The Effect of Tungsten, Molybdenum and Tantalum on the Characteristics of Cu - Pb Shaped Charge Liners.

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ABSTRACT

The shaped charge liners have extensive applications in military and drilling industries. The effective parameters on the depth of penetration after the explosion are density, jet length and speed of sound in the liner material. The effect of tungsten, molybdenum and tantalum on depth of penetration was investigated both in isolation and in combination. Tungsten increased the material density, tantalum increased the jet length and molybdenum was found to promote the speed of sound in the liner material, resulting in coherency in jet tip. Tungsten, tantalum and molybdenum increased the depth of penetration about %50, %42 and %57 respectively. It was concluded that the composite powder containing 15Cu-20Pb-25W-20Ta-20Mo produced the maximum penetration depth (99mm) in steel samples after explosion tests.

KEYWORDS

Shaped charge liner; effects of alloying elements; depth of penetration.

1. INTRODUCTION

An explosive cylinder with a detonator on one side and a hollow metallic cone on the other is known as a shaped charge liner. The geometry of the liner is designed in such a way to produce a large jet which moves at a high speed to penetrate the target [1].

Explosive engineering has made extensive applications in oil industries. The drilling of an oil well is normally followed by a complementary operation to produce perforations in side rocks leading to an increased oil flow rate.

The shaped charge liners can be classified into two categories:

1- Deep penetration gun (DP), which is based on the existence of a long jet.

2- Big hole gun (BH), which is intended to produce holes of large diameter in drilling procedures [2].

Figure 1, illustrates the jet formation steps. After the explosion, jet forms at the tip and extends towards the bottom of the liner. Under normal conditions, the jet speed can reach to as high as 8 km/hour [3]. The remainder of the jet tip is known as "slug". At the time of explosion, the jet tip penetrates the target and slug follows the path. It is desired to have a slug as short as possible since there is the possibility that it might block the exit path of oil. Alloying elements are added to the liner to increase the penetration depth and also inhibit the elongation of slug [4].

Liners are produced by a variety of methods such as, machining, spinning and powder metallurgy. The latter method has proved to produce the shortest slug. Powder metallurgy process has the advantage that it can introduce both high and low melting point elements in the liner alloy. The low melting point element would have a destabilizing effect upon the slug, which eventually leads to its disintegration. This phenomenon is an important factor in shaped charge liners [5]. The aim of this project is to increase the depth of penetration (DOP) of shaped charge liners in target materials. It is believed that the addition of W, Ta and Mo would be beneficial in increasing the well efficiency.

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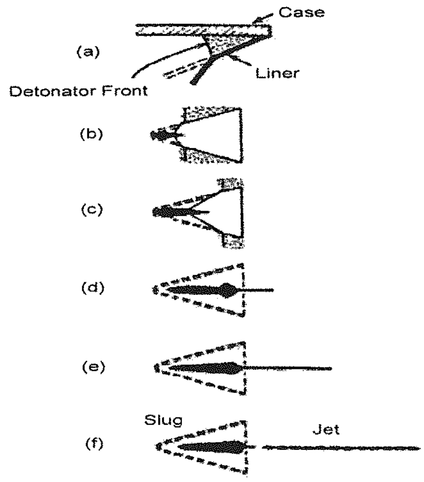

Figure 1: Jet formation steps of shaped charge liners.

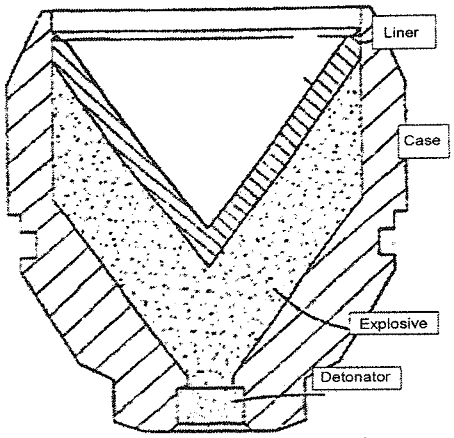

Figure 2: Shaped charge liner assembly.

2. EXPERIMENTAL PROCEDURE

Figure 2 illustrates the shape charge liner assembly. The main body and the lid are made of st37 steel. The explosive material was RDX (Hexogen). Suitable O'ring and packing were used as sealants. Moreover, insulating materials were used to prevent any undesirable interaction between the liner and the explosive making a capsule. Normally, a series of these capsules are assembled on a rack, which operate in turn. The characteristics of the shaped charge liners in this paper were obtained after tests on steel blocks of uniform hardness of 180 HV. A detonator connected to a 12 volt power supply was connected to RDX explosive. As a result, a hole is generated in the steel blocks. The composition, diameter and length of steel blocks were St37, 40mm and 150mm, respectively. The depth of penetrations was measured after the steel specimens were sectioned longitudinally. Firstly, the effect of alloying elements on depth of penetration was investigated individually. Secondary tests were carried out to assess the effect of alloying elements in combination. Table 1 depicts the powders used in this research. Copper and lead powders were made by atomization with rounded shape and fairly fine size (Figures 3 and 4). Tungsten powder which was produced by chemical reduction of oxide was almost rectangular in shape and particle size was in the range of 10 – 80 microns (Figure 5).

The particle size of molybdenum and tantalum powders were in the range of 10-50 microns and 10-40 microns, respectively.

The shock wave velocity in W, Ta and Mo are 4.0, 3.4 and 5.1 km/sec, respectively [6]. The effect of alloying elements was investigated both individually and in combination.

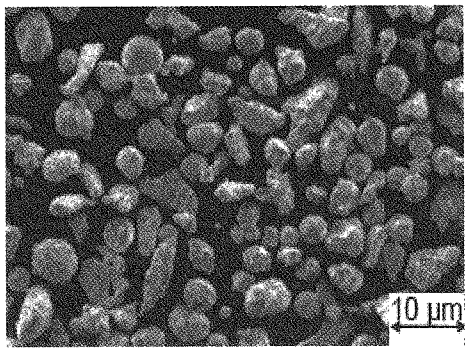

Figure 3: Photomicrograph of copper powders.

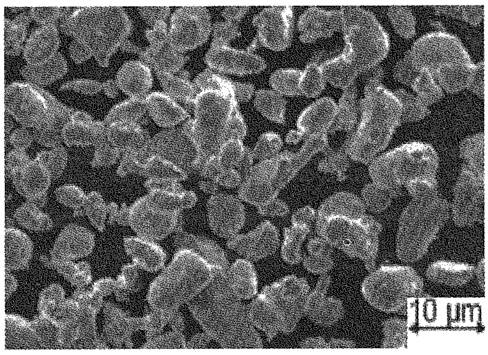

Figure 4: Photomicrograph of Lead powders.

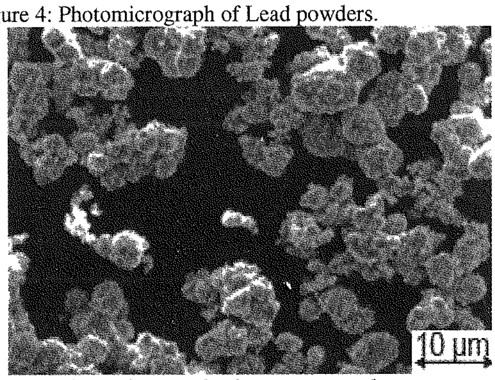

Figure 5: photomicrograph of tungsten powder.

TABLE 1:POWDER SIZE RANGE AND SIZE DISTRIBUTIONS.

Powder	Range(micron)	Sieve mesh size	%Weight
Copper	1-60	>270	6
		<270	21
		<325	73
Lead	10-40	<325	92
		>325	8
Tantalum	10-40	<325	90
		>325	10
Molybdenum	10-50	<325	54
		>325	46
Tungsten	10-80	>270	20
		<270	80

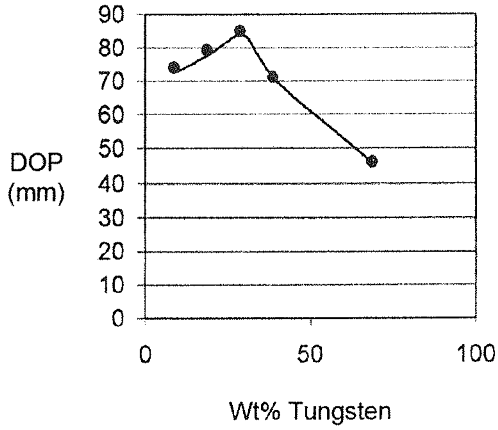

Figure 6: The effect of W on depth of penetration (DOP).

3. RESULTS AND DISCUSSION

Tungsten was one of alloying element used in this study. It has a density of 19.3 g/cc, thus tungsten elevates the jet density and also promotes the depth of penetration in shaped charge liners. Five combinations were investigated which were as follows:

30Pb-40Cu-30W,
30Pb-50Cu-20W,
30Pb-60Cu-10W,
30Pb-70W,
30Pb-30Cu-40W,

The density of the liners is shown in Table 2. In order to reduce errors in measurements, three samples were tested for each alloy. Figures 6, illustrates the effect of tungsten, upon depth of penetration. The alloy with a chemical composition of 30Pb 40Cu 30W showed the highest depth of penetration in steel samples.

TABLE 2:CHEMICAL COMPOSITION, DENSITY AND DEPTH OF PENETRATION (DOP) OF TUNGSTEN BEARING SHAPED CHARGE LINERS.

Composition	Density (g/cc)	Weight(g)	DOP (mm)
30Pb60Cu10W	9.08	19.47	75
30Pb50Cu20W	10.65	21.3	79
30Pb40Cu30W	11.5	23.2	84
30Pb30Cu40W	12.55	25.1	70
30Pb70W	15	15	45

Molybdenum was another alloying element used in this study. Its density is 10.2 g/cc which is much less than tungsten. The following chemical compositions were investigated for alloys containing molybdenum:

30Pb-40Cu-30Mo
30Pb-50Cu-20Mo
30Pb-60Cu-10Mo
30Pb-30Cu-40Mo
30Pb-70Mo

Table 3 shows the information regarding the alloying elements and Figure 7 shows that the highest depth of penetration relates to 30Pb 40Cu 30Mo composition.

TABLE 3:CHEMICAL COMPOSITION, DENSITY AND DEPTH OF PENETRATION (DOP), OF SHAPED CHARGE LINERS CONTAINING MOLYBDENUM.

Composition	Density (g/cc)	Weight (g)	DOP (mm)
30Pb10Mo60Cu	8.9	17.80	80
30Pb20Mo50Cu	9.06	18.08	85
30Pb30 Mo40Cu	9.15	18.31	88
30Pb40 Mo30Cu	9.3	18.66	75
30Pb70Mo	9.62	19.25	53

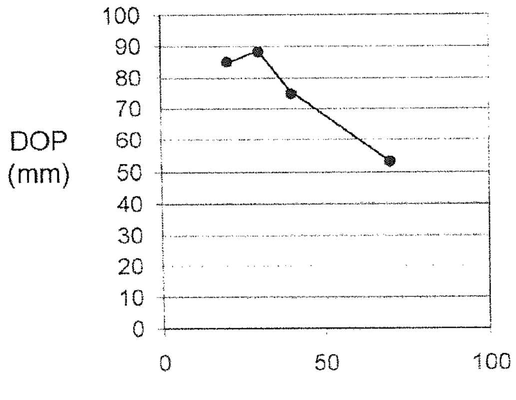

Figure 7: The effect of Mo on depth of penetration (DOP).

Tantalum was another alloying element used in this study. Its density is 16.6 g/cc. The following compositions were investigated:

30Pb-40Cu-30Ta,
30Pb-50Cu-20Ta,
30Pb-60Cu-10Ta,
30Pb-30Cu-40Ta,
30Pb-70Ta.

Data related to alloys containing tantalum are depicted in Table 4 and Figure 8. It appears that maximum depth of penetration is favorable to 30Pb 50Cu 20Ta composition.

Figures 6, 7 and 8, illustrate the ideal composition in order to achieve the maximum DOP in each material. Molybdenum had the greatest effect on the depth of penetration when used in isolation suggesting that speed of sound in the material plays an important role among other properties. Then tungsten showed a high DOP at 30 percent tungsten, which can be attributed to its high density of 19.3 g/cc.

A comparison of the alloying elements is shown in Figure 9. Various tests were then performed to investigate the effect of the alloying elements in combination on the DOP which resulted in optimum alloying group is shown in Table 5.

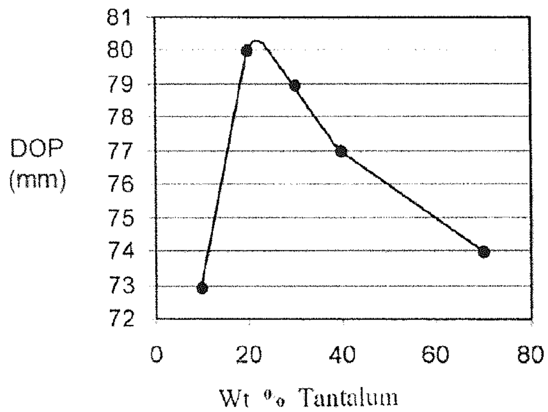

Figure 8: The effect of Ta on depth of penetration (DOP).

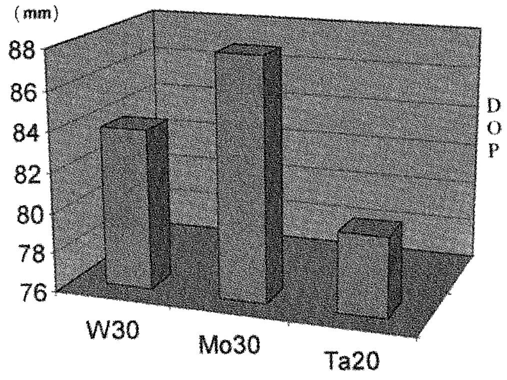

Figure 9: Comparison of DOP among W, Mo and Ta.

Microstructure and chemical analysis after explosion tests were examined using SEM (Table 6). The stress-strain curves under shock waves have been investigated by Cooper [6].

As the shock wave spreads in the material in fraction of a second it cannot change the chemical composition but it can modify the normal stress–strain curve of the material. In the elastic region, the shock wave velocity is constant. This velocity is proportional to the density of the material.

Table 4: Chemical composition, density and depth of penetration of shaped charge liners containing tantalum.

Chemical composition	Density (g/cc)	Weight	DOP (mm)
30Pb60Cu10Ta	9.19	9.2	73
30Pb50Cu20Ta	10.58	10.15	80
30Pb40Cu30Ta	11.18	10.45	79
30Pb30Cu40Ta	11.89	11.45	77
30Pb70Ta	14.62	27.3	74

Table 5 : Properties of the ideal shaped charge liner.

Composition	Density (g/cc)	Weight (g)	DOP (mm)
20Pb15Cu20Ta25W20Mo	9.19	23.8	99

Table 6: Chemical analysis of the liner test pieces before and after explosion tests.

Chemical analysis before explosion			Chemical analysis after explosion		
W	Cu	Pb	W	Cu	Pb
10	60	30	13	65	22
20	50	30	21	68	11
30	40	30	39	36	25
40	30	30	43	44	13
70	-	30	88	-	11
Mo	Cu	Pb	Mo	Cu	Pb
10	60	30	11	67	22
20	50	30	24	56	20
30	40	30	34	43	23
30	40	30	44	35	21
70	-	30	83	-	17
Ta	Cu	Pb	Ta	Cu	Pb
10	60	30	12	64	24
20	50	30	23	56	21
30	40	30	36	49	15
40	30	30	47	36	16
70	-	30	79	-	21
25W15Cu20Ta25Mo15Pb			28W17Cu21Ta29Mo5Pb		

This means that in the elastic region, pressure and density are linearly related. Beyond the elastic region, the wave velocity increases with pressure or density. Wave velocity continues to increase with stress throughout the region of interest. Thus, up to the elastic limit, the velocity increases with increase in pressure. Microstructure of selective liner materials after explosion tests is shown in figure 10. It is apparent that although there has been a spontaneous rise in the temperature, it was enough to sinter the powders together. Microstructure shows white (tungsten) and dark (Pb and Cu) phases.

Figure 11 illustrates the microstructure of 20Pb15Cu20Ta25W20Mo alloy. This composition showed the highest depth of penetration (99mm) compared to other alloys, although the density was not so high. Microstructure shows bonding has taken place between tungsten, molybdenum and tantalum embedded in Pb-Cu matrix. This indicates that a diffusion path has been made at the moment of explosion.

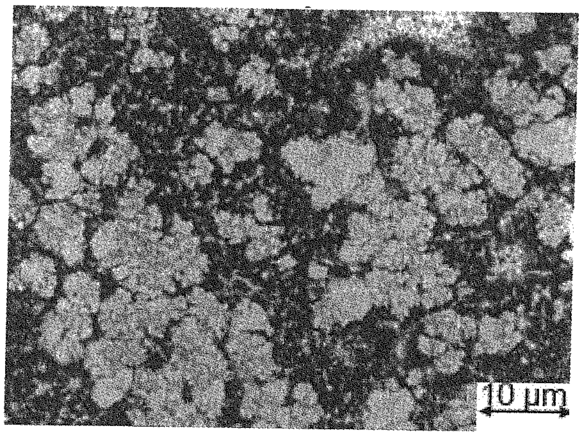

Figure 10: Microstructure of 30Pb30W40Cu after explosion, showing dark (Pb and Cu) and white (W) phases.

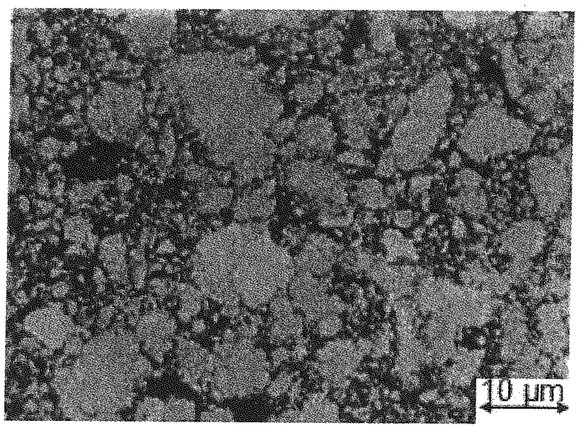

Figure 11: Microstructure of 20Pb15Cu20Ta25W20Mo, showing dark (Pb, Cu, Ta and Mo) and white (W) phases.

4. Conclusion

1- In copper-lead based shaped charge liners containing tungsten, the composition 30Pb40Cu30W showed highest depth of penetration in steel targets.

2- In Cu-Pb shaped charge liners containing tantalum, the composition 30Pb50Cu20Ta presented the highest depth of penetration.

3- In Cu-Pb based shape charge liners containing molybdenum, the composition 30Pb40Cu30Mo produced the highest depth of penetration.

4- In shaped charge liners with tungsten, molybdenum and tantalum additions, the composition 20Pb15Cu20Ta25W20Mo showed the highest depth of penetration. Properties such as shock wave velocity, density and ductility exhibited pronounced effects.

5. References

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