COMPARISON OF PIEZO AND BALL COPPER PRESSURE MEASUREMENTS IN CLOSED VESSEL SYSTEM

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A series of Closed Vessel firings are carried out at different pressure levels in the range of 0 to 1800 kg/cm² covering the complete pressure range of ball copper and Mark 8 crusher gauge combination. The pressures are simultaneously measured by a piezo (tourmaline) gauge and the ball copper pressures are evaluated from the Tarage table for existing standard ball coppers as required by U.K. ordnance, using suitable temperature corrections. The results indicated that the agreement between the piezo and ball copper pressures is generally very good. At the pressure levels of 600,1200 and 1800 kg/cm², the magnitudes of percentage deviation of ball copper pressures from piezo pressures are from 0·2 to 3·4, 2·6 to 4·2 and 2·0 to 4·6 respectively. The pressures recorded by ball coppers are found to be slightly on higher side compared to piezo pressures in nearly all the measurements.

The ball copper with Mark 8 crusher gauge combination[1] is a simple, cheap and fairly accurate device for the measurement of peak pressures developed in ordnance stores. The ball coppers are calibrated for pressures which are actually realised in ordnance like guns and mortars against the pressures recorded simultaneously by piezo and strain gauge transducers. The calibration data is represented in the form of a table known as Tarage table which gives the values of pressures recorded by ball copper—Mark 8 crusher gauge combination at certain specified temperature in relation to the diameters of the compressed copper balls. The diameter of the uncompressed ball copper is 0·4763± 0·0008 cm and these are made of oxygen free high conductivity copper material and are manufactured under very careful and controlled conditions.

The Closed Vessel (CV) system is a very well established technique for the testing of gun propellants and it is described in details elsewhere[2]. It is a convenient and economical laboratory method for generating transient pressures. In the Closed Vessel the transient pressures upto 20 T.S.I. (3100 kg/cm²) are generated by burning propellants. The time required to reach the maximum pressure is roughly 10 to 30 milliseconds depending upon the loading density and the type of propellant. It is more compared to the time required for reaching the maximum pressure in guns which is roughly in the range of 2 to 15 millisecs. The performance of ball coppers under transient stresses is independent of the duration of pressure pulses.

The comparison of the pressures recorded by ball coppers in conjunction with Mark 8 crusher gauge and piezo transducer in CV system has not been reported in the literature and hence, it is thought fit to present this experimental data which will be useful to scientific workers who are engaged in the field of design, development and performance evaluation of different types of crusher gauges and copper crushers.

EXPERIMENTAL METHOD

The Closed Vessel (vol. 700 cc) and its associated electronic recording system which are used in this laboratory for testing ballistic characteristics of gun propellants, are employed for these measurements. In each Closed Vessel firing, five Mark 8 crusher gauges assembled with ball coppers are used. These gauges are placed inside the chamber of the Closed Vessel alongwith propellant charge. Adequate care regarding the correct assembly of the Mark 8 crusher gauges is taken during these experiments. A large number of firings are carried out in the Closed Vessel at various pressure levels namely 300, 600, 900, 1200, 1500 and 1800 kg/cm² which extensively cover the pressure range of 250 kg/cm² to 1900 kg/cm² of ball copper Mark 8 crusher gauge combination. Of these, the three representative and equi-spaced pressure levels which are selected for analysis and discussions are 600, 1200 & 1800 kg/cm². The propellant used is *NQ*/*M*036 which is found to give consistent and repeatable results. The quantity of propellant required for generating these pressure levels is found by experimentation to be 39, 71 & 98 grammes respectively. The time required for reaching these pressure levels is 23·1, 13·3 & 9·4 milliseconds respectively. The pressure sensor used in these measurements is the Gem type Tourmaline crystal of 1·27 cm diameter and 0·635 cm (Nominal) thickness and the pressures are recorded by using oscillographic technique on a photographic paper. The dimensions of ball coppers before and after firings are measured by a 'Mercer Dial Gauge' which can read upto 4th place of decimal of an inch. The copper pressures at the temperature of firing are evaluated from the Tarage table and temperature correction chart as required by U.K. ordnance. The piezo pressures are measured accurately by using a microscope. The results are given in Table 1. The same experiments are also carried out

TABLE 1

PRESSURE MEASUREMENTS BY PIEZO GAUGES AND MARK 8 BALL COPPER CRUSHER GAUGES, IN CLOSED VESSEL SYSTEM

Pressure level	Round No.	Average R.L. × 10^4 (cm)	Corrected copper pressure (kg/cm^2.)	Piezo pressure (kg/cm^2)	Percentage deviation from Piezo pressure (%)
600 kg/cm^2	1	3810	613	612	—0·2
	2	3815	613	616	+0·5
	3	3818	608	610	+0·3
	4	3807	613	611	—0·3
	5	3871	569	560	—1·6
	6	3818	603	596	—1·2
	7	3843	584	579	—0·9
	8	3846	584	572	—2·1
	9	3815	613	605	—1·3
	10	3818	603	583	—3·4
1200 kg/cm^2	1	3066	1247	1210	—3·0
	2	3063	1247	1202	—3.7
	3	3066	1247	1208	—3·2
	4	3071	1240	1209	—2·6
	5	3073	1240	1190	—4·2
	6	3076	1240	1194	—3·9
	7	3063	1247	1209	—3·1
	8	3071	1240	1202	—3·2
	9	3076	1240	1192	—4·0
	10	3071	1240	1200	—3·3
1800 kg/cm^2	1	2560	1827	1782	—2·5
	2	2581	1811	1768	—2·4
	3	2560	1827	1791	—2·0
	4	2563	1827	1766	—3·5
	5	2570	1835	1763	—4·0
		2553	1850	17[illegible]9	—4·6
	7	2578	1819	1740	—4·5
	8	2565	1835	1765	—4·0
	9	2576	1811	1753	—3·3
	10	2558	1843	1775	—3·8

in onjunction with Mark 9 (BAF) gauges. But due to limitations of Closed Vessel bomb which cannot be used beyond 20 Tons per square inch (3100 kg/cm^2 approx.), extensive firings as in case of Mark 8 could not be carried out for Mark 9 gauges. A series of five firings are carried out to generate 20 T.S.I. (3100 Kg./cm^2 approx.) pressure using these gauges. The results are given in Table 2.

TABLE 2

PRESSURE MEASUREMENTS BY PIEZO GAUGES AND MARK 9 BALL COPPER CRUSHER GAUGES, IN CLOSED VESSEL SYSTEM

Pressure Level	Round No.	Average R.L. $\times 10^4$ (cm)	Corrected copper pressure (kg/cm²)	Piezo pressure (kg/cm²)	Percentage deviation from Piezo pressure
3100 kg/cm²	1	3510	3165	3087	—2 5
	2	3536	3087	3039	—1·6
	3	3526	3118	3071	—1·5
	4	3531	3102	3055	—1·5
	5	3520	3134	3071	—2·1

Some firings are also carried out to make a comparative evaluation of gun and closed vessel firings incorporating Mark 8 gauges. These experiments entail generation of same pressure levels in Closed Vessel as obtained in two ordnances of different types and study of deformation behaviour thereof. The results are given in Table 3. However, a large number of firings at various pressure levels are essential to establish a correlationship between Closed vessel and gun firing data. This work will be taken up separately at a later date.

TABLE 3

STUDY OF BALL COPPERS IN GUN AND CLOSED VESSEL FIRINGS

Gun Firings			Closed Vessel Firings		
No. of Firings		Average R.L. $\times 10^4$ (cm)	No. of Firings	Average Pressure (kg/cm²)	Average R.L. $\times 10^4$ (cm)
13	803	3571	10	803	3564
7	1575	2784	10	1543	2786

RESULTS AND DISCUSSIONS

The tabulated results of the Closed Vessel firings given in Tables 1 & 2 show close agreement between the piezo and ball copper pressure measurements. From Table 1, it is seen that agreement between ball copper pressures and piezo pressures is better at lower pressures. This is stipulated in the expected behaviour of ball copper and Mark 8 crusher gauge combination in ordnances. These tables further reveal that the pressures recorded by piezo transducers are slightly less compared to ball copper pressures. The percentage deviation of pressure was calculated as follows :

$$\% \text{ deviation} = \frac{\text{Piezo Pressure} - \text{Copper Pressure}}{\text{Piezo Pressure}} \times 100$$

It is found to vary from +0·5 to —3·4 at the pressure level of 600 kg/cm². At the pressure level of 1200 kg/cm² the percentage deviation is varying from —2·6 to —4·2 and at the pressure level of 1800 kg/cm² it is from —2·0 to —4·6. And in case of ball copper —Mark 9 combination the percentage deviation varies from —1·5 to —2·6. This clearly brings out the fact that the agreement between the piezo pressures and ball copper pressures is close. The perusal of Table 3, indicates good agreement in deformation behaviour of coppers in Gun and Closed Vessel firings where the duration of pressure pulses differ considerably. This substantiates that the behaviour of ball coppers is independent of duration of pressure pulses.

It is concluded from above discussions that the Closed Vessel can be considered as a performance evaluation tool for the design, development and out-turn proof of crusher gauges and copper crushers. These studies have further opened up the possibility of calibrating ball copper—Mark 8 combination in Closed Vessel replacing Gun firings, where cost is prohibitive. But this would obviously require extensive firing trials in Gun and Closed Vessel using ball copper—Mark 8 crusher gauge-combination, to establish a correlationship between the two systems. These conclusions are valid upto 1800 kg/cm^2 only.

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