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FRAGMENTATION OF RING TYPE CYLINDRICAL SHELL MADE OF VARIOUS METALS

Michael Famiglietti

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(6) FRAGMENTATION OF RING TYPE CYLINDRICAL SHELL MADE OF VARIOUS METALS.

(10) Michael Famiglietti.

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BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 597

MFamiglietti/bts
Aberdeen Proving Ground, Md.
March 1952

FRAGMENTATION OF RING TYPE CYLINDRICAL SHELL MADE OF VARIOUS METALS

ABSTRACT

To study the fragmentation characteristics of shell made of various metals, a series of ring-type cylindrical shell, made of various metals, having widely different densities and physical properties, were statically fragmented. The resulting data were analyzed in conjunction with a theory governing the sizes of fragments.

The following conclusions were reached:

1. A direct variation appears to exist between the mean fragment mass and the maximum fragment mass when different materials are compared.

2. The mean fragment mass is partially dependent upon the following metallurgical properties of the shell:

   a. The density of the metal.

   b. The tensile strength of the metal.

   c. The static reduction of area of the metal.

Further, semi-empirical relations were obtained by which mean fragment mass could be predicted with some statistical accuracy from the preceding quantities, the geometry, and from the initial fragment velocity, *V_o. Although the experiments all involved explosive RDX composition C3, there are theoretical reasons for expecting the same relations to hold for other explosives, whose identity may influence the mean fragment mass only through V_o.

* V sub zero

[redacted]

INTRODUCTION

To study the basic fragmentation characteristics of shell made of various metals, having widely different densities and physical properties, and to determine whether shell made of metals other than steel or steel alloys can be used advantageously in special fragmentation problems, a number of series of shell have been statically fragmented.

In this report, the fragmentation data on ring-type cylindrical shell were analyzed in conjunction with a theory governing the sizes of fragments.

SHELL ASSEMBLY AND TESTING FACILITIES

The ring-type cylindrical shell were assembled from coaxial rings, stacked end to end, each ring having an inner diameter of 2.2 inches, an outer diameter of 3.0 inches and an axial dimension of 0.4 inches. The shell were loaded with Composition C-3 and end initiated by an engineer's special number 8 blasting cap through a tetryl booster (Fig. 1).

The shell were detonated with the shell axis vertical in two types of fragmentation facilities. Facility Type 1 (Fig. 2) consisted of 6 cane fiber board filled fragment recovery boxes, each 4' x 8' x 3' thick, placed on the circumference of a circle having a 10 foot radius and a photo-velocity recovery box, faced with either 0.022 inches dural sheet or copper screen. Dural sheet was used to face the photo-velocity recovery box except when the impinging fragments created a flash of light that made the individual fragments indiscernible.

Test Facility Type II consisted of 12 fragment and 2 photo-velocity recovery boxes placed on the circumference of a circle of 20 foot radius.

The filler of the recovery boxes was searched for fragments and the recovered fragments were weighed to the nearest grain. The weight distribution of the recovered fragments was tabulated and a mean fragment weight, weighted by weight, was determined excluding fragments less than one grain, (Table II).

Photographic velocities were obtained by a high speed motion picture Fastax camera and the form developed in the appendix of BRL Report No. 774[1], was used to compute initial velocities. The average fragment area in square inches projected on a plane normal to the trajectory was taken to be $m^{2/3}/83.3$, where m is the mass of the fragment in grains, and the value used for the drag coefficient was 0.58.

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[1] BRL Report No. 774, "A Measurement of the Drag Coefficient of High Velocity Fragments", J. E. Shaw.

GENERAL THEORY

A theory, informally proposed by Dr. T. E. Sterne, which permits the determination of a semi-empirical measure of the limiting amount of internal kinetic energy, per unit mass, that a material can convert into plastic and elastic strain energy without rupture, for spherical and cylindrical shell, is based upon the following hypotheses:

H-1 - The size of a fragment is determined by the limiting amount of internal kinetic energy, per unit mass, that the material can convert into plastic and elastic strain energy without rupture.

H-2 - The mean fragment mass varies as the maximum fragment mass when different materials are compared.

CYLINDRICAL FRAGMENTATION THEORY

For cylindrical shell assembled from coaxial rings let

b = the axial dimension of a ring.
t = the thickness of a ring.
ℓ = the length of a mean circumferential portion of a ring.
r = the initial mean radius of a ring.
ρ = the density of the metal.
V_o = the initial fragment velocity assumed to be imparted instantaneously, everywhere at once and radially.

Consider a portion of a ring of circumferential length ℓ. Then the velocity, relative to the center of mass of the portion, of material at a circumferential distance x from the center of mass (Fig. 3) is

$$V_x = x\frac{V_o}{r},$$

the internal kinetic energy of the portion is

$$\frac{bt\rho V_o^2\ell^3}{24r^2},$$

and the internal kinetic energy per unit mass is

$$\frac{V_o^2\,\ell^2}{24r^2}.$$

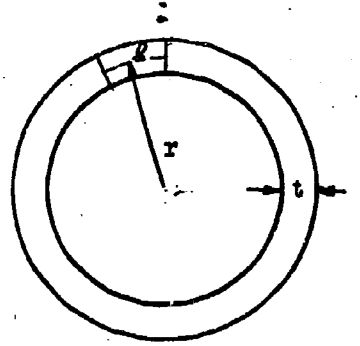


Fig. 3

Let α = the limiting amount of internal kinetic energy, per unit mass, that the material can convert into plastic and elastic strain energy without rupture.

Then using H-1 the largest fragment mass is

$$M_{max} = \frac{\sqrt{24}\ \alpha^{1/2} b\rho tr}{V_o} . \qquad \ldots (1)$$

Using H-2 the mean fragment mass is

$$\bar{M}^w = \frac{K\sqrt{24}\ \alpha^{1/2} b\rho tr}{V_o} , \qquad \ldots (2)$$

where

$\bar{M}^w$ = the mean fragment weight, weighted by weight.
K = a constant independent of materials, explosives, and geometric proportions.

If b, t, and r are expressed in inches, ρ in grams per cu. cm., $\bar{M}^w$ in grains, V_o in ft/sec and if c is a constant equal to $K^2 \times 10^{-6}$, after a slight rearrangement equation (2) becomes

$$c\alpha = \left[\frac{\bar{M}^w V_o}{4.615\ b\rho tr}\right]^2 \times 10^{-6} . \qquad \ldots (2A)$$

ANALYSIS

To test the validity of H-2 the mean fragment masses were plotted against the maximum fragment masses. An examination of the resulting plot (Plot 2) indicated that the data supports H-2 and that the variation is apparently direct.

The mean fragment mass, initial velocity, and physical properties of each shell were systematically substituted in equation (2A) to obtain experimental values of $c\alpha$ (Table III).

Various attempts were than made to establish a functional relationship between α and the known metallurgical properties of the shell so that predictions of mean fragment weight could be made. The relationship that yielded the best result was obtained by considering

$$\alpha \propto \frac{s}{\rho}\ \epsilon_D \qquad \ldots (3)$$

where

s = the static tensile strength of the casing.
ρ = the density of the metal.

ϵ_D = the percent of dynamic strain at rupture.

= the amount of permanent extension experienced by the metal during rapid stressing expressed as a percentage of the original gage length.

To determine the dynamic strain of a particular casing material at rupture in the absence of a stress strain relationship, the following assumptions were made:

H-3 - The density and the volume of the casing remain unchanged.

H-4 - The axial dimension of a ring remains constant.

Let

t = the initial thickness of a ring.
T = the thickness of a ring at rupture.
r_1 = the initial inner radius of a ring.
R_1 = the inner radius of a ring at rupture.
r_2 = the initial outer radius of a ring.
R_2 = the outer radius of a ring at rupture.
$\bar{r}$ = the initial mean radius of a ring.
$\bar{R}$ = the mean radius of a ring at rupture.
$\bar{c}$ = the initial mean circumference of a ring.
$\bar{C}$ = the mean circumference of a ring at rupture.
A_D = the percent dynamic reduction in cross sectional area of the fragments.
ϵ_D = dynamic strain at rupture.

Then using H-3

$$R_2 + R_1 = \frac{r_2^2 - r_1^2}{R_2 - R_1},$$

and H-4 yields

$$T = t\left(1 - \frac{A_D}{100}\right).$$

Thus

$$\bar{R} = \frac{r_2^2 - r_1^2}{2t\left(1 - \frac{A_D}{100}\right)}.$$

By definition

$$\epsilon_D = \frac{\bar{C} - \bar{c}}{\bar{c}} \times 100 .$$

Upon substitution and simplification

$$\epsilon_D = \frac{A_D}{1 - \frac{A_D}{100}} .$$

Hence (3) becomes

$$\alpha \propto \frac{s}{\rho} \frac{A_D}{1 - \frac{A_D}{100}} . \qquad \ldots (3A)$$

To enable a determination of α from static data, the experimental values of A_D, which were obtained by measuring the reduction of area of approximately 50 percent of the recovered fragments, were plotted against A_s (Plot 2) where

$A_s \cong$ static reduction of area.
$\cong$ the percent reduction of area extracted from a handbook or obtained from a conventional tensile test.

The resulting scatter diagram indicated a linear trend which was assumed. The line

$$A_D = 1.05\ A_s - 1.08$$

was obtained by least squares where both variables were considered to be in error.

Thus (3A) becomes

$$c'\alpha = \frac{s}{\rho} \left[\frac{100\ (1.05\ A_s - 1.08)}{100 - (1.05\ A_s - 1.08)} \right] \times 10^{-5} \qquad \ldots (3B)$$

The semi-empirical values of $c\alpha$ obtained from equation (2A) were plotted versus the $c'\alpha$ values obtained from (3B), (Plot 3). The equation of the regression line of $c\alpha$ on $c'\alpha$ was determined and the correlation coefficient was computed to be 0.68. The probability that such a correlation should arise, by random sampling, from an uncorrelated population was computed, by Students t test of significance, to be less than 0.01. Thus, it appears that the limiting amount of internal kinetic energy, per unit mass, that the material can convert into plastic and elastic strain energy without rupture, and therefore the mean fragment mass, is partially dependent upon the density, the tensile strength, and the static reduction of area of the metal.

ACKNOWLEDGMENTS

Dr. T. E. Sterne suggested that the fragmentation of metals of widely different physical properties should be investigated and made helpful suggestions for the treatment of the data. Mr. N. A. Tolch and Mr. Norman Brown planned the broad program and designed the shell casings. Mr. F. A. Weymouth directed the accomplishment of the experiments.

SUMMARY

When the fragmentation data on ring-type cylindrical shell, made of various metals, were used in conjunction with a theory governing the sizes of fragments, the following conclusions were noted:

1. A direct variation appears to exist between the mean fragment mass and the maximum fragment mass when different materials are compared.

2. The mean fragment mass is partially dependent upon the following metallurgical properties of the shell:

    a. The density of the metal.

    b. The tensile strength of the metal.

    c. The static reduction of area of the metal.

3. If hypotheses H-1 and H-2 were correct, the equation

$$\left[\frac{\bar{M}^{W} V_{o}}{4.615\ b\rho tr}\right]^{2} \times 10^{-6} = 62.4\,\frac{s}{\rho}\left[\frac{100\,(1.05\,A_{s} - 1.08)}{100 - (1.05\,A_{s} - 1.08)}\right] \times 10^{-5} + 224$$

should enable predictions of mean fragment mass to be made for other metals provided correct values of V_o were employed.

Although the experiments all involved explosive RDX Composition C3, there are theoretical reasons for expecting the same relations to hold for other explosives, whose identity may influence the mean fragment mass only through V_o.

Michael Famiglietti
Michael Famiglietti

TABLE I[1]
METALLURGICAL PROPERTIES OF RING TYPE SHELL MADE OF VARIOUS METALS

MATERIAL	ABR.	COMPOSITION	DENSITY* GMS/CU.CM. ρ	TENSILE STRENGTH PSI s	YIELD STRENGTH PSI	STATIC ELONGATION % s	STATIC REDUCTION OF AREA % A_s	HARDNESS
Magnesium (Commercially Pure)	Mg.	Mg. 99.5%	1.74	20,000	---	9	9	BHN 40 (500 KG Load 10mm Ball)
Magnesium Alloy (Dowmetal R)	Mg.A.	Al. 7.7% Zn. 0.3% Mn. 0.2% Remainder Mg.	1.81	42,000	30,000	14	22	BHN 60 (500 KG Load 10mm Ball)
Aluminum (Type 2 SO)	Al.	Al. 99.5%	2.71	14,200	5,000	42	72	BHN 21.5 (500 KG Load 10mm Ball)
Aluminum Alloy (Type 24 ST)	Al.A.	Cu. 4.5% Mn. 0.6% Mg. 1.6% Remainder Al.	2.77	68,000	40,000	18	22	BHN 120 (500 KG Load 10mm Ball)
Titanium (Commercially Pure)	Ti.	98.77% Ti. .12 Fe. .74 C*	4.54	95,113*		21*	37	RB 89
Zinc (Commercially Pure)	Zn.	Pb. 0.08% Remainder Zn.*	7.13	19,500*		65*		BHN 38* (500 KG Load 10mm Ball)
Grey Cast Iron	G.C.S.	C. 3.23%	7.15	25,000	None	None	None	RB 144
Cast Steel	C.S.	C. 0.35% Mn. 0.85%	7.85	70,000	37,200	10	16	RB 90
Hadfield Manganese Steel	H.Mn.S.	C. 1.2%* Mn. 13.0%*	7.90	140,000*	52,000*	40*	35*	BHN 200 Standard
Stainless Steel	S.S.	Cr. 18.0%* Ni. 8.0%	7.93	85,000	40,000	60	60	BHN 150* Standard
Beryllium Copper	Be.Cu.	Cu. 97.65% Be. 2.0% C. 0.35%	8.26	70,000*	73,800	40*	57	RB 70
Yellow Brass	Y.B.	Cu. 61.8% Zn. 23.1% Pb. 3.15% Sn. 2.56%	8.50	49,000*	18,000*	53*	53	BHN 62 (500 KG Load 10mm Ball)
Monel	ML.	Ni. 67.5% Cu. 31.0%	8.84	88,000	40,000	41	50	BHN 160 Standard
Aluminum Bronze	Al.B.	Cu. 92.5% Al. 6.5%	8.86	78,000*	25,000*	25*	30*	BHN 163 (500 KG Load) 10mm Ball)
Nickel (Commercially Pure)	Ni.	Ni. 99.9%	8.90	67,000*	30,000*	40*	67*	RB 50*
Copper (Commercially Pure)	Cu.	Cu. 96.4%	8.96	34,000	18,000	50	60	BHN 120 (500 KG Load 10mm Ball)
Lead (Commercially Pure	Pb.	Pb. 99.94%	11.34	1,700*		35*		

* Denotes data taken from handbooks or reliable sources.

[1] This table was prepared by Mr. Fred A. Weymouth.

TABLE II

FRAGMENT WEIGHT DISTRIBUTION OF RING TYPE SHELL MADE OF VARIOUS METALS

MATERIAL	RD NO.	1-2	3-4	5-7	8-10	11-15	16-20	21-35	36-55	56-75	76-100	101-130	131-175	176-220
		Grains												
Mg.	2	353	339	204	59	8								
	1	370	315	197	58	8								
Mg.A.	2	934	281	74	9			1						
	1	802	262	68	9	1								
Al.	2	35	37	52	96	169	89	22						
	1	30	28	37	86	170	96	36						
Al.A.	2	150	137	142	100	161	76	7						
	1	132	151	140	106	130	64	8						
Ti.	1	238	189	157	102	118	90	211	69	7				
Zn.	2	49	28	26	23	37	26	118	127	52	9	1		
	1	25	29	26	19	27	39	89	103	37	15	1		
G.C.S.	1	Fragment Distribution Doubtful Due to Brittle Nature of Grey Cast Iron												
C.S.	2	25	14	31	27	15	21	66	93	64	31	7	2	
	1	16	14	21	10	20	26	53	82	78	41	13	3	
H.Mn.S.	2	30	32	54	27	45	36	84	78	45	35	15	3	
	1	43	34	42	40	28	34	79	83	50	23	11	4	1
S.S.	2	13	15	12	13	19	22	55	94	72	49	13	3	
	1	13	13	14	12	17	19	36	70	52	55	24	9	
Be.Cu.	2	20	25	16	18	25	28	56	94	87	36	20	2	
	1	11	7	6	4	9	16	45	79	73	48	18	6	
Y.B.	2	114	78	77	53	91	90	164	95	40	6	1		
	1	162	86	88	59	121	99	179	95	29	5			
ML.	2	11	5	2	1	6	7	19	40	38	59	43	21	
	1	19	8	4	2	8	4	34	53	65	55	30	6	2
Al.B.	2	39	40	27	24	45	45	142	113	56	10	2		
	1	51	38	34	39	58	49	126	129	45	10	3		
Ni.	2	9	1	4	3	6	4	15	25	32	41	43	29	10
	1	1		1	3	4	7	16	32	36	40	33	32	3
Cu.	2	13	10	12	15	27	26	106	129	81	21	8		
	1	9	17	21	12	22	27	122	159	80	21	2	1	
Pb.	1	Very fine powder - no recovery												

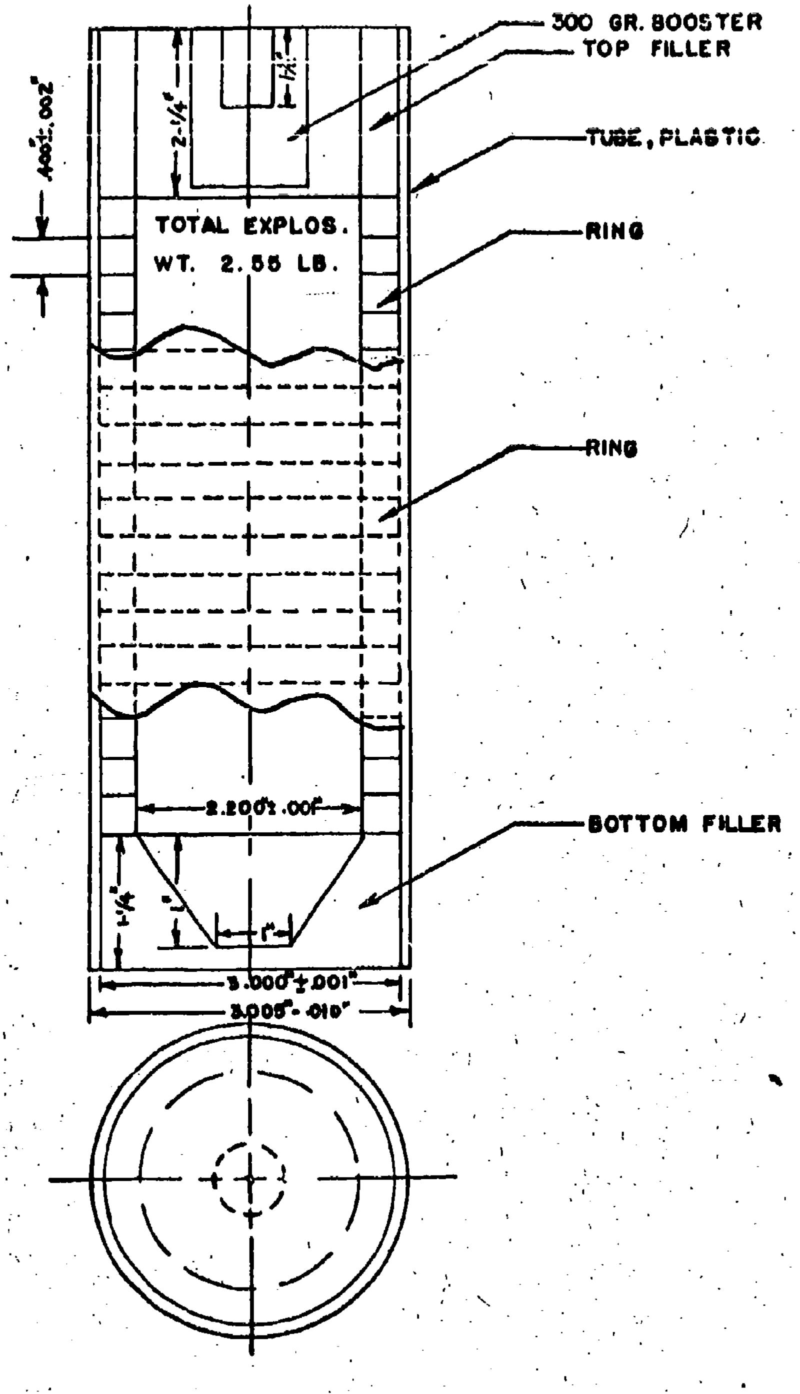
TABLE III

DATA ON RING TYPE SHELL MADE OF VARIOUS METALS

MATERIAL	RD NO.	DATE FRAG.	RECOVERY BOXES NO.	RECOVERY BOXES RADIUS FT	DIST. TO VEL. BOX FT	PHOTO. VEL FT/SEC	V_c INITIAL VEL FT/SEC	A_D DYNAMIC REDUCT. OF AREA %	$\bar{M}^w$ MEAN FRAG. WT. GRS.	cc
Mg.	2	6-10-49	12	20	20.00	4693	5444	43.9	5.1	277
	1	5-31-49	12	20						
Mg.A.	2	6-30-49	12	20			5731	45.9	3.4	125
	1	6-20-49	12	20	19.83	4816				
Al.	2	12-27-48	6	10	17.96	5483	6031	76.2	15.0	1207
	1	12-17-48	6	10						
Al.A.	2	4-26-49	12	20			5945	28.7	11.8	696
	1	12-31-48	6	10	17.96	5356				
Ti.	1	11-8-51	15	10	10.33	4102	4362	17.94	26.0	677
Zn.	2	9-1-50	12	20			4057	50.7	46.1	746
	1	8-21-50	12	20	20.00	3792				
G.C.S.	1	3-10-49	6	10	17.87	3735	Not Det.	Frag too Small	Not Det.	--
C.S.	2	1-25-50	12	20			3656	29.4	63.0	934
	1	1-20-50	12	20	20.00	3417				
H.Mn.S.	2	6-19-50	12	20			3773	19.0	60.9	918
	1	6-14-50	12	20	19.92	3526				
S.S.	2	3-15-50	12	20	20.08	3100	3286	43.1	72.2	971
	1	3-10-50	12	20						
Be.Cu.	2	10-25-50	12	20			3444	51.5	68.9	895
	1	10-21-50	12	20	19.88	3249				
Y.B.	2	2-17-49	6	10			3888	42.5	35.4	284
	1	2-3-49	6	10	17.92	3634				
ML.	2	11-17-49	12	20			3427	50.1	90.2	1328
	1	10-27-49	12	20	19.92	3233				
Al.B.	2	1-27-49	6	10			3745	36.1	44.5	384
	1	1-12-49	6	10	17.96	3500				
Ni.	2	12-12-50	12	20			3390	48.6	110.6	1926
	1	12-8-50	12	20	19.78	3229				
Cu.	2	9-26-49	12	20			3639	67.8	52.6	495
	1	9-12-49	12	20	20.00	3401				
Pb.	1	7-28-49	12	20		3393	--	--	--	--

FIGURE I

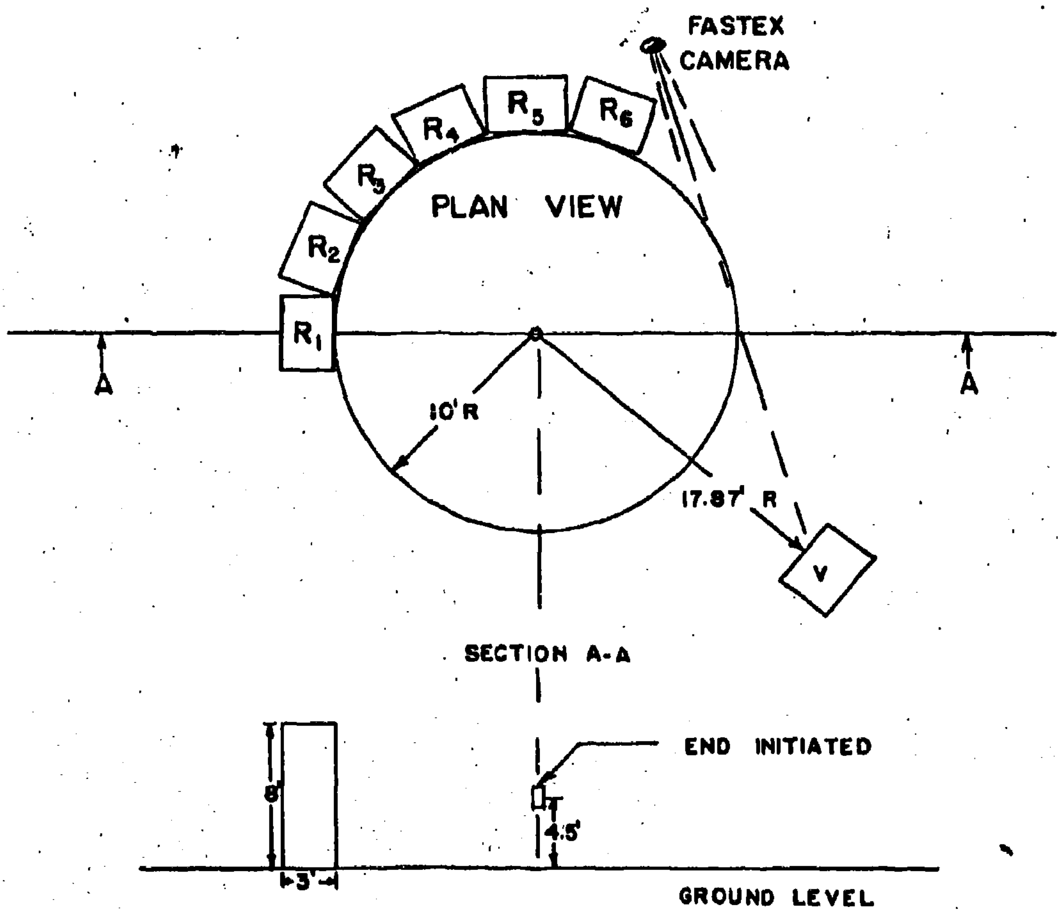
SHELL ASSEMBLY



TITANIUM 14 RINGS
ALL OTHERS 20 RINGS

FIGURE 2

FRAGMENTATION FACILITY FOR RING TYPE SHELL



R_1- R_6: CANE FIBER BOARD FILLED FRAGMENT RECOVERY BOXES 4'X8'X3'.

V : PHOTO VELOCITY RECOVERY BOX.

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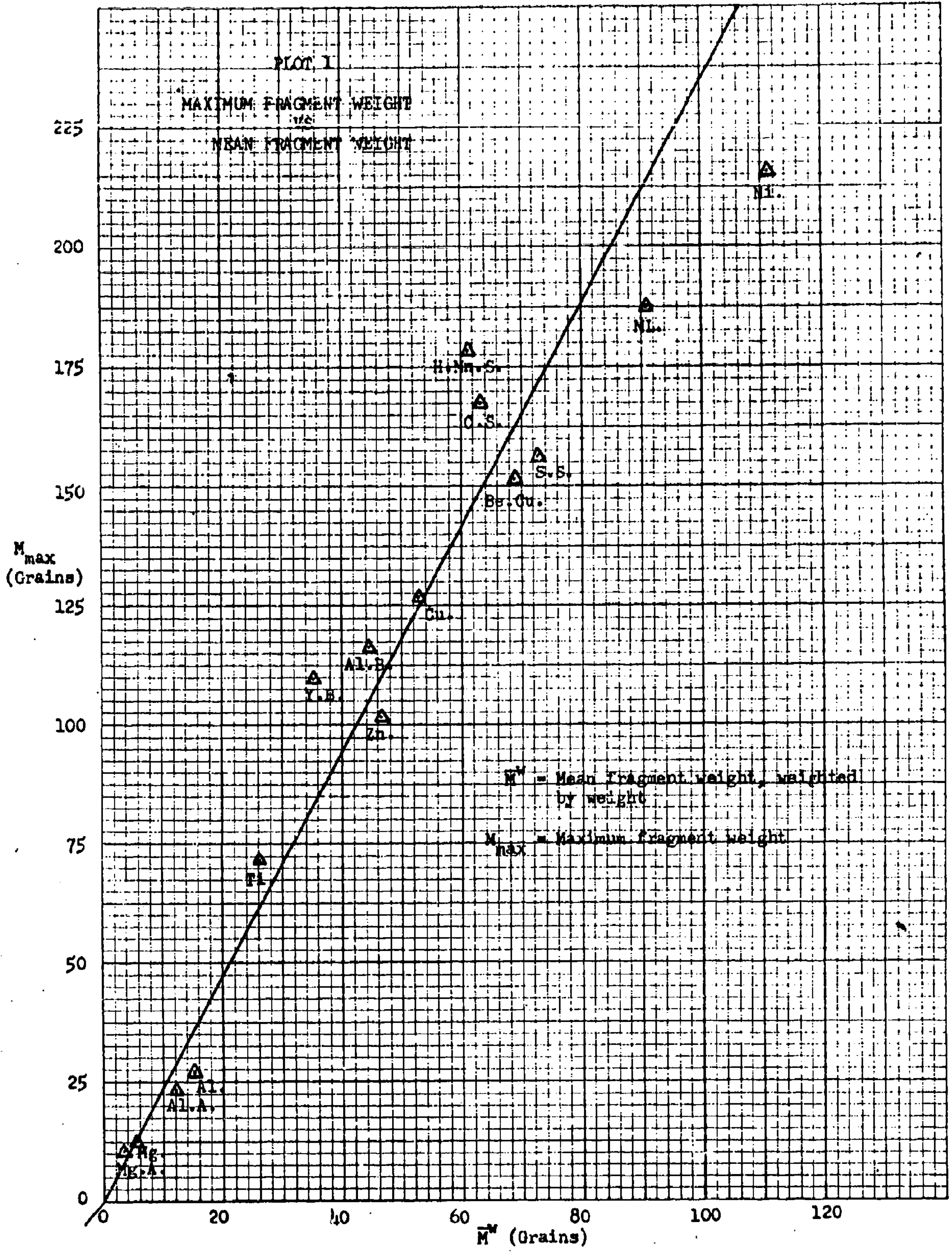
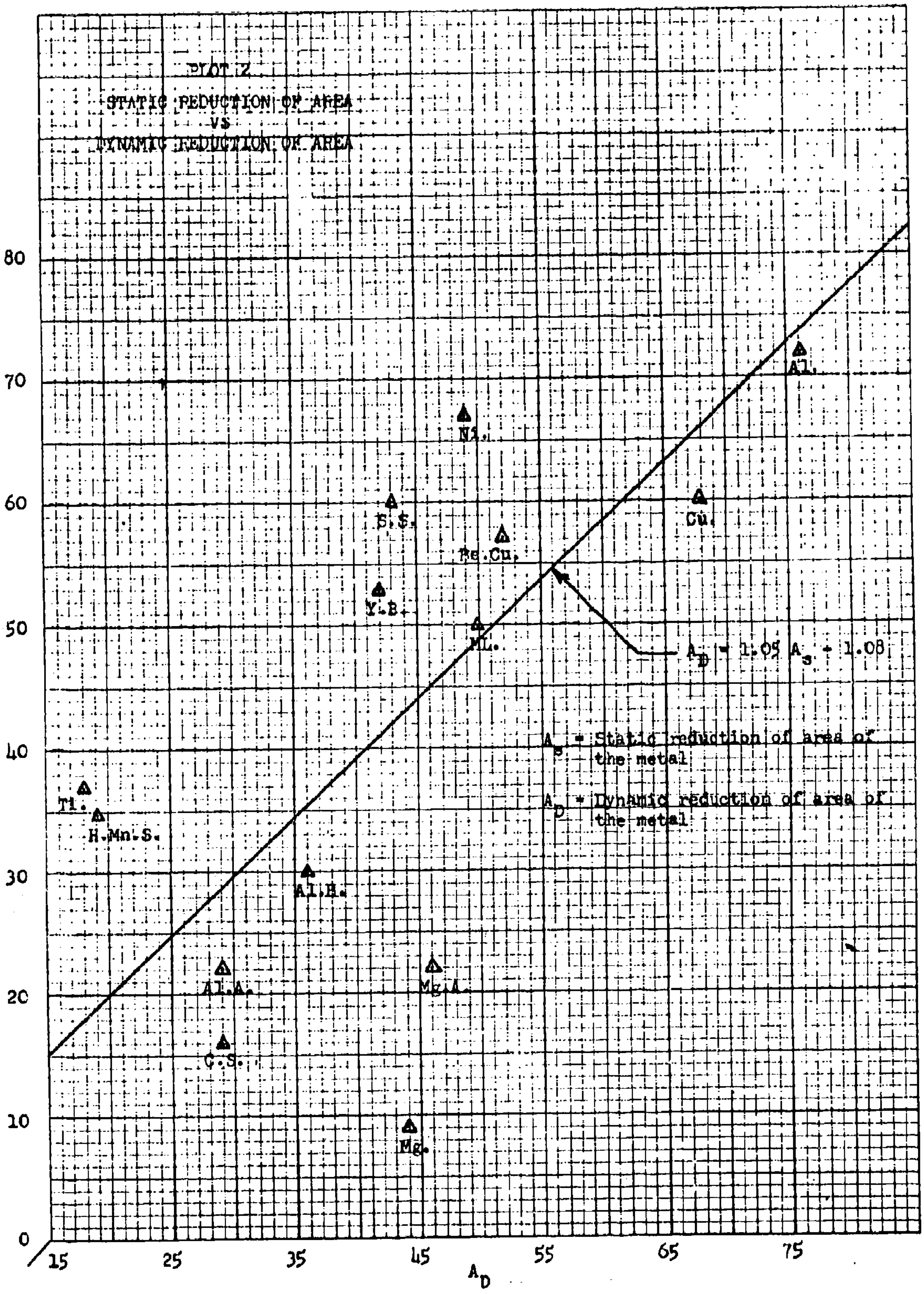
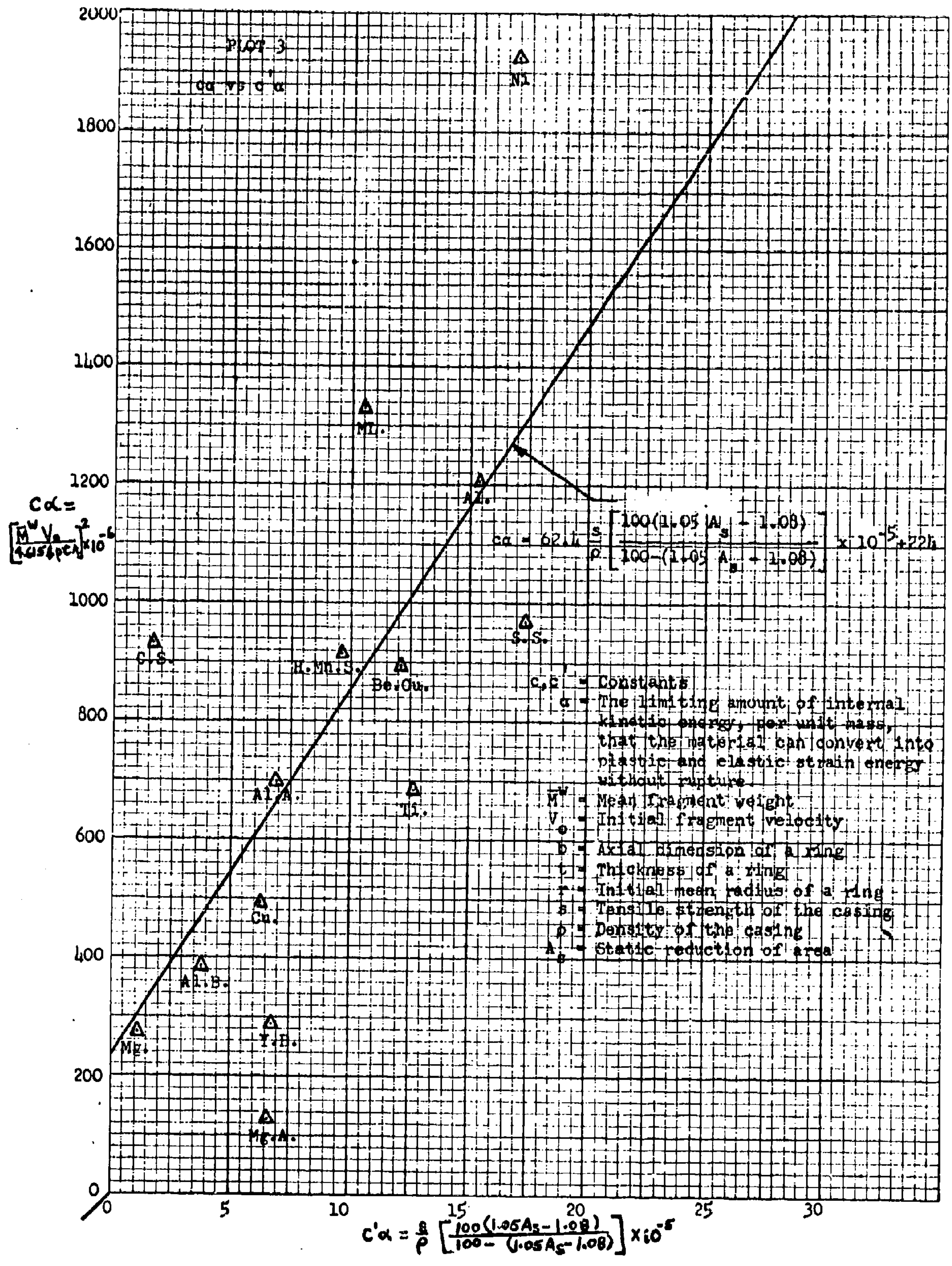

PLOT I
MAXIMUM FRAGMENT WEIGHT
vs
MEAN FRAGMENT WEIGHT
$\bar{M}^w$ = Mean fragment weight, weighted by weight
M_{max} = Maximum fragment weight
M_{max} (Grains)
0
25
50
75
100
125
150
175
200
225
0
20
40
60
80
100
120
$\bar{M}^w$ (Grains)
Ni.
Nl.
H.Mn.S.
C.S.
S.S.
Bs.Cu.
Cu.
Al.B.
Y.B.
Zn.
Ti
Al.
Al.A.
Mg.
Mg.A.



PLOT 2

STATIC REDUCTION OF AREA
VS
DYNAMIC REDUCTION OF AREA



$$c\alpha = 62.4\,\frac{s}{\rho}\left[\frac{100(1.05\,A_s - 1.08)}{100-(1.05\,A_s - 1.08)}\right] \times 10^{-5} + 224$$

c, c' = Constants
α = The limiting amount of internal kinetic energy, per unit mass, that the material can convert into plastic and elastic strain energy without rupture.
$\bar{M}^w$ = Mean fragment weight
V_o = Initial fragment velocity
b = Axial dimension of a ring
t = Thickness of a ring
r = Initial mean radius of a ring
s = Tensile strength of the casing
ρ = Density of the casing
A_s = Static reduction of area

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ATI- 162 156

Aberdeen Proving Ground, Ballistic Research Labs., Md. (Memo Report No. 597)
FRAGMENTATION OF RING TYPE CYLINDRICAL SHELL MADE OF VARIOUS METALS - PROJECT NO. TB3-0112A, by Michael Famiglietti. March '52, 19 pp. incl. tables, diagrs, graphs. RESTRICTED

To study fragmentation characteristics, a series of ring-type cylindrical shell, made of various metals, having widely different densities and physical properties, were statistically fragmented. Resulting data were analyzed in conjunction with a theory governing the sizes of fragments. Conclusions were
(over)

DIVISION: Ordnance and Armament (22)
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1. Projectiles - Fragmentation
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