
|                         | 4 | 1.37 | 14 | 12 |
|                         | 5 | 1     | 12 | 10 |
|                         | 6 | 1.1   | 12 | 10 |
|                         | 7 | 1.2   | 12 | 10 |
|                         | 8 | 1.3   | 12 | 10 |
|                         | 9 | 1.4   | 12 | 10 |

In reference [30], in the influence of the curvature radius of liner on EFP shaping characteristics, the structure adopted is that the liner center thickness is unchange, and the R1 and R2 increases at the same
time, and also, in this study, the curvature center of the inner wall, outer wall and liner are not in the same horizontal line. Therefore, to study the influence of the R1 and R2 on the forming of the integrated and separated EFP, the structural design with the inner wall curvature center (O1), the outer wall curvature center (O2), and the liner center (O) at the same horizontal line is adopted in scheme 1-4, as shown in Figure. 5 (a). However, when the R1 and R2 increases regularly, the liner center thickness increases irregularly. To study the influence of the ∆t on the shaping law of the integral and separate EFP, in scheme 5-9, the O1, O2, and O are not on the same horizontal line, as shown in Fig. 5 (b).

![Figure 5. Structure diagram: (a) The curvature radius and the liner center thickness increase simultaneously; (b) The liner curvature radius is constant, and the liner center thickness increase.](image)

In table 1, the 3D structure of the MEFP is designed, and the structural mesh is divided. The FEM of the MEFP warhead structure is shown in Figure 6 a). The three-dimensional structure of the MEFP is imported into ANSYS / ICEM for structural topology design, and then meshed to obtain the FEM of the separate type circumferential MEFP, as shown in Figure 6 b).
4.2. Influence of the liner curvature radius

4.2.1. Forming Results. The influence of the liner curvature radius is shown in Figure 7. The shaping results of the MEFP with integral type are shown in Figure 7a), the forming results of the MEFP with Separate type are shown in Figure 7a).

In Figure 7, with the increase of the R1, whether it is an integral type or a separate type, the length/diameter of the projectile reduces gradually. However, the ratio of length to the diameter of the integrally shaped projectile decreases slowly, and the ratio of length to the diameter of the separated shaped projectile decreases rapidly. When the R1 is between 10mm-12mm (corresponding to the R2 is between 12mm-14mm), the shape is more suitable, and the shape is better than separated.
The forming velocity of 1#EFP, 2#EFP, 3#EFP and 4#EFP shown in Figure 7 is shown in Table 2.

Table 2. 1#EFP, 2#EFP, 3#EFP and 4#EFP formed velocity

|        | R1=8mm, R2=6mm | R1=10mm, R2=8mm | R1=12mm, R2=10mm | R1=14mm, R2=12mm |
|--------|----------------|-----------------|-----------------|-----------------|
| 1#EFP  | Integral type  | 2318 m/s        | 2094 m/s        | 2139 m/s        | 2069 m/s        |
|        | Discrete type  | 2173 m/s        | 2127 m/s        | 2161 m/s        | 2138 m/s        |
| 2#EFP  | Integral type  | 2363 m/s        | 2141 m/s        | 2153 m/s        | 2081 m/s        |
|        | Discrete type  | 2250 m/s        | 2230 m/s        | 2296 m/s        | 2273 m/s        |
| 3#EFP  | Integral type  | 2500 m/s        | 2167 m/s        | 2172 m/s        | 2095 m/s        |
|        | Discrete type  | 2273 m/s        | 2242 m/s        | 2306 m/s        | 2285 m/s        |
| 4#EFP  | Integral type  | 2585 m/s        | 2187 m/s        | 2191 m/s        | 2125 m/s        |
|        | Discrete type  | 2235 m/s        | 2196 m/s        | 2230 m/s        | 2207 m/s        |

According to the velocity of the formed projectiles shown in Table 2, with the increase of the liner curvature radius, the comparison diagram of the speed of the separation type and the integral type is shown in Figure 8.

Figure 8. Comparison curve of the forming projectile velocity: (a) 1#EFP velocity comparison curve; (b) 2#EFP velocity comparison curve; (c) 3#EFP velocity comparison curve; (d) 4#EFP velocity comparison curve.

In Figure 8, the speed of 1#EFP to 4#EFP of the integral and separate structure first decreases, then increases, and then decreases again with the increase of the curvature radius of the liner. That is, when the curvature radius of the liner is increased from 8 mm to 10 mm, the forming velocity are decreases of the 1#EFP, 2#EFP, 3#EFP and 4#EFP. When the curvature radius of liner is increased from 10mm to 12 mm, the forming velocity are increases of the 1#EFP, 2#EFP, 3#EFP, and 4#EFP. When the curvature radius of the liner is increased from 12 mm to 14 mm, the forming velocity decreases again of the 1#EFP, 2#EFP,3#EFP, and 4#EFP. When the inner wall curvature center, the outer wall curvature center and the center thickness of the liner are in the same horizontal line, the liner center thickness increases with the increase of the liner inner wall and outer wall curvature radius, as shown in Figure 5 (a), therefore, the shaped velocity fluctuates slightly. The results show that, when the inner wall, outer wall curvature center, and liner center are in the same horizontal line, with the increase of the curvature...
radius of liner, there is no obvious rule to follow in the forming velocity of EFP. When \( R_1 = 8 \) mm, the forming velocity of 1\#EFP to 4\#EFP of the integral structure is higher than that separate type; when \( R_1 > 10 \) mm, the shaping speed of 1\#EFP to 4\#EFP of integral structure is less than that of separate type.

According to the velocity of the formed projectiles shown in Table 2, when the liner curvature radius is different, the velocity comparison curves from the 1\#EFP to 4\#EFP of the integral type and separate type are shown in Figure 9.

Figure 9. Velocity comparison curves from the 1\#EFP to 4\#EFP: (a) velocity comparison curve of \( R_1 = 8 \) mm, \( R_2 = 6 \) mm; (b) velocity comparison curve of \( R_1 = 10 \) mm, \( R_2 = 8 \) mm; (c) velocity comparison curve of \( R_1 = 12 \) mm, \( R_2 = 10 \) mm; (d) velocity comparison curve of \( R_1 = 14 \) mm, \( R_2 = 12 \) mm.

In Figure 9, the shaping speed of 1\#EFP to 4\#EFP increases first and then decreases, that is, the forming velocity from 1\#EFP to 3\#EFP increases gradually, and the forming velocity from 3\#EFP to 4\#EFP reduces, and the speed of 1\#EFP to 4\#EFP of the integral structure gradually increases. When \( R_1 = 8 \) mm, the speed of the integrally formed projectile is higher than that the separately formed projectile, when \( R_1 > 10 \) mm, the speed of the integrally shaped projectile is less than that the separately formed projectile.

In the results of Figure 7, Figure 8, and Figure 9 that considering the forming results and forming velocity of the integral structure and the separated structure, when the liner inner wall curvature radius is between 10 mm and 12 mm, the forming result of EFP is better, and the forming velocity is between 2100 m/s and 2300 m/s. When the inner wall curvature center, outer wall curvature center, and liner center are in the same horizontal line, the liner center thickness increases with the liner curvature radius increase. The influence of the liner center thickness the shaping speed of EFP is not clear. To further study the influence of the liner center thickness on the forming characteristics of EFP, \( R_1 = 12 \) mm (corresponding to the \( R_2 = 10 \) mm), the forming characteristics of EFP with different liner center thickness were analyzed.

4.3. The Influence of the liner Center Thickness

4.3.1. Forming Results. When the liner inner and outer walls curvature radius is unchange, the forming results of the integral structure and the separate structure EFPs are shown in Figure 10. With the liner thickness increase.
4.3.2. Forming velocity. The shaping speed of 1#EFP-4#EFP shown in Figure 10 is shown in Table 3.

Table 3. Comparison table of the 1#EFP-4#EFP formed velocity

|      | $\Delta t=1$mm | $\Delta t=1.1$mm | $\Delta t=1.2$mm | $\Delta t=1.3$mm | $\Delta t=1.4$mm |
|------|----------------|------------------|------------------|------------------|------------------|
| 1#EFP Integral type | 2074m/s         | 2054m/s          | 1994m/s          | 1926m/s          | 1884m/s          |
|      | 2126m/s         | 2088m/s          | 2054m/s          | 2020m/s          | 1990m/s          |
|       | 2082m/s         | 2065m/s          | 2038m/s          | 2036m/s          | 2011m/s          |
| 2#EFP Integral type | 2258m/s         | 2212m/s          | 2187m/s          | 2154m/s          | 2126m/s          |
|      | 2093m/s         | 2081m/s          | 2071m/s          | 2046m/s          | 2027m/s          |
|       | 2272m/s         | 2234m/s          | 2202m/s          | 2167m/s          | 2137m/s          |
| 3#EFP Integral type | 2143m/s         | 2114m/s          | 2094m/s          | 2017m/s          | 1996m/s          |
|      | 2206m/s         | 2166m/s          | 2130m/s          | 2095m/s          | 2064m/s          |

It can be obtained from Table 6 that as the liner center thickness increases, the velocity comparison curve of separation type and Integral type of 1#EFP-4#EFP is shown in Figure 11.
Figure 11. The speed comparison curve: (a) 1#EFP velocity comparison curve of the integral type and discrete type; (b) 2#EFP velocity comparison of integral type and discrete type; (c) 3#EFP speed comparison of integral type and discrete type; (d) 4#EFP speed comparison of integral type and discrete type.

As can be seen from Figure 11, when the liner curvature radius is constant, the forming velocity of the integrated and separated EFP reduces with the liner center thickness increase, moreover, the shaping speed of integral structure is less than that the separate structure. In Figure 11 (a), with the liner center thickness increase, the 1#EFP velocity of integral structure is 2.5%, 1.6%, 2.9%, 4.7%, and 5.3% lower than that the separate structure, respectively. In Figure 11(b), with the liner center thickness increase, the 2#EFP velocity of integral structure is 7.8%, 7.0%, 6.8%, 5.5%, and 5.4% lower than that of the separate structure, respectively. In Figure 11(c), with the liner center thickness increase, the 3#EFP velocity of the integral structure is 7.9%, 6.8%, 5.9%, 5.6%, and 5.1% lower than that of the separate structure, respectively. In Figure 11(d), with the liner center thickness increase, the 4#EFP velocity of the integral structure is 2.9%, 2.4%, 1.7%, 3.7% and 5.1% lower than that the separate structure, respectively. It can be seen that the forming speed of integrated structure is between 1.5% and 8% less than that the separate structure with the liner center thickness increase.

It can be obtained from Table 3 that the speed comparison of separation type and Integral type from 1#EFP to 4#EFP is shown in Figure 12.
In Figure 12, for the integral structure, the speed of 1#EFP to 4#EFP raises gradually when $\Delta t < 1.3$ mm, and the velocity from 1#EFP to 3#EFP raises gradually when $\Delta t > 1.3$ mm, and the speed from 3#EFP to 4#EFP begins to decrease. For the separated structure, the velocity from 1#EFP to 3#EFP gradually raises, and the speed from 3#EFP to 4#EFP begins to decrease with the increase of the center thickness of the liner. In Figure 12 (a), the shaping speed of 1#EFP, 2#EFP, 3#EFP and 4#EFP with integral structure is 2.5%, 7.8%, 7.9% and 2.9% less than that the separate structure, respectively. In Figure 12 (b), the forming velocity of 1#EFP, 2#EFP, 3#EFP and 4#EFP with integral structure is 1.6%, 7.0%, 6.8% and 2.4% less than than the separate structure, respectively. In Figure 12 (c), the forming velocity of 1#EFP, 2#EFP, 3#EFP and 4#EFP with integral structure is 2.9%, 6.8%, 5.9% and 1.7% less than than the separate structure, respectively. In Figure 12 (d), the forming velocity of 1#EFP, 2#EFP, 3#EFP and 4#EFP with integral structure is 4.7%, 5.5%, 5.6% and 3.7% less than than the separate structure, respectively. In Figure 12 (e), the forming velocity of 1#EFP, 2#EFP, 3#EFP and 4#EFP with integral structure is 5.3%, 5.4%, 5.1% and 3.3% less than than the separate structure, respectively.

From the results of Figures 10, 11, and 12, it can be seen that the velocity of EFPs with separate structures is between 1.5% and 8% higher than that integral structure, but the forming result of integrated structure is better than that the separated structure. Therefore, for small-caliber ammunition, considering the forming results and forming velocity, the integral structure is more suitable.

5. Conclusions
In this study, the integrated design of MEFP warhead and separate design of MEFP warhead are simulated respectively, and the numerical simulation results are compared and analyzed, and the following conclusions are obtained:

(1) For small caliber circumferential MEFP, when the liner center thickness less than the shell thickness is selected, the forming results of EFP is more appropriate.

(2) When the inner wall, the outer wall curvature center, and the liner center are in the same horizontal line, the liner center thickness increases with the liner curvature radius increase, and the shaping speed of the EFP with integral structure and separate structure fluctuates slightly, in other words, the position of the liner inner wall and the outer wall curvature center has a certain influence on the shaped projectile velocity. When the liner inner wall and the outer wall curvature radius is constant, the inner wall, the outer wall curvature center and the liner center will not be on the same horizontal line with the liner center thickness increase. The EFP velocity of integral structure and separate structure will gradually decrease with the liner center thickness;

(3) Results of EFP with the integral structure are better than separate structure, however, the forming velocity of the integrated structure is slightly lower than that of the separate structure, that is, the forming velocity of the integrated structure is between 1.5% and 8% lower than that the separate structure. For the small caliber circumferential MEFP with integrated design of liner and shell, the integral structure is more suitable considering the forming structure and forming velocity of EFP.
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