Slugless Jet with Bimetallic Lined Shaped Charge

Santosh N Ingole and M J Rathod

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SLUGLESS JET WITH BIMETALLIC LINED SHAPED CHARGE

Santosh N Ingole*[a], M J Rathod[b]

Department of Metallurgy and Material Science,

College of Engineering Pune, Shivajinagar, Pune- 411005(INDIA)

[*a]ingolesn14.meta@coep.ac.in, [b]mjr.meta@coep.ac.in

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Abstract. Slug of about 80% mass of the liner produced in the traditional shaped charges. When the liners diffusion welded under isostatic conditions, the bimetallic cones produced can provide a slug to less than 20% theoretically and less than 10% in practice. Such slugless jets provide different advantages like exothermicity and improved penetration performance. Soft recovery of the collapsed liner on detonation proved an effective method to study the phenomenon. Physical and metallurgical investigation of the recovered slug and jet particles confirms the facts postulated to get about slug with 20.45% of the original liner mass.

Introduction

A metallic lined cavity of explosive is used for creating larger crater in different targets. The targets exploited using such charges varies from stones, bunkers, Oil wells, or armour/metallic sheaths. Partial focusing of blast energy caused by a hollow or void cut into a piece of explosive, a property which is exploited by a shaped charge. The focusing of the detonation products creates an intense localised force [1,2,3,4]. This concentrated force when directed against a metal plate is capable of creating a deeper cavity than a cylinder of explosive without a hollow cavity, even though more explosive is available in the latter case. In this process, energy gets focused with use of metallic lining and deeper hole of smaller size is obtained. On detonation of explosives, typically in shaped charges detonation wave propagates through explosive column. The detonation front reaches liner and the wall of the liner in ntact with explosive experiences an intense pressure of 0.8-1.0 GPa. Pressure generated exceeds the yield strength of the liner material, behaving as inviscid, incompressible fluid. Liner collapses from apex to base under point initiation of explosive. At this intense pressure, the collapse of the material gets initiated with apex of cone striving to collide on Axis of Symmetry (AOS). Collision results in liner material under tremendous pressure-being extruded along AOS. The extruded material is the jet while the portion of liner flows into compact slug at rear of jet. On collapse of the liner the material in contact with explosive contributes in slug mass, while the material on opposite wall of the liner contributes in jet, which actually responsible for penetrating the targets. The conical liner on implosion by explosive shock wave converted into a rod which on further stretching splits into variable speed particles; the frontal are high velocity jets whereas the rear ones are low velocity slugs. Typically, the mass of liner going into jet is about 20% whereas that in slug is about 80%. Thereby the penetration performance associated with the reduction in slug mass in the design of conical liner. Further, there is always possibility to block the hole created by jet tip due to higher mass and diameter of the slug. Carefully designed and fabricated Bimetallic liners obviate the problem. Skolnick and Goodman [5] have elaborately discussed specific advantages for using multi-layered liners in combination with different explosives in regards to enhancement of performance and also offered possible mechanism. Chanteret et al [6] reported combination of two different liner materials, one with high sound velocity and other with high ductility, in designing the shaped charge. According to these authors, high tip velocity is controlled by the material having higher sonic velocity and supported by the material having high ductility.

In the present study, while improving the penetration performance of shaped charges with use of bimetallic liner, slugless jets have been encountered. The study involved replacement of monolithic liner (copper) with bimetallic liner consisting of aluminum (outer cone) and copper (inner cone). Theoretical prediction by computer simulation using hydrocode (AutoDYN) verified with soft recovery trials of the fabricated bimetallic lined shaped charges.

Experimental.

Morphology of Shaped Charge: The Shaped charge of 60mm caliber designed with 60^o liner made out of 2 mm effective wall thickness aluminum-copper bimetal selected filled with HMX and encased in carefully designed aluminum alloy; as outlined in Fig.1.

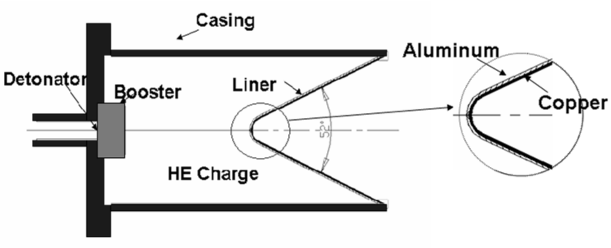

Fig.1 Bimetallic lined Shaped Charge

Modeling of Shaped Charge: The Shaped charge with 60mm diameter and 60^o conical angle was modeled using nonlinear hydrocode–AutoDYN-2D (As per Fig.2). Computational speed accelerated with use if axial symmetry. The materials have been selected from the material library and the fine meshing at desired locations. Comparative studies using various combination of aluminum and copper material has been attempted as liner material, maintaining the same effective thickness for all cases. In addition to the penetration studies, the simulation accrued analysis of slug particle at complete breakup. Fixed and moving gauges placed at various location in order to assess the performance in terms of pressure, temperature, velocity at that particular gauge point.

Parameters for Modeling used are:

Point detonation
Medium : Still Air
Booster : RDX – JWL EOS
Main Charge : HMX- JWL EOS
Casing : AL 2024T351 - Shock EOS & Johnson Cook strength model
Bimetallic liner : Al 1100 –O - Shock EOS & Steinberg Guinan strength model
Cu OFHC - Shock EOS & Steinberg Guinan strength model
Target : Steel 4340 - Linear EOS & & Johnson Cook strength model

Different combinations for bimetallic liner were examined as:

(a) Monolithic (Only copper) (MLSC)
(b) Bimetallic (Aluminum: Copper: 45:55) (BMLSC4555)
(c) Bimetallic (Aluminum: Copper: 50:50) (BMLSC5050)
(d) Bimetallic (Aluminum: Copper: 55:45) (BMLSC5545)
(e) Bimetallic (Aluminum: Copper: 85:15) (BMLSC8515)

Shaped Charge fabrication: Shaped charge assembled in different stages of manufacture as below and also explained in Fig.3

(a) Aluminum Liner – fabricated from aluminum sheet of 2 mm thick by shear forming followed by solution annealing with final thickness of 1 mm;
(b) Copper Liner – fabricated from aluminum sheet of 2 mm thick by shear forming followed by vacuum annealing;
(c) Bimetallic Liner – fabricated by diffusion welding of the aluminum and copper liners under optimised isostatic condition [7];

(d)Main Explosive charge- HMX: Wax(95:5) pressed with double action pressing alongwith bimetallic liner;
(e)Booster explosive charge- RDX: Wax(95:5) pressed;
(f) Case- Fabricated from Aluminum alloy rod.
(g) Main explosive charge alongwith booster assembled in the casing and concentricity of the assembly is ensured.

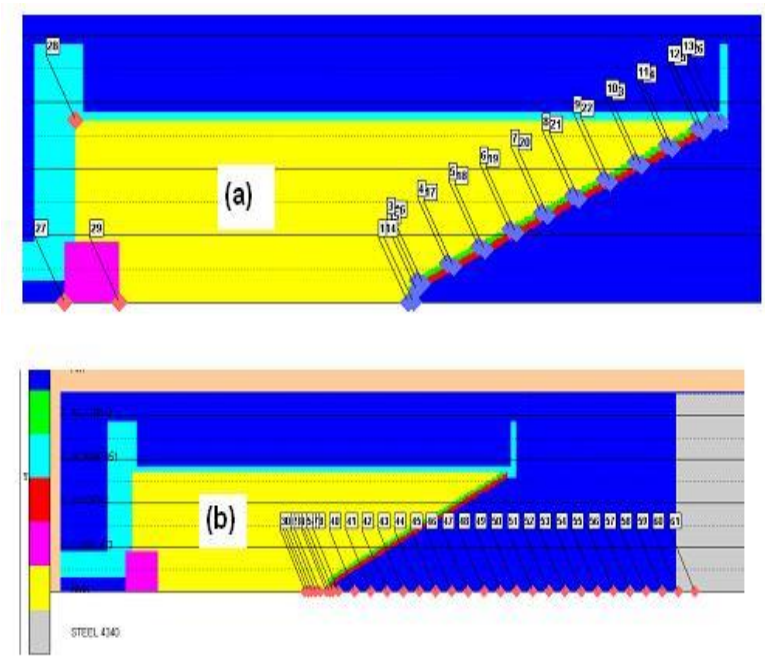

Fig. 2 Modeled Shaped Charg indicating guage points for simulation study

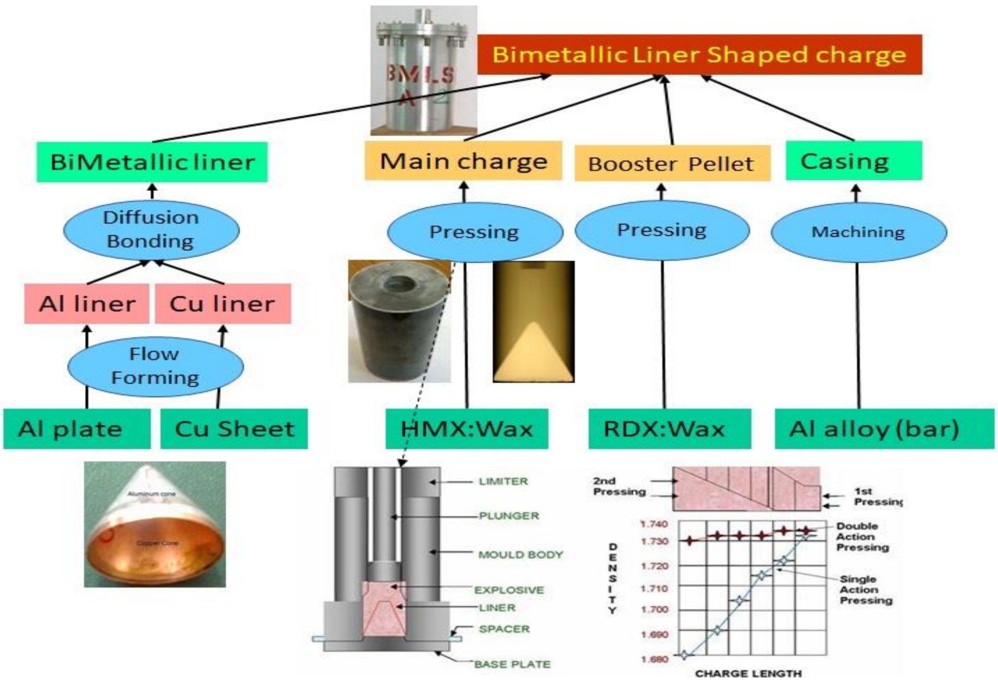

Fig.3 Assembly of Shaped Charge

Soft Recovery Trials:
Study of Slug involved capturing of the jet and slug particles formed after collapse of the conical liner on detonation in the shaped charges. Soft recovery of shaped charge jet and slug particles at its maximum stretch is made as per setup shown in Figure 4, which is based on the setup described by Lassila et al [8]. The Column for soft recovery consists of series of material with increase in density so that deceleration of the high velocity particles accompanied with capture of the particles. Different materials used in series are Air gap (ρ=1.29kg/m^3), Aqueous film forming foam (ρ=3kg/m^3), expanded polystyrene foam (ρ=8kg/m^3), Polyethylene foam (ρ=16 kg/m^3), crosslinked polyurethane foam (ρ=32 kg/m^3 and 40kg/m^3) and water (ρ=1000kg/m^3) and finally steel block (ρ=7800kg/m^3). Water and steel column provided as the backup in case of escape of high velocity jet particles.

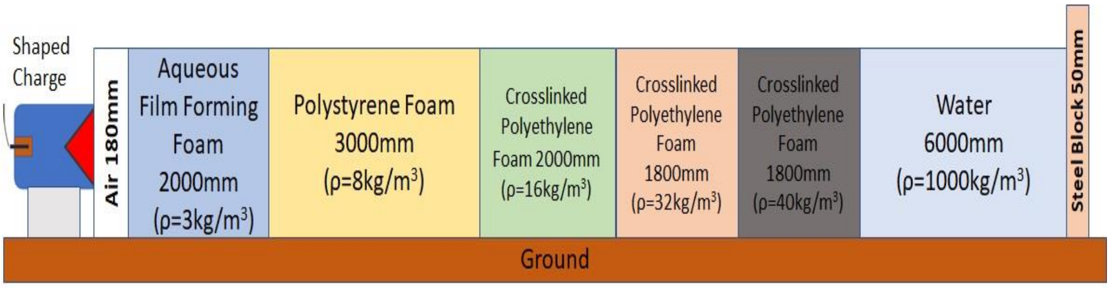

Fig.4 Setup for Soft recovery experiment

The length of column designed based on the models presented by Lambert [9]. It assumed steady state incompressible and inviscid fluid flow conditions applied to hypervelocity projectile impacting a target in 1-D. Also, in the reference frame being fixed to the penetrator/target interface, giving the streamline energy equality and solution.

The jet tip velocity is predicted by

$$V = V_0(\frac{x}{x_0})^{-\gamma} \quad (1)$$

Where , V is the output jet velocity on assig the column, V_0 is the input velocity in the particular column , x is the column length and x_0 is the standoff for the particular column at the initiation in that column. γ is the square root ratio of target density(ρ_t) and penetrator density (ρ_p).

$$\gamma = \sqrt{\frac{\rho_t}{\rho_p}} \quad (2)$$

Conversely, length of the column can be obtained using

$$x = x_0(\frac{V}{V_0})^{\gamma} \quad (3)$$

For the present experiments the estimated velocity and length of columns are tabulated in Table 1; assuming initial jet tip velocity as 8000m/s and penetrator density as 8320kg/m^3.

Metallography: The Slug and jet particles captured in the column is recovered and subjected for physical measurements and metallographic investigation. Weight and size of the slug particles was measured. The slug and jet particles wire cut carefully and hot mounted to analyse the microstructure.

Results and Discussion.

Simulation Study: Liner collapse and formation in jet at various time intervals (1.7µs, 12µs, 17µs, 23µs, 40µs, 60µs, 70µs and 100µs) was analysed for all the simulation experiment. (Fig. 5 to Fig. 10). Maximum Jet Tip Velocity and slug velocity of the stretching jet for simulated experiments also analysed (Fig.11) alongwith comparative velocity gradient in the stretching jet at various time (Fig 12) as well as for various simulated configurations (Fig. 13).

It was observed that

(a) The outer material of the bimetallic liner goes into the slug whereas the inner material forms the core of the jet.

(b) Collapse, jet/slug formation, stretching and breakup phenomenon remained similar. However, early jet/slug formation or breakup in case of bimetal than the monolithic lined shaped charge.
(c) With increase of lighter material as outer layer in bimetallic liner the amount of slug mass is reduced.
(d) Higher jet velocity accrued in bimetallic lined shaped charge with increase in lighter material as outer layer.
(e) Slug analysis for monolithic and bimetallic lined shaped charges revealed the mass of 95.0g and 25.0g respectively.

Table 1. Velocity Estimation for Shaped charge jet particle in different materials

Material	Density (kg/m^3) ρ_t	Density ratio γ	Column Length (mm) (x)	Input jet tip velocity (m/s) V_0	Output jet tip velocity (m/s) V
Air	1.29	0.012	180	8000	8000
Aqueous film forming foam	3	0.018	2000	8000	7987
expanded polystyrene foam	8	0.03	3000	7987	7857
Polyethylene foam	16	0.042	2000	7857	7443
polyurethane foam	32	0.06	1800	7443	6760
crosslinked polyurethane foam	40	0.067	1800	6760	5996
Water	1000	0.335	6000	5996	4249
Steel	7800	0.935	50	4249	18

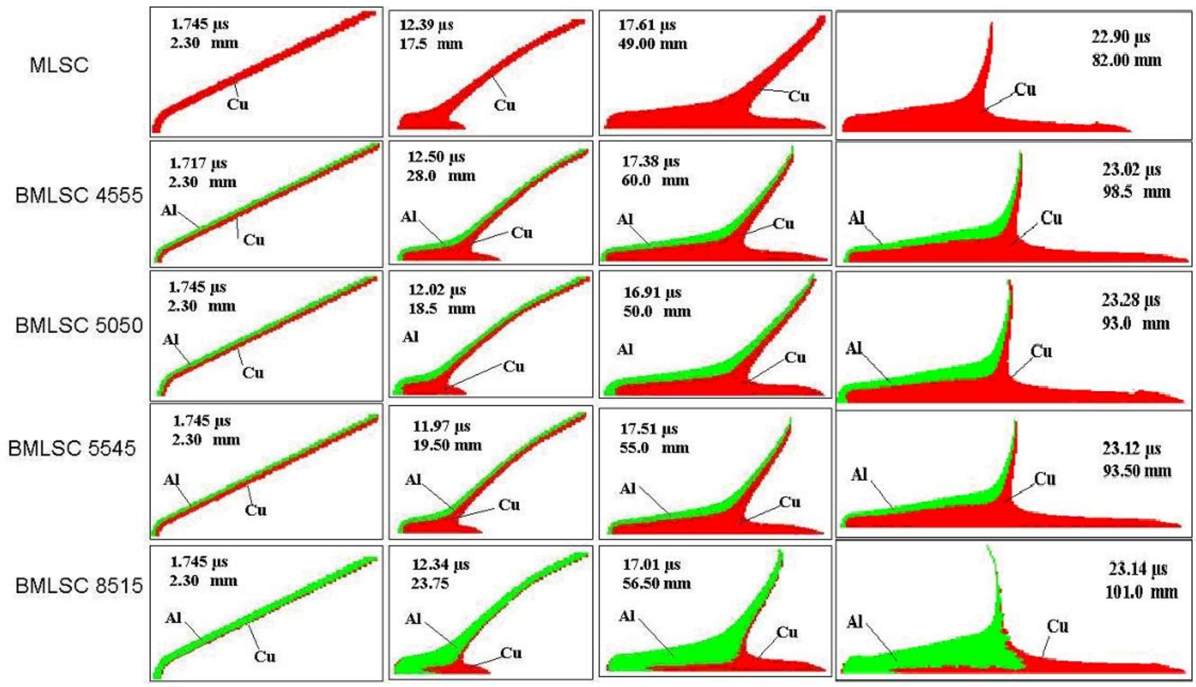

Fig. 5. Jet & collapse of liner in Monolithic & Bimetallic Lined shaped charge at 1.7µs, 12µs, 17µs and 23µs

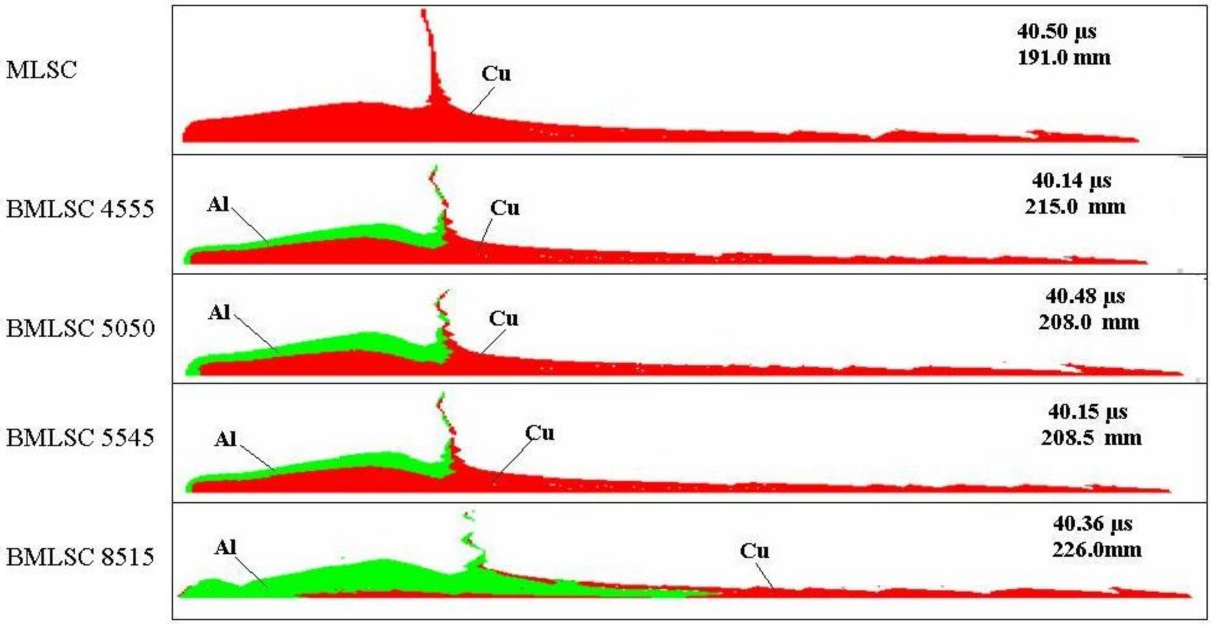

Fig. 6. Jet & collapse of liner in Monolithic & Bimetallic Lined shaped charge at 40 µs

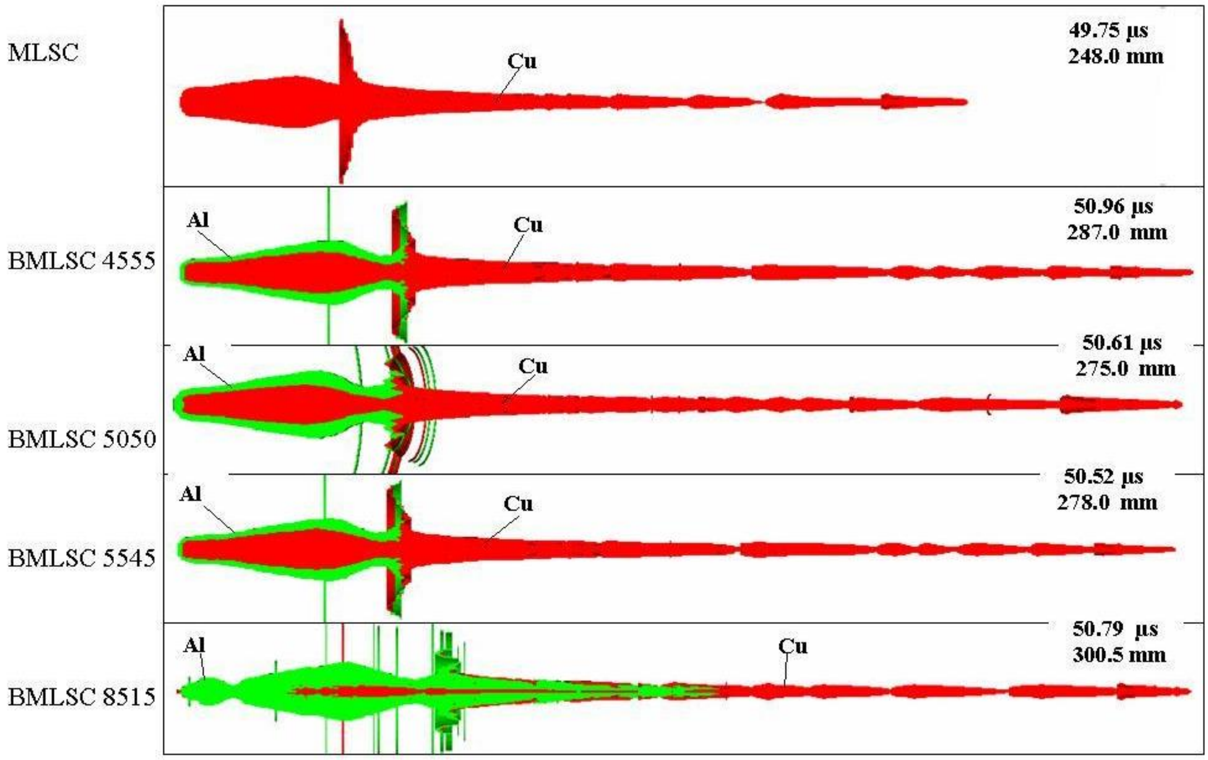

Fig. 7. Jet & collapse of liner in Monolithic & Bimetallic Lined shaped charge at 50 µs

Physical Measurement of Slug:

Mathematical deduction helped in ascertaining the column length for capture of most of the jet/slug particles and also confirms possibility of capturing the jet/slug particles in carefully designed system (Fig. 4). Soft recovery trial carried out for Bimetallic and monolithic shaped charge The slug MLSC recovered is shown in Fig.14 while that for Bimetallic has also been partially recovered shown in Fig.15 alongwith simulated data. During the experiment about 37 jet particles were recovered with total mass of 72.30g, which is about 77% of total liner mass.

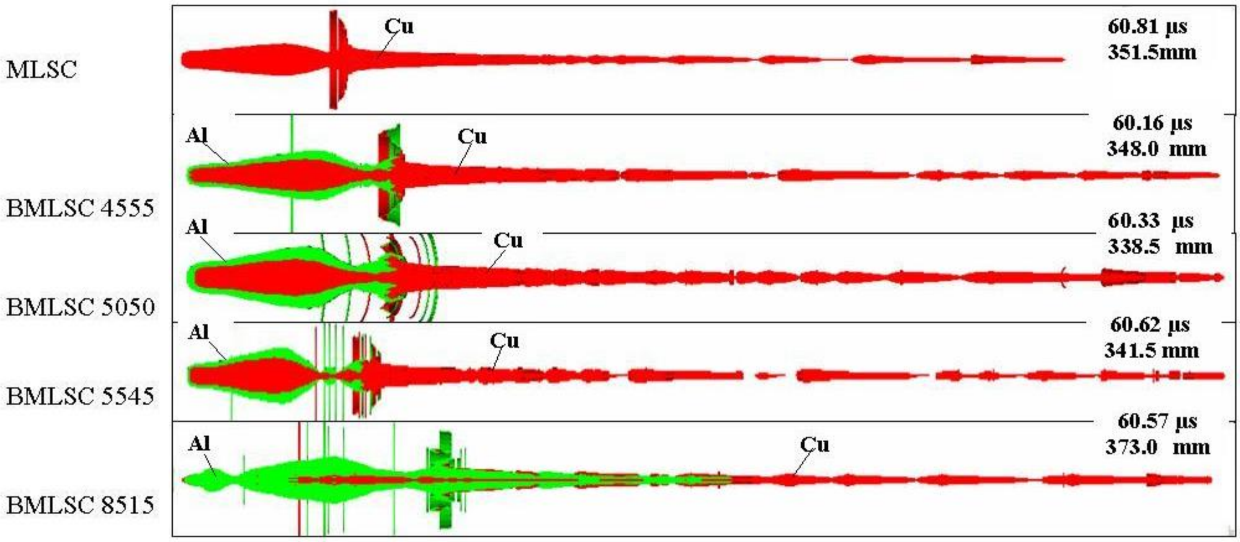

Fig. 8. Jet & collapse of liner in Monolithic & Bimetallic Lined shaped charge at 60 µs

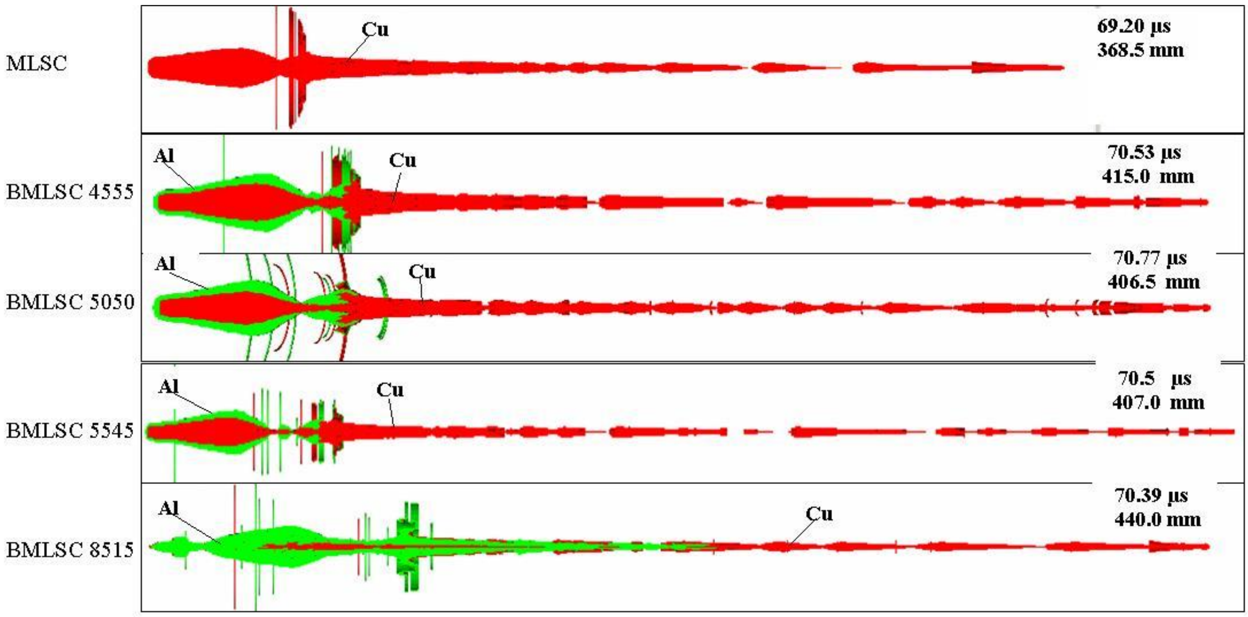

Fig. 9. Jet & collapse of liner in Monolithic & Bimetallic Lined shaped charge at 70 µs

Monolithic slug has mass is 79.16g against original liner mass of 134.50g and hence % mass of liner in slug is 58.85% while that in Jet is 41.15%. The cut section of the slug clearly shows the theory put forth in formation of jet/slug i.e., the rear liner encases the frontal liner in the slug. Further the slug recovered from bimetallic liner has mass 19.25g against total liner mass of 94.10g. Thus, the slug forms only 20.45% of total liner mass and it is seen that the aluminum has been evaporated and visible in thin layer with forming of Copper-Aluminum (duralumin) alloy.

Metallography:

(a) Slug from MLSC and BMLSC indicate the recrystallized grain structure, due to melting and realigning in the direction of flow of jet.
(b) Cut section of Slug from BMLSC do not show any trace of Al or alloy of Al-Cu formed inside the core, thus it can be said that the Al would have been vaporised from outer core of the slug

and visible evidence of Al-Cu alloy on the surface might be due to high temperature interaction of both the metals.

(c) In BMLSC slug the micro structure at tip, middle & base are same as finer grain than MLSC slug.
(d) Hardness: 48-65 BHN for MLSC & 54-58 BHN for BMLSC
(e) Outer micro structure of MLSC slug shows larger grain at tip & center while at base both inner & outer reveal almost similar coarser grains with variation

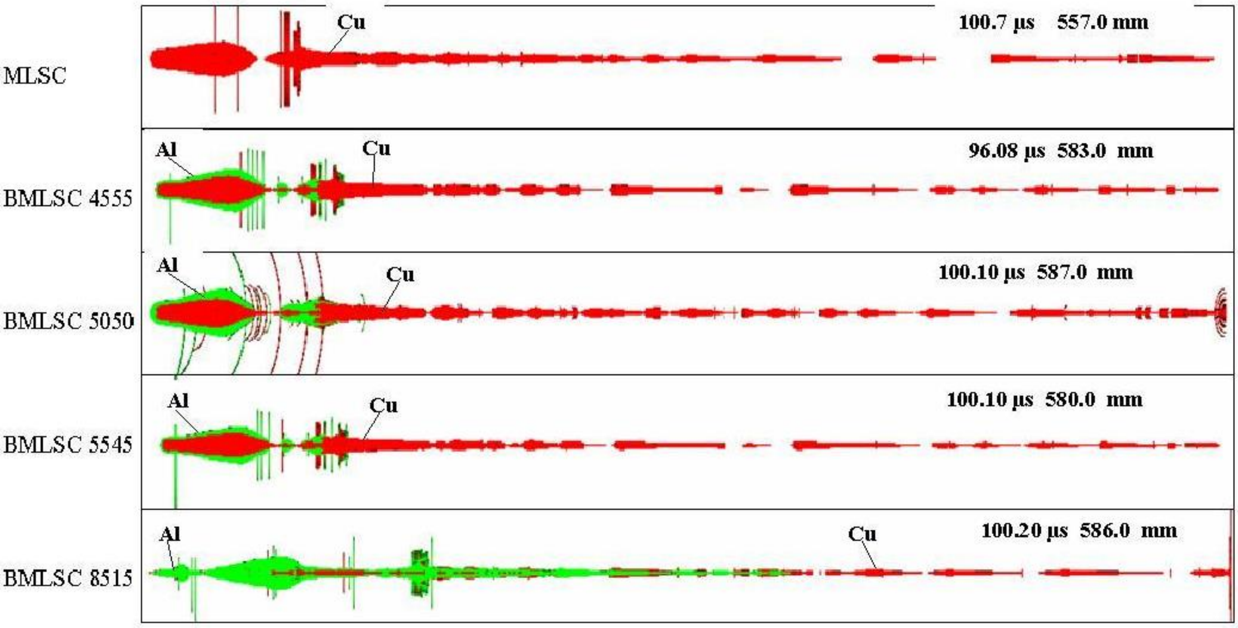

Fig.10 Jet & collapse of liner in Monolithic & Bimetallic Liner shaped charge at 100 µs

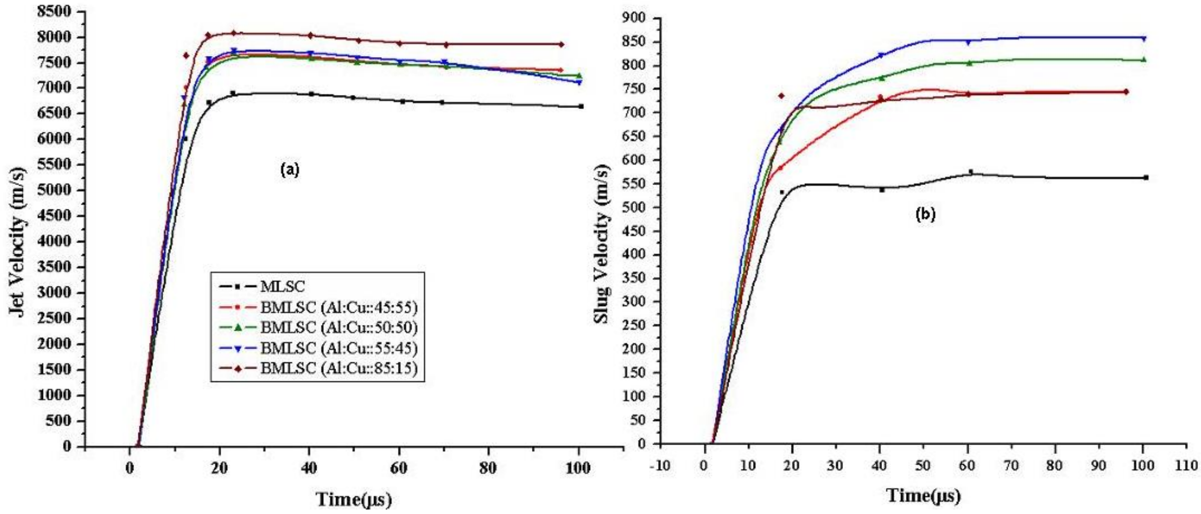

Fig. 11 Maximum (a) Jet Tip Velocity & (b) Slug Velocity – for various configurations

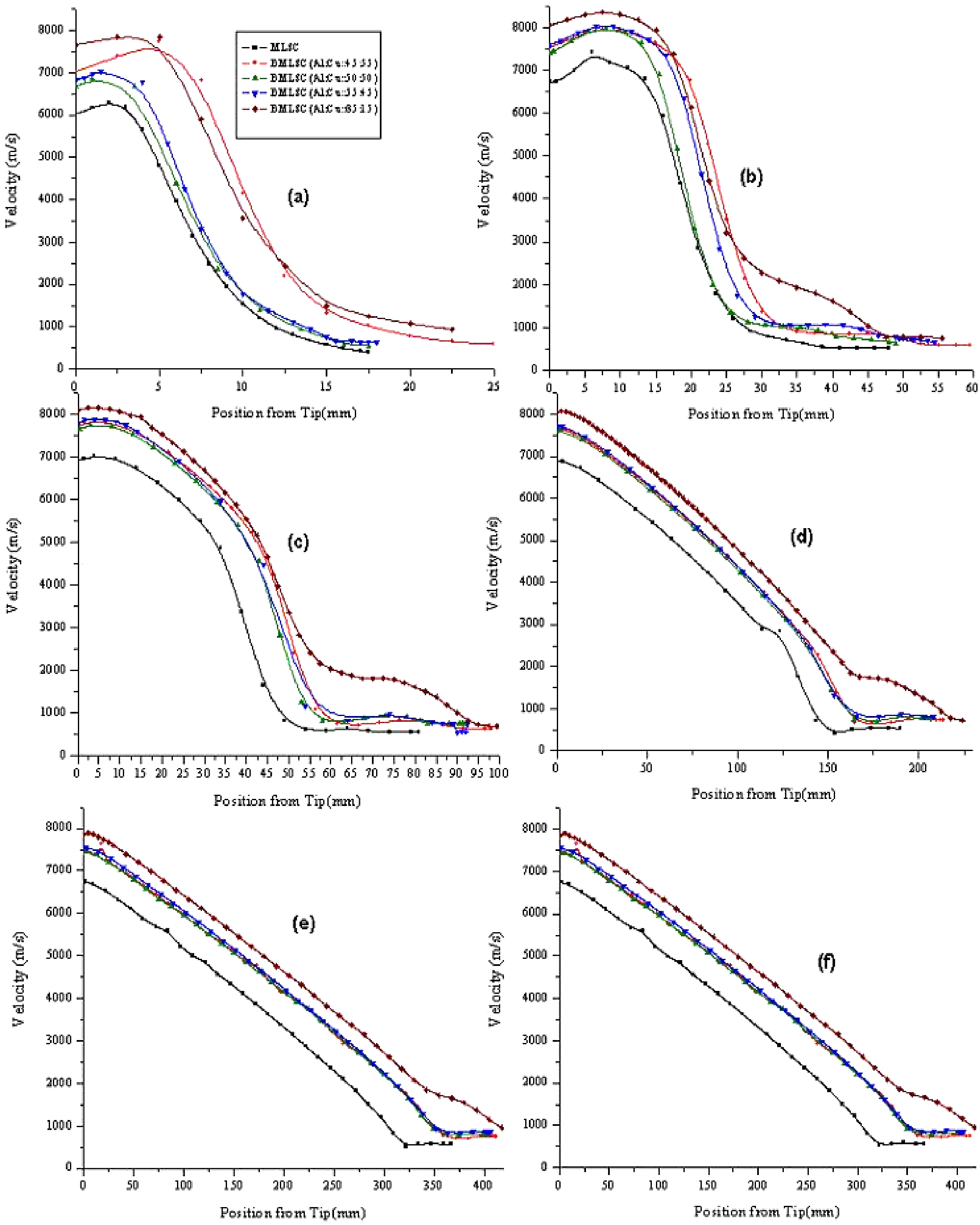

Fig.12 Velocity gradient of stretching jet for various configurations at (a)12µs, (b)17µs, (c)23µs, (d)40µs, (e) 60µs, (f) 70µs

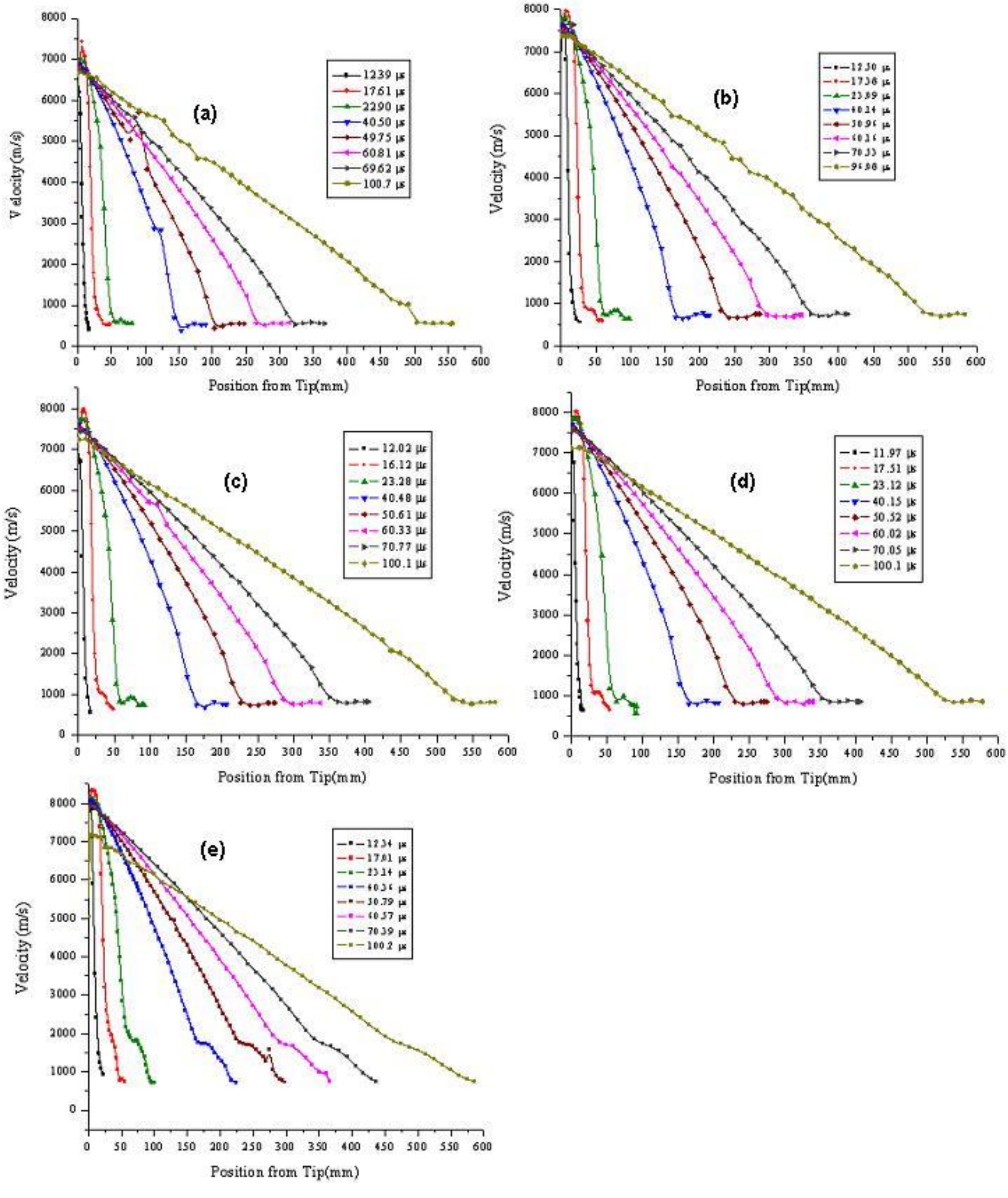

Fig.13 Velocity gradient of stretching jet at different times for (a)MLSC(Cu); (b)BMLSC(Al:Cu::45:55); (c) BMLSC(Al:Cu::50:50); (d) BMLSC(Al:Cu::55:45); (e) BMLSC(Al:Cu::85:15)

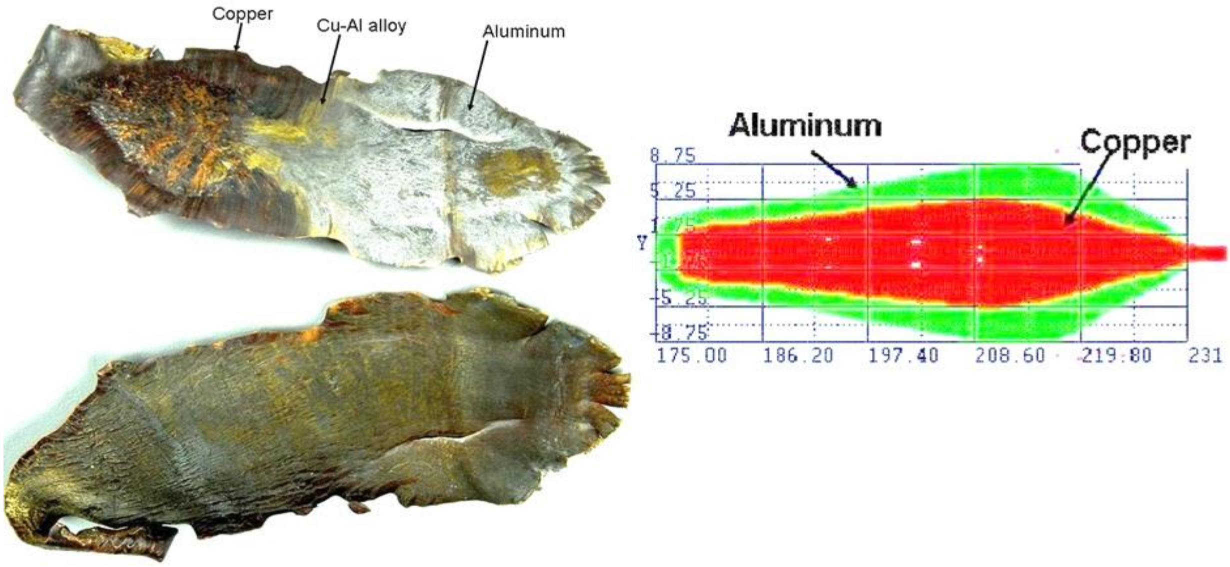

Fig.14. Slug from Bimetallic charge with comparison of that from simulation

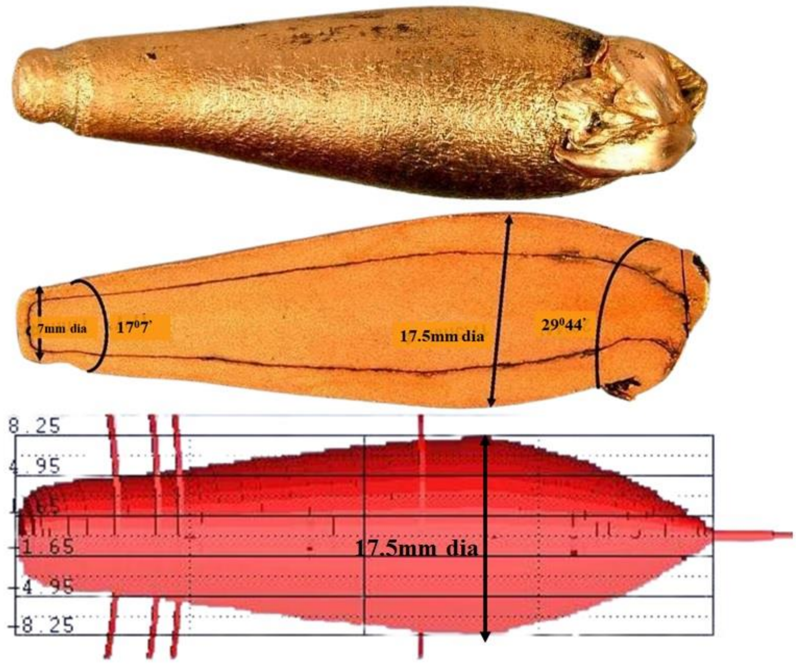

Fig.15. Slug from Monolithic charge with comparison of that from simulation

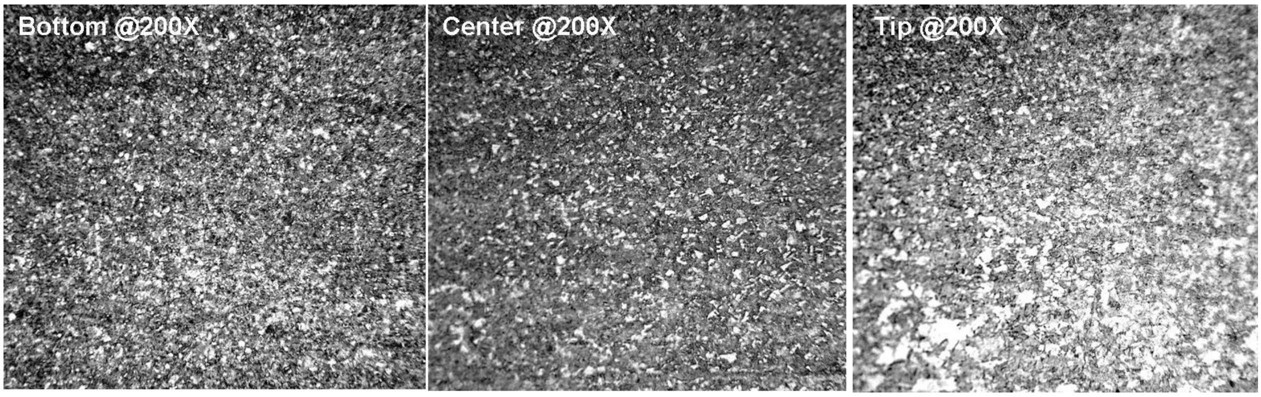

Fig. 16 Microstructure of recovered Slug from monolithic lined shaped charge

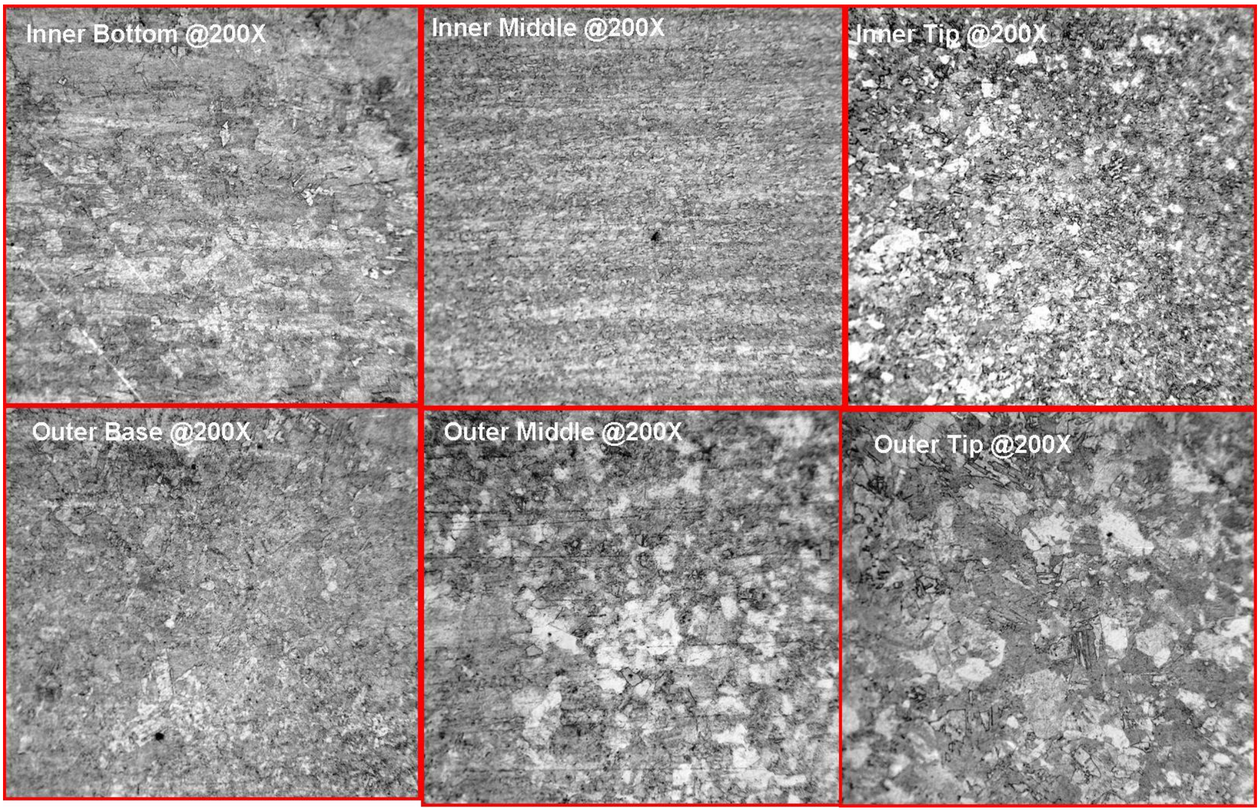

Fig. 17 Microstructure of recovered Slug from Bimetallic lined shaped charge

Conclusions.

From the Comprehensive study of Slug recovery in bimetallic lined shaped charges it is evident that the bimetallic lined shaped charge provides improved performance about 0.42 times higher than the monolithic. Slug mass considerably reduced to about 20% in practice compared to that about 60% in monolithic charges. Simulation study complements the practical study.

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