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毁伤增强型破片探索研究

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摘要: 为提高破片式防空武器的毁伤效能,对毁伤增强型材料进行了探索研究,并设计制备了一种 $\Phi 10\text{ mm} \times 10\text{ mm}$ 的铝/聚四氟乙烯毁伤增强型破片。毁伤性试验表明该破片除具有对目标的动能打击外,还具有爆炸、冲击超压、高温作用、纵火等复合毁伤打击,其毁伤性明显优于同尺寸的钢破片,其化学潜能是动能的 12.4 倍。

关键词: 爆炸力学; 毁伤增强; 反应性材料; 破片

中图分类号: O389; TJ41

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1 引言

毁伤增强型破片 (damage enhanced fragments, DEF) 又叫反应性破片或含能破片, 当其与目标撞击时引发反应, 释放化学能和热能, 增强对目标的破坏能力, 增加破片式反导导弹对敌导弹的拦截杀伤威力和杀伤半径。据报道^[1] 美海军研究署 (office of naval research, ONR) 已完成其反应性破片战斗部的原型演示试验, 试验表明其威力半径是普通破片战斗部的两倍, 并断定其潜在的毁伤威力相对普通破片战斗部可提高 500%。

毁伤增强型破片由具有“类爆轰”性的亚稳态反应性材料 (reactive materials, RM) 制造而成。亚稳态反应性材料在高速撞击目标时能点火释放大量能量, 通常由两种或更多种非爆炸性固体组成, 这类材料包括铝热剂、金属间化合物、金属/聚合物的混合物、亚稳态分子间复合物、复合材料和氢化物等^[2-6]。为了探索破片式防空战斗部实现高效毁伤的技术途径, 本课题组开展了毁伤增强型破片探索研究。

2 毁伤增强型破片的制备及相关性能

将平均粒径约 $25\ \mu\text{m}$ 的铝粉和聚四氟乙烯粉按 25/75 的质量配比混合均匀, 将混合好的粉末压制成 $\Phi 10\text{ mm} \times 10\text{ mm}$ 的圆柱, 然后在约 $380\text{ }^\circ\text{C}$ 下真空烧结 2~6 h, 即得到毁伤增强型破片 (见图 1), 其质量为 1.78 g, 有关性能见表 1。

3 毁伤增强型破片毁伤性试验研究

3.1 试验测试装置

试验测试装置如图 2 和图 3 所示。

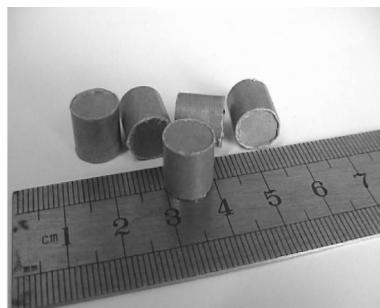


图 1 制作的毁伤增强型破片

Fig. 1 The prepared damage enhanced fragments

表 1 毁伤增强型破片的有关性能

Table 1 Properties of damage enhanced fragments

$\rho_t/\text{g} \cdot \text{cm}^{-3}$	$\rho_a/\text{g} \cdot \text{cm}^{-3}$	$Q/\text{J} \cdot \text{g}^{-1}$	σ/MPa	ε
2.29	2.23	14856.15	113	79.8%

Note: ρ_t , theoretic density; ρ_a , actual density; Q , reactive heat; σ , compression strength; ε , maximum compressibility.

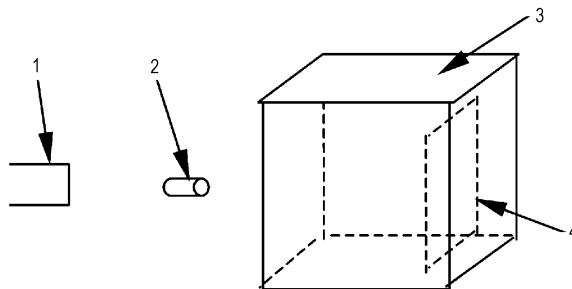


图 2 毁伤性测试装置

1—发射装置头部, 2—毁伤增强型破片, 3—箱体靶板, 4—箱体内目标物

Fig. 2 Experimental set-up of damage test

1—fire device, 2—DEF, 3—target case, 4—inside target

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图 5 毁伤增强型破片的外爆效果
Fig. 5 Exploding Effect outside targets by a damage enhanced fragment



图 6 毁伤增强型破片对铁制箱体的内爆打击效果
Fig. 6 Exploding effect inside iron cases by a damage enhanced fragment

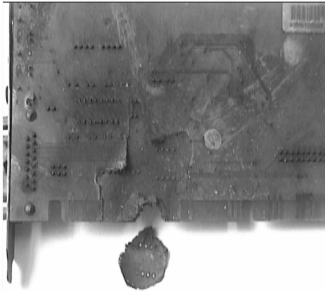
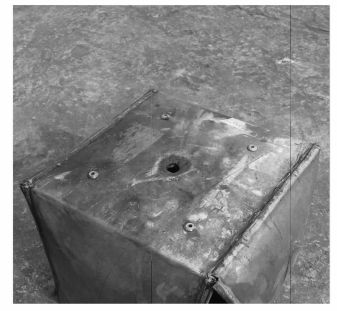


图 7 毁伤增强型破片对铁箱体内电路板的毁伤效果
Fig. 7 Damage effect of a damage enhanced fragment against circuit board inside iron case

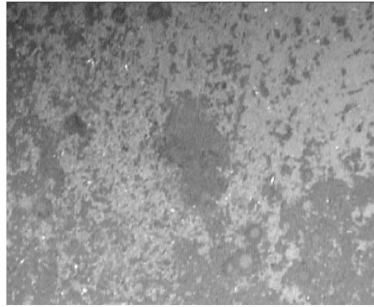


图 8 铁箱体内部的镀锌层汽化照片
Fig. 8 Vaporization picture of zincification layer inside iron case

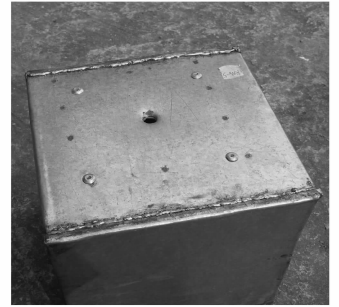


图 9 惰性破片对铁制箱体的打击效果
Fig. 9 Attacked effect of iron case by inert fragment

表 4 说明,箱靶形变量,对白铁皮箱体,各向约为 6.60 ~ 36.62 mm,对壁厚 2 mm 的 A3 钢制箱体,形变量各向约为 1.24 ~ 2.70 mm。空心箱靶的箱体,发生了外向性形变、破裂、撕裂等现象,足以说明毁伤增强型破片穿透箱体后,产生了爆炸超压,测得其初始冲击超压在(0.14 ~ 0.26) MPa 范围,测试数据见表 5。

假定白铁皮箱体内部的气体为理想气体,并且不考虑破片反应释放的气体,根据测量的箱体形变量(表 4)和测得的超压值 p (表 5),可以按如下方法估算破片反应后箱体内部的气体温度 T :

$$T = \frac{p_1 V}{p_0 V_0} \cdot T_0 = \frac{p + p_0}{p_0} \cdot \frac{V_0 + \Delta V}{V_0} \cdot T_0 =$$

$$3 \times 1.2 \times 298 = 1072.8(\text{K}) = 799.65(^\circ\text{C})$$

式中, p_0 为箱体内初始压强, p_1 为爆炸后箱体内压强, V_0 为箱体初始体积, ΔV 为箱体变形增加的体积。

计算结果表明,白铁皮箱体内部气体温度为 799.65 °C,与上述根据镀锌层汽化估计的爆炸产生的高温 1000 °C 比较一致,这也说明超压测试结果较真实。反过来说,如果假定箱体内部温度为 1000 °C,同样可以推算超压约为 0.26 MPa,这正好是实测结果,进一步说明了测试结果的真实性。

表 4 毁伤增强型破片打击后,铁/钢箱的变形量
Table 4 Distortion of iron/steel cases attacked by damage enhanced fragments

No.	case materials	thickness of wall/mm	distortion/mm					
			front	left	right	top	bottom	back
1	A3 steel	2	2.16	1.98	1.72	2.08	1.24	2.70
2		0.80	open	15.88	11.92	14.08	8.90	
3		0.80	28.42	23.60	22.26	35.34	27.04	
4		0.80	14.36	27.62	17.98	29.40	19.42	
5	galvanized	0.80	20.40	19.98	6.60	13.52	14.84	less
6	iron	0.80	13.30	11.38	27.00	36.62	12.78	distinct
7		0.75	9.12	26.4	17.14	9.54	18.64	
8		0.75	8.78	15.7	32.64	34.0	27.04	

表 5 实验测得的超压峰值
Table 5 Measured overpressure peak values

No.	fragments	positions of pressure sensors	over pressure /MPa
1	DEF	bottom	0.19
2	DEF	bottom	0.26
3	DEF	side	0.14
4	DEF	side	0.14
5	steel fragment	bottom	

Note: target cases, 25 cm³ cube iron cases with 0.75 mm wall thickness.

综上所述,毁伤增强型破片对目标的毁伤除了动能打击之外,还有爆炸、冲击超压和高温作用等复合毁伤,而且后者决定其最终毁伤效果,这是因为毁伤增强型破片的化学潜能(据表1计算得26444 J)约为其平均动能(表2)的12.4倍。

4 结 论

以铝/氟聚物复合材料制备的毁伤增强型破片比相同尺寸的惰性钢破片具有更大的毁伤性,除了对目标给予类似钢破片的穿甲打击之外,毁伤增强型破片对目标还同时具有猛烈的爆炸作用、高温作用、纵火等复合毁伤。毁伤增强型破片的化学潜能约为其平均动能的12.4倍。

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Preliminary Research on Damage Enhanced Fragment

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Abstract: Damage enhanced materials were used to improve damage efficiency of fragments antiaircraft weapons. A kind of damage enhanced fragments (DEF) containing Al/PTFE with dimension of $\Phi 10$ mm \times 10 mm was designed and prepared. Damage performance experiments show that damage enhance fragments attack targets not only by kinetic energy, but also by combined damages such as exploding, overpressure, high temperature, and setting fire etc. The results show that the designed damage enhance fragments have remarkably higher damage performances than steel fragments with the same dimensions, and its potential chemical energy is 12.4 times as high as its kinetic energy.

Key words: explosion mechanics; damage enhance; reactive material; fragment

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Numerical Investigation on Perforation of Projectile Impacting Stiffened Plate

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Abstract: Based on the experimental perforation of projectile impacting stiffened plate, numerical simulations were conducted to study the failure pattern of target, projectile trajectory and the anti-perforation capability of target. The results show that stiffeners enhance the strength and rigidity of target, and change the whole structure capability and the failure pattern of target. For the single stiffened plate, single stiffened plate with "T" sectioned stiffener and cross stiffened plate, the increase of limit penetration velocity for different stiffeners and projectiles is 35% ~ 80%. The maximum deflexion angle of projectile is 35° ~ 40°.

Key words: explosion mechanics; projectile; stiffened plate; impact load; perforation; numerical simulation