The Waveshaper Effect on Ta-MS Multiliner Explosive Formed Pojectile with Tantalum as Penetrator and Mild Steel as Stabilization Base

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ABSTRACT

Numerical simulation was carried out using Autodyn 2D code to study the formation and tandem behavior of multiliner EFPs (Explosively Formed Projectiles). The main aim of multiliner configuration is to develop tandem behavior and to increase the length of explosively formed projectile in different applications. The high ductility and high dynamic material behavior of Ta (Tantalum) makes it difficult to generate a solid and stable projectile. To get these specific characteristics, mild steel was used for being the most stable liner material in the EFP technology. So when we used mild steel as a stabilization base and tantalum as a penetrator then solid and stable projectile was achieved. The tandem behavior with tantalum-mild steel multiliner configuration was studied. The effects of detonation method, confinement and waveshaper on the multiliner EFP configuration have also been determined by simulation. The detonation method has its effect on the tandem behavior whereas confinement has not. The waveshaper is found to have 40.4% more prominent and faster tandem effect on the multiliner EFPs.

Key Words: **Tandem, Multiliner, Detonation Method, Confinement, Waveshaper.**

1. INTRODUCTION

EFP formation depends on liner curvature and mass distribution of the liner if warhead configuration including parameters like casing, explosive, liner material etc. remain same. A proper liner material should be use in order to have good penetration capability. Ta is most widely used as a liner material in existing weapon systems because of its superior material properties [1]. The shape and velocity of the penetrator depends on optimization of parameters like liner shape, thickness and material; casing material and thickness; type of explosive and head height. Head height is very important design parameter and often it is 0.75 calibers [2]. The Ta EFP has 20% better perforation performance than Armco iron (Fe) EFP [3]. But one serious problem is the bad matching of tantalum, it is not possible to produce a defined mass distribution over liner diameter. Although too much ductile, high dynamic material behavior of tantalum makes it difficult to generate a projectile which is a solid, elongated and additionally owns a projectile base which provides good flight stability [4].

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At EMI in 1986 a technique was developed where projectile was built out of an insert of a multiliner [5]. This means that at least two disks, one made of Ta and other made of Fe are arranged directly behind each other, with the Fe liner as stabilization base of the Ta penetrator.

To reduce the number of firings and obtain knowledge about multiliner formation, numerical simulations are performed. During numerical simulation study it could be shown that two disks accelerated by explosive always lead to two slugs with a velocity difference of 300-400 m/s [6]. The investigation has shown the possibility to form flight-stable, solid Ta EFP by using multiliner technique [7]. With waste Fe EFP, the formation of the Ta EFP was controlled without complex cost effective matching of the Ta liner. The described multiliner technique offers a wide area for system applications. The multiliner is used to increase the length of a penetrator for a given geometry of warhead to improve the perforation performance and is also used as a tandem warhead. Here we use this multiliner concept and implement it on the same Ta penetrator with different materials as stabilization base to search the best. The detonation methods e.g. point initiated detonation and peripheral initiated detonation is simulated to see their performances on the multiliner EFPs. Likewise Confinements e.g. cylindrical and tapered casing are simulated to see their effects on multiliner EFPs. The waveshaper is also used in the multiliner EFP in this study.

2. MODELING AND SIMULATION SCHEME

The explosive metal interaction applications are of very high cost together with explosive nature experiments, difficult to conduct. The computer simulation techniques have been developed to overcome such problems. Different simulation codes have been introduced to investigate the Munroe effect and Misznay-Schardin effect. The Munroe effect is the focusing of explosive power into deep penetrating jet by hollow charge, also known as shaped charge effect [8-9]. The Misznay-Schardin effect is similar to the shaped charge in that liner pushed by explosive forms a fragment whereas a recess concave dish is used instead of cone in the Misznay-Schardin effect or EFPs [10-14]. The explosive metal interaction phenomenon of these two effects is same except the apex angles involved among them. The large plastic deformations are observed in shaped charge due to focusing of large explosive energy by reducing the apex angle [15]. The energy focusing is reduced by increasing the apex angle of EFPs which cause moderate plastic deformations. Therefore Euler processor in Autodyn 2D hydrocode is used to meet the requirement of coupling problem of fluid and solid [16-17].

The explosive performance in the EFP warhead increases with density of explosive. Therefore we selected HMX explosive of high density (1.89 g/cm^3) [18-9]. The Ta, MS (Mild Steel), Cu (Copper), Fe and Al (Aluminum) are used as liner materials. The MS contains 0.16-0.29% carbon. The numerical modeling is conducted with Autodyn 2D hydrocode to study the stability of each liner material. The caliber of the EFP warhead is 36mm with L/D (Length to Diameter Ratio) of 1.17. As the thickness of the liner increases, because of the increased inertia, projectile velocity decreases. Also it is less likely to have EFP formation for high density materials for higher liner thickness [20].Therefore liner materials of uniform thickness 1.5mm are used as front and rear liners in the multiliner configuration warhead. The Al is used as casing of the warhead. The mesh generation in the Autodyn 2D simulation has grid information listed in Table 1.

The Euler grid is the podium on which geometrical configuration with liner materials, explosive and confinement is implanted. The materials are modeled with a linear equation of state and Johnson-Cook strength model. The explosive is modeled using the JWL EOS (Equation Of State). The plexiglas is used as a waveshaper with shock equation of state. The reference temperature for all liner's materials is selected as 300^{o}K and instantaneous geometric strain as an erosion model is selected with erosion strain 2.5.

2.1 Strength Model and Equation of State

Johnson-Cook Model is used as a strength model in the simulation. It expresses flow stresses in terms of equivalent plastic strain, plastic strain rate and homologous temperature. The yield stress δ is given by equation given as:

$$\delta = [A + (B^{\varepsilon P})n]\,[1 + C\ln\varepsilon^*]\,[1 - T^*n] \qquad (1)$$

The expression in the first bracket gives the stress as a function of strain; expressions in second and third brackets represent the effect of strain rate and temperature respectively. Where ε^p is the effective plastic strain and nondimensional ε^* strain rate. A is yield stress constant, B is strain hardening coefficient, n is strain hardening exponent, C is strain rate dependence coefficient and m is temperature dependence exponent. T* is homologous temperature and is given by equation given as:

$$T^* = (T - T_{ref}) / (T_{melt} - T_{ref}) \qquad (2)$$

Heat is generated in an element by plastic work and the resulting rise in temperature is computed using specific heat for the material. We applied the JWL EOS to HMX proposed by Lee, E.L., [1], and the equation of the state is shown in Equation.

$$P = A_{JWL}\left(1 - \frac{\omega\eta}{R_1}\right)\exp\left(-\frac{R_1}{\eta}\right) + B_{JWL}\left(1 - \frac{\omega\eta}{R_2}\right)\exp\left(-\frac{R_2}{\eta}\right) + \omega\eta\rho_{ref}\,e \qquad (3)$$

Where P is the pressure, η is ρ/ρ_{ref}, ρ is the current density, ρ_{ref} is the reference density, e is the specific internal energy, A_{jwl}, B_{jwl}, R_1, R_2, and ω are the material properties of the chemical high explosive given in Table 2 [21-22].

The input material parameters for Ta, Fe, Cu, MS, Al and plexiglas for EFP simulations are tabulated in Tables 3-4 [21-25].

3. RESULTS AND DISCUSSION

The propagation of the shock wave as a result of initiation HMX explosive within the explosive is distributed in such a way that there creates a vacuum in the centre. When the shock wave front reaches the tip of the cone, after 3.5μs, there is a high stress concentration at this singular point, the deformation rates are tremendous and a fast temperature rise follows. The initiation of the jet and velocity contour plots are represented in Fig. 1. The velocity reaches a maximum at the jet's center and reducing its value towards the edges. Initially multi-jets behave as compacted single jet after getting exposure of shock wave. The L/D ratio of the jet gradually decreases with time to obtain its optimized value and shape.

TABLE 2. MATERIAL PROPERTIES OF HIGH ENERGY EXPLOSIVE HMX

Variables	Properties	Units
ρ_{rd}	1.89	Kg/cm^3
AJ_{WZ}	9.4334E-1	Tpa
B_{JWZ}	8.8053E-3	Tpa
R_1	4.700e+0	-
R_2	9.00E-1	-
ω	3.5E-1	-
E	1.02E-2	Kj/mm^3
V_{det}	9.1	m/ms

TABLE 1. GRID GENERATION WITH INDICES IN THE AUTODYN 2D SIMULATION

Grid No.	Grid Name	Processor	Index		Axis		Grid Finest Ratio	
			i	j	x	y	i/x	i/y
1.	CPH361	Euler	240	90	80	30	3	3
2.	CPH362	Euler	240	90	80	30	3	3
3.	TP363	Euler	240	90	80	30	3	3
4.	TP364	Euler	240	90	80	30	3	3
5.	CP365	Euler	240	90	80	30	3	3
6.	CP366	Euler	240	90	80	30	3	3
7.	WCH367	Euler	240	90	80	30	3	3
8.	WCH368	Euler	240	90	80	30	3	3

TABLE 3. MATERIAL PARAMETERS FOR TANTALUM, ARMCO IRON AND COPPER

Parameters	Tantalum	Armoc Iron	Copper
Equation of State	Linear	Linear	Linear
Reference Density (g/cm^3)	16.69	7.89	8.96
Bulk Modulus (Kpa)	140E+08	164E+08	1.29+8
Reference Temperature (K)	300	300	300
Specific Heat (j/kg K)	135E+02	4.52E+02	3.83E+02
Strength Model	Johnson Cook	Johnson Cook	Johnson Cook
Shear Modulus (Kpa)	6.90E+07	8.00E+07	4.60E+07
Yield Tress (Kpa)	8.00E+05	1.00E+06	1.00E+05
Hardening Constant (Kpa)	5.50E+05	3.80E+05	2.92E+05
Hardening Exponent (Tpa)	4.00E-01	3.10E-01	3.10E-01
Strain Rate Constant	5.75E-02	6.00E-02	2.60E-02
Thermal Softening Exponent	4.40E-01	5.50E-01	1.09E+00
Melting Temperature (K)	3293	1812	1356
Failure Model	None	None	None
Erosion Model	Institute of Geometric Strain	Institute of Geometric Strain	Institute of Geometric Strain
Erosion Strain	2.5	2.5	2.5

TABLE 4. MATERIAL PARAMETERS FOR MILD STEEL, ALUMINUM AND PLEXIGLAS

Parameters	Tantalum	Armoc Iron	Copper
Equation of State	Linear	Linear	Linear
Reference Density (g/cm^3)	7.89	2.7	1.183
Bulk Modulus (Kpa)	180E+08	5.83E+07	-
Reference Temperature (K)	300	300	300
Specific Heat (j/kg K)	4.52E+02	9.10E+02	-
Strength Model	Johnson Cook	Johnson Cook	None (Hydrogen)
Shear Modulus (Kpa)	8.18E+07	2.69E+07	-
Yield Tress (Kpa)	3.50E+05	1.67E+05	-
Hardening Constant (Kpa)	2.75E+05	5.96E+02	-
Hardening Exponent (Tpa)	3.60E-01	5.51E-01	-
Strain Rate Constant	2.20E-02	1.00E-03	-
Thermal Softening Exponent	1	8.59E-01	-
Melting Temperature (K)	1811	893	-
Failure Model	None	None	None
Erosion Model	Institute of Geometric Strain	Institute of Geometric Strain	Institute of Geometric Strain
Erosion Strain	2.5	2.5	None
Gruneisen Coefficient	-	-	2.589
CI (m/ms)	-	-	1.516
SI			1.516

The L/D ratio is approximately 3-4 for EFP designs of calibers with one CD (Charge Diameter). To produce EFPs with greater perforation capability it would be necessary to form EFPs that are much longer than one CD and greater than an L/D of 5. Designing and forming repeatable EFPs with these characteristics is very difficult. A study was made of the penetration data from two- and three-liner warheads to determine if these complex EFP geometries had similar armor penetrating characteristics and efficiencies as single EFP warheads. The experiments were conducted at EMI using tantalum as penetrator and Armco iron as stabilization base [1]. The flash X-ray shadowgraph and soft recovered EFP is shown in Fig. 2. The length of this multiliner EFP was increased by 65% which can penetrate into a target plate more than single EFP.

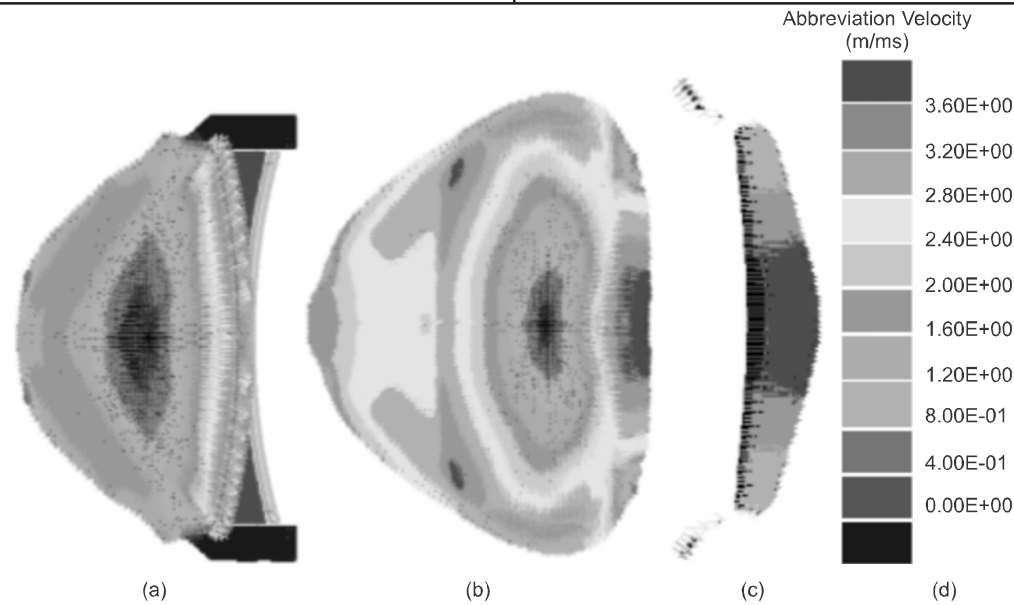

FIG. 1. VELOCITY GRADIENT AT THE INSTANTS OF (A) 3.5µs, (B) 11µs (C) 23µs

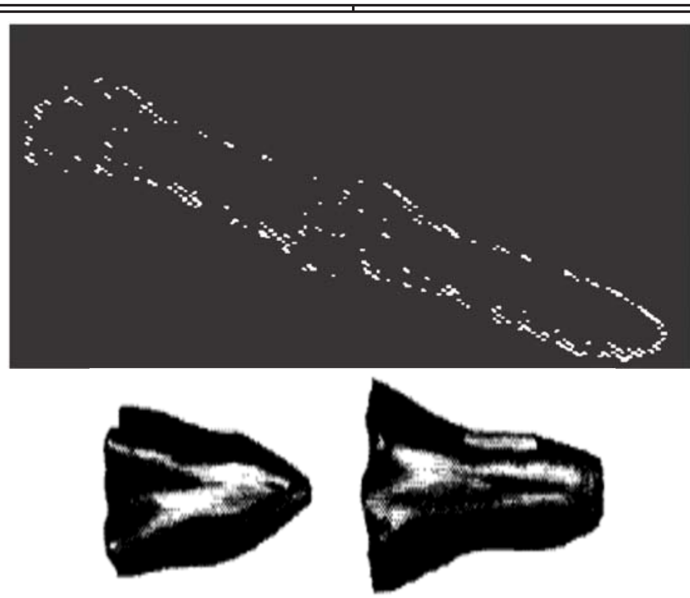

FIG. 2. FLASH X-RAY SHADOWGRAPH AND SOFT RECOVERED EFP [1]

4.1 Selection of MS as Stabilization Base

Earlier Ta as penetrator and MS as stabilization base were used in multiliner EFP. The stabilization based liner is important to provide the stability to Ta penetrator, so it should have good stability. Since tantalum was used as EFP because of its high ductility and high dynamic material behavior but it was found difficult to produce a solid and stable projectile. That is the reason why we are looking for a material which has capability to provide a stabilization base to make the tantalum solid, elongated and a stable projectile. Previously Armco iron was used as rear liner material to provide the stabilization base to tantalum penetrator as front liner material [3]. But when the stability of different materials i.e. Cu, Fe, MS, and Al is determined, then we came to know that stability of the aluminum is found minimum due to its micro-atomic structure, lowest density or softness and MS is the most reliable or stable material due to minimum divergence at stable velocity as shown in Table 5. So we replaced Armco iron to mild steel in multiliner EFP to see the effects of detonation, confinement and waveshaper on the formation, length and tantalum behavior.

4.2 The Effects of Detonation Methods on Multiliner EFP

The effect of detonation method on the formation of EFPs was studied and it came to know whatever casing was used, L/D ratio of EFPs was found to be greater in case of peripheral initiated detonation method which favors better perforation performance because of planner shock wave striking at normal to the liner's material which converge it more toward its axis due to elongated jet tip and higher jet tip velocity. The tantalum penetrator in front and mild steel as stabilization base of a multiliner with peripheral initiated detonation and point detonation was simulated and the effects of both detonation methods on multiliner EFP were observed as shown in Figs. 3-4. At 50µs, two liners are stuck with each others, After this time they began to separate due to velocity gradients with Ta penetrator as a front liner and MS as rear liner. The Ta has higher velocity than MS due to their density difference with density of Ta as 16.69 g/cm^3 and density of MS as 7.89 m/cm^3. The Ta and MS remained struck with each other after 218µ sec for point initiated detonation whereas they were separated after this time for peripheral initiated detonation. The separation of the projectiles is very effective in the under-water applications where front projectile bears the load of drag force exerted by water on the projectile and produces vacuum behind itself. The rear projectile moves in the vacuum without retardation of the velocity due to drag force of water. The quick separation of the projectiles is necessary in the short-range proximity fuse applications.

4.3 The Effects of Confinements on Multiliner EFP

The formation of multiliner EFP with tantalum as penetrator and mild steel as stabilization base with tapered and cylindrical casings was simulated and the effects of both casings on multiliner EFP were observed. Both casings for this warhead design as shown in Figs. 4-5 had no effect on the formation of multiliner EFP and remained stuck with each other throughout the simulation.

4.4 Effect of Waveshaper on Multiliner

When planer shock wave strikes the target then it has maximum impact on the target. In case of EFPs, the shock

TABLE 5. STABILITY OF LINER MATERIALS USED AS EFP IN AUTODYN 2D SIMULATIONS

Parameters	Mild Steel	Copper	Armoc Iron	Aluminum
Divergence (at Maximum Velocity)	-1.625E-2 to 1.62E-3	-9.032E-3 to 8.45E-2	-9.127E-3 to 1.52E-2	-6.839E-2 to 3.412E-3
Divergence (at Stable Velocity)	0.0 to 5.63E-4	-1.58E-3 to 9.89E-4	-2.035E-3 to 0.0	-3.53E-3 to 5.67E-3

wave striking at liner is not a planer but of a spherical shape. The planar shock wave is achieved by introducing waveshaper in the explosive to get maximum effect. The waveshaper permits a wider cone angle to be used which in turn reduces the warhead length. The explosive must be initiated from the rear, so that the detonation wave travels towards the liner. The formation of multiliner EFP with tantalum as penetrator and mild steel as stabilization base with point detonation and waveshaper is shown in Fig. 6. The liner materials were separated from each others after 130 μsec which was faster compared to peripheral initiated detonation method. The stability behavior of the multiliner EFPs after 218 and 130 μsec was approximately similar with slightly better stability in case of waveshaper. The velocity in case of waveshaper was higher than without waveshaper, so has capability to penetrate more depth.

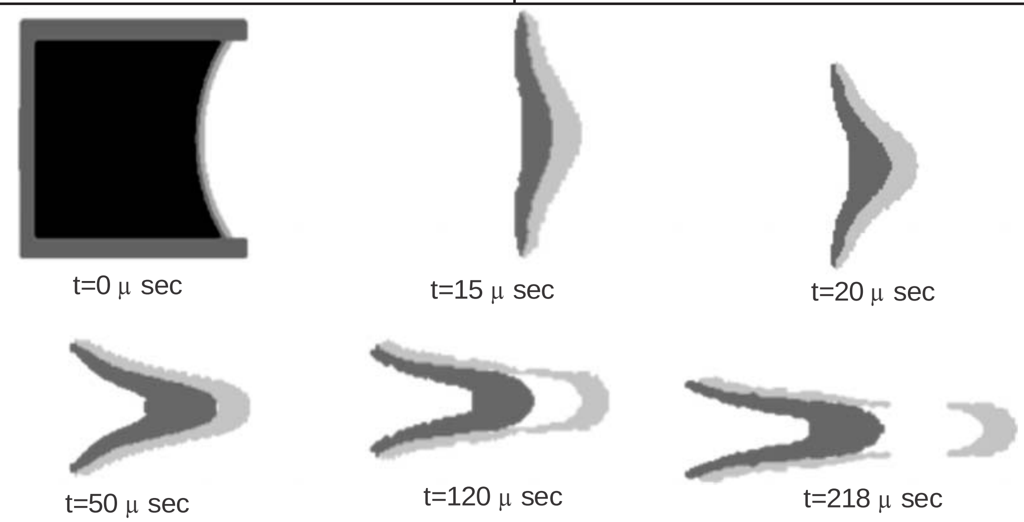

FIG. 3. FORMATION STEPS OF MULTILINER TA AND MS EFP WITH PERIPHERAL INITIATED DETONATION

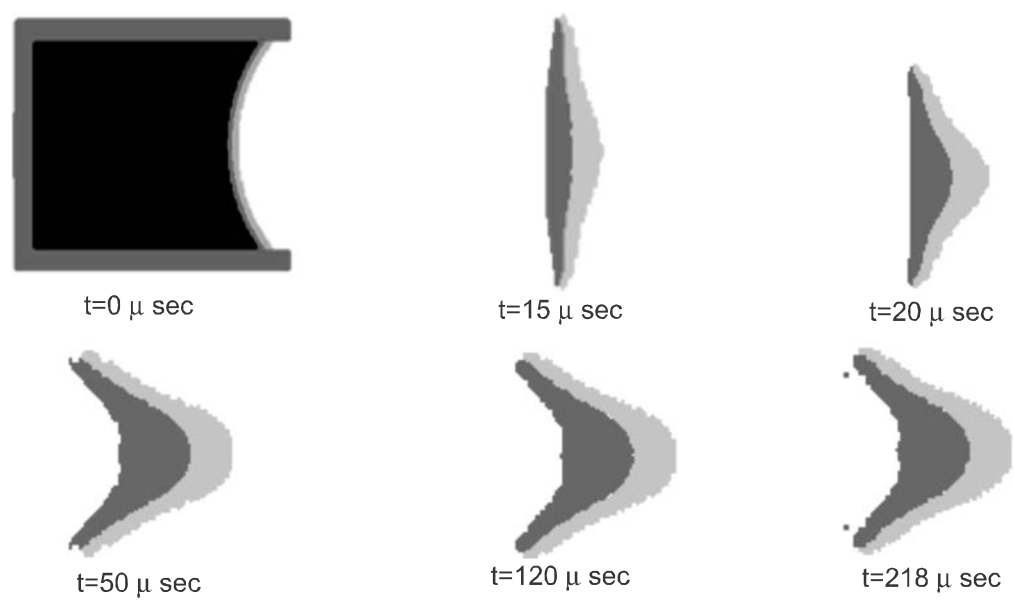

FIG. 4. FORMATION STEPS OF MULTILINER TA AND MS EFP WITH POINT INITIATED DETONATION

5. CONCLUSIONS

The single Ta EFP cannot be solid, elongated and stable projectile due to high ductility and high dynamic material behavior, so in order to obtain these characteristics, stabilization base is provided. The Fe was used as a stabilization base to Ta penetrator in multiliner EFP. The Fe has stability less than MS that is why we replaced Fe to MS as a stabilization base and Ta as a penetrator to get solid, elongated and stable projectile. The multiliner EFP with Ta as penetrator and MS as stabilization base was investigated and found that Ta EFP separated from the MS EFP after 218μ sec. When we used point detonation instead of peripheral initiated detonation no tandem behavior was found but both materials remained stuck together. When a waveshaper was introduced in the

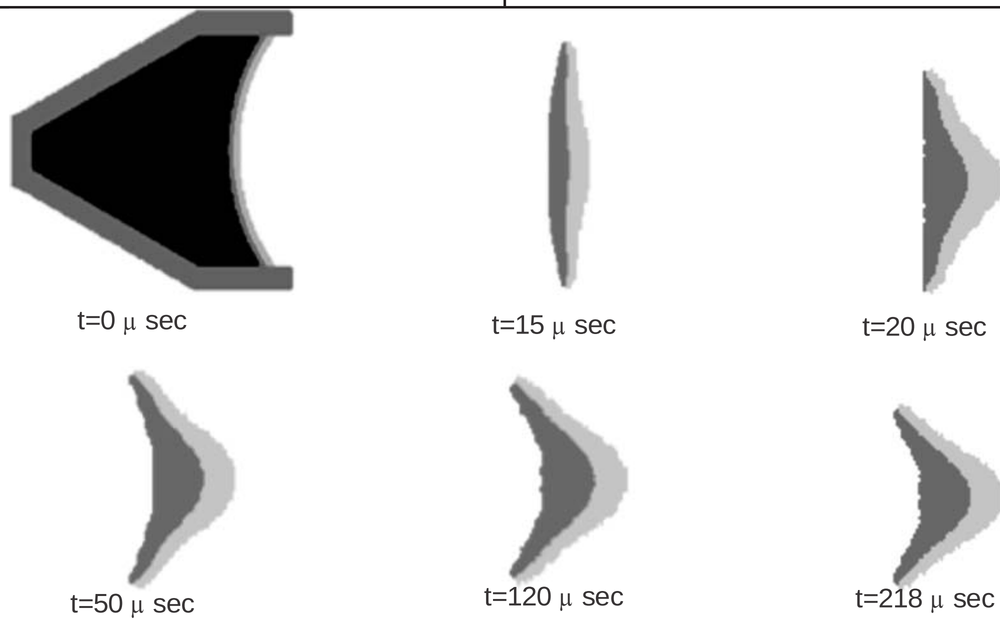

FIG. 5. FORMATION STEPS OF MULTILINER TA & MS EFP WITH TAPERED CASING AND POINT INITIATED DETONATION

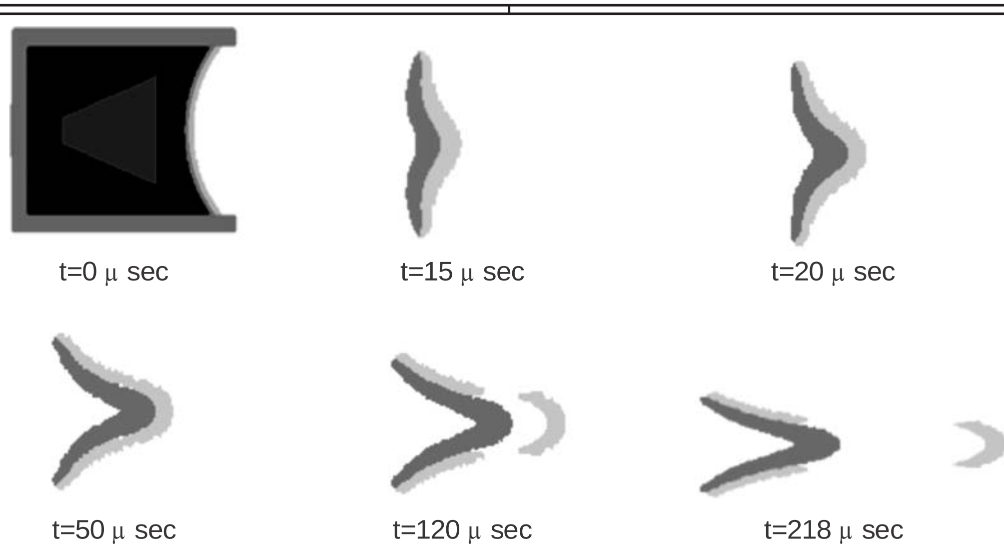

FIG. 6. FORMATION STEPS OF MULTILINER TA AND MS EFP WITH WAVE SHAPER

explosive to make planer shock wave that struck normal to the liner material then these two materials were separated after 130 μsec. Hence, the waveshaper has prominent and faster tandem effect on the multiliner EFPs. The cylindrical and tapered casings have no effect on multiliner EFP.

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