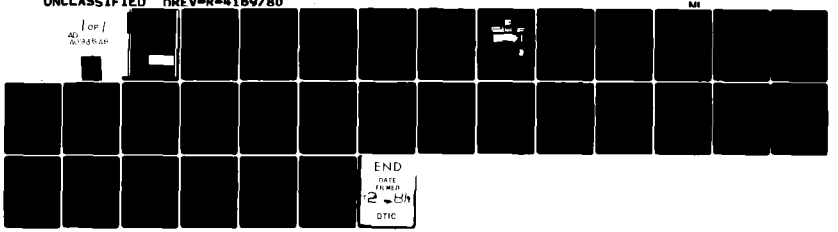
AD-A093 648 DEFENCE RESEARCH ESTABLISHMENT VALCARTIER (QUEBEC) F/G 19/1
A CASTABLE COMPOSITE EXPLOSIVE: THE COEFFICIENT OF CUBICAL EXPA--ETC(U)
OCT 80 C BELANGER, F BEDFORD, A OUELLET
UNCLASSIFIED DREV-R-4169/80 NL



Centre de Recherches pour la Défense
Defence Research Establishment
Valcartier, Québec

BUREAU RECHERCHE ET DEVELOPPEMENT
MINISTERE DE LA DEFENSE NATIONALE
CANADA

RESEARCH AND DEVELOPMENT BRANCH
DEPARTMENT OF NATIONAL DEFENCE
CANADA

CRDV R-4169/80
DOSSIER: 3621A-003

UNCLASSIFIED

DREV-R-4169/80
FILE: 3621A-003

A CASTABLE COMPOSITE EXPLOSIVE: THE COEFFICIENT OF CUBICAL EXPANSION

by

C. Bélanger, F. Bedford and A. Ouellet

CENTRE DE RECHERCHES POUR LA DEFENSE

DEFENCE RESEARCH ESTABLISHMENT

VALCARTIER

Tel: (418) 844-4271

Québec, Canada

October/octobre 1980

RESUME

Le volume d'un échantillon d'explosif composite (RDX/liant-83/17) a été mesuré dans une gamme de températures comprise entre 248 et 338 K en utilisant le principe d'Archimède. Les échantillons étaient enrobés d'un film protecteur développé spécialement pour éviter la dissolution du liant dans l'huile de silicone utilisée comme liquide d'immersion. Les résultats ont montré que la moyenne de 15 mesures du coefficient de dilatation cubique de l'explosif à 296 K est 3.57 x 10^{-4} K^{-1} avec un écart type de 0.066 x 10^{-4} K^{-1}. Une technique similaire appliquée à un échantillon d'aluminium, dont le coefficient est connu, a donné une valeur 2.0 pour cent supérieure. (NC)

ABSTRACT

The volume of a composite explosive (RDX/binder-83/17) has been measured at temperatures from 248 to 338 K using Archimedes' principle. The specimens were covered with a protective film specially developed to prevent the binder from dissolving in the fluid, a silicone oil. From the results the coefficient of cubical expansion of the explosive at 296 K is 3.57 x 10^{-4} K^{-1} as the mean of 15 measurements having a standard deviation of 0.066 x 10^{-4} K^{-1}. A similar technique applied to an aluminum specimen whose coefficient is known gave a value about 2.0 percent too large. (U)

.000357/K

.000066

TABLE OF CONTENTS

LIST OF SYMBOLS

C	:	Constant	
D	:	Diameter	[cm]
L	:	Length	[cm]
T	:	Temperature	[K]
V	:	Volume	$[cm^3]$
W	:	Weight	[g]
α	:	Coefficient of linear expansion	$[K^{-1}]$
β	:	Coefficient of cubical expansion	$[K^{-1}]$
ρ	:	Density	$[Mg/m^3]$

Subscripts

air	:	In air
c	:	Copper
e	:	Composite explosive specimen
n	:	Nilvar
p	:	Protective film

1.0 INTRODUCTION

Castable composite explosives developed at DREV have been extensively studied to ascertain their mechanical, thermal and detonation properties (Refs. 1 - 3). These explosives consist of one or several energetic ingredients embedded in a fluid called the binder. After the explosive is poured into place, this binder is cured by a nonreversible process. The binder consists of hydroxyl-terminated polybutadiene prepolymer R-45M, sold by Arco Chemical, along with a plasticizer, a diisocyanate as a curing agent, and small concentrations of a catalyst and a wetting agent.

This report treats the laboratory measurement of the thermal expansion of one of these composite explosives as a means of ascertaining its coefficient of cubical expansion. The explosive consisted of only one energetic ingredient, RDX, at a concentration of 83 percent. The only other ingredient was binder. Our method used Archimedes' principle to determine the volume of explosive specimens over a range of temperatures, by measuring their loss in weight when immersed in a silicone oil maintained in turn at each of several temperatures.

The work described in this report was completed at DREV between November 1974 and February 1976 under PCN 21A03 Composite Explosives.

2.0 APPARATUS

The apparatus assembled for our experiments consists mainly of a balance which permits an additional bottom load below the pan, a copper beaker for the oil, a controlled-temperature bath, a fine copper wire and several recording instruments. These are illustrated schematically in Fig. 1, and by photographs as Figs. 2 and 3.

FIGURE 2 - Apparatus for the buoyancy measurements

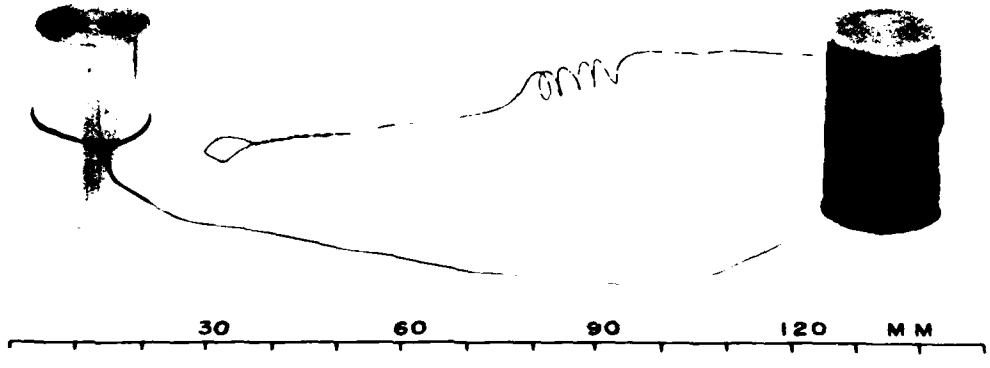


FIGURE 3 - Specimens, aluminum at left, explosive at right, and copper wire for suspending them in oil

The balance is a Mettler H-20-E electronic, with a least count of 0.05 mg. Its weight reading is indicated by a digital voltmeter, Dana 5000.

The silicone oil was furnished by General Electric under the designation SF-81. It is contained in a 0.4-ℓ copper beaker immersed in a 9-ℓ thermostatically-controlled bath of ethylene glycol, Lauda model TUK-30, kept at a constant temperature within ± 0.03 K.

The copper wire, of 0.305 mm diameter, is used for suspending each specimen immersed in the oil. It is partially twisted into a small helix to minimize the transmission of vibrations from the specimen to the balance.

3.0 THEORY AND METHOD

3.1 Theory

The coefficient of cubical expansion β is defined as the ratio of the change in volume of a unit volume divided by the corresponding change in temperature. If volume can be expressed by an algebraic equation as a function of the temperature T, then the value of β at that temperature can be obtained by differentiating the equation.

$$\beta = \frac{1}{V}\frac{dV}{dT} \qquad [1]$$

A convenient and versatile laboratory method for measuring the volume of a solid makes use of Archimedes' principle, namely, that the loss in weight of a solid when immersed in a liquid is equal to the weight of an equal volume of that liquid. We used this principle in two ways: for determining the volume of explosive specimens each was immersed in turn into the silicone oil (dimethyl polysiloxane), and for determining the density of this silicone oil a steel specimen

of known dimensions and weight was immersed in it. We rejected the use of any direct measurement of the amount of liquid displaced by a solid specimen as a measure of the volume of that specimen, because this latter method seemed impractical for our requirements and less convenient to accomplish.

In determining the density of the silicone oil we used a rectangular parallelepiped of "nilvar" steel obtained from the Driver-Harris Company, Harrison, New Jersey. This metal, according to information furnished by the supplier, has a coefficient of linear expansion α_n of $1.26 \times 10^{-6}\ K^{-1}$, about one-tenth that of most other steels. This small expansion rate was considered desirable for our experiments so that (a) the observed change in its buoyancy with changing temperature would be due principally to changes in the density of the oil, and (b) any inaccuracy in our assumed value of α_n would have a minimal influence on the measured density of the oil. We assumed that α_n would have the same value in all directions, hence the volume of the nilvar at any temperature T will be given by

$$V_n = L_1 L_2 L_3 [1 + \alpha_n (T-T_o)]^3 \qquad [2]$$

where L_1, L_2 and L_3 are the dimensions of the nilvar block at room temperature T_o. By measuring the weight of that block when immersed in oil W_i, the density ρ of the oil can be determined at any temperature T using the equation

$$\rho_{oil} = \frac{W_{air} - W_i}{V + V_c} \qquad [3]$$

where W_{air} is the weight of the entire copper wire used for supporting the nilvar when immersed in oil, along with that of the nilvar, both weighed together in air, V in this instance is V_n, and V_c is the volume of that portion of the copper wire immersed in oil during the buoyancy

weighing. This partial volume V_c is given by

$$V_c = \frac{\pi}{4} [1 + \alpha_c (T-T_o)]^3 L_c D_c^2 \qquad [4]$$

where α_c, the coefficient of linear expansion of copper, is assumed to be equal to 16.6×10^{-6} K^{-1}, D_c is the diameter and L_c the length at room temperature T_o of the copper wire immersed, and T is the temperature of the oil bath. By measuring W_i at several temperatures, the corresponding densities of the oil can be computed using eqs. 3 and 4.

3.2 Method

It was found convenient to make the first buoyancy measurements at about room temperature toward the end of a working day, then to set the thermostat at the lowest temperature desired. This provided sufficient time overnight to reach equilibrium at the required temperature, in spite of the small cooling capacity of the heat sink immersed in the ethylene glycol. The other (higher) temperatures could then be conveniently reached during the course of the same working day.

In applying Archimedes' principle to measurements with the composite explosive it was discovered that our initial results had to be discarded because the explosive was partially soluble in the silicone oil. This solubility was confirmed by immersing into the oil at 343 K some specially prepared specimens composed entirely of binder. These specimens showed losses in weight of about 10 and 15 percent after immersions of 24 and 48 h respectively. This difficulty was averted by coating all subsequent specimens of composite explosive with a thin protective film before subjecting them to buoyancy measurements. An alternative would have been to find a liquid which did not attack the explosive, but such a search would not necessarily have been successful and also it would have meant abandoning much work already done.

We developed a formulation for coating our explosive specimens with a film which seemed satisfactory in every way. It was compatible with the explosive and sufficiently flexible so as not to crack easily. It could be readily applied in a film sufficiently thin (weighing only about 2 percent of the weight of the explosive) so as not to unduly influence the explosive in expanding and contracting freely with temperature changes. There was no detectable change in the weight of film-coated explosive specimens upon immersion in oil for 27 h at temperatures up to 343 K and so the film is sufficiently insoluble for the duration of a series of our buoyancy measurements. The formulation used consisted of the epoxy resin Armstrong A32 at a concentration of 66.6 percent, the only other ingredient being the polysulfide LP33 manufactured by Thiokol Canada Ltd.

Composite explosive specimens were prepared by casting approximately to the desired size, then machining on a lathe and coating with protective film by dipping. The upper end of each casting was machined flat; the other surfaces were also turned on a lathe to eliminate the smooth outer "skin" consisting mainly of binder, in order that the film would adhere adequately. To apply the film a pin was stuck into each specimen so it could be conveniently dipped into the liquid and then mounted with the head of the pin embedded in Plasticine while curing. Any excess film material which gathered at the bottom of a specimen was removed by wiping lightly. When cured each specimen was removed from its pin and each hole filled with a drop of film fluid.

Thermal expansion of the protective film had to be taken into account in measuring the volume of coated composite explosive [illegible] expansion was studied by a separate series of buoyancy experiments in which the volumes of six film specimens were determined at temperatures comparable to those used in the experiments with film-coated explosive [illegible]

The film volume V at each temperature T was computed using eqs. 3 and 4; it was convenient to express each of these results also in the form of its specific volume, that is, volume per unit mass.

Thermal expansion for a specimen of 99.999 percent aluminum was also measured using the buoyancy method, for comparison with literature data as an indication of the accuracy of our other measurements. Again eqs. 3 and 4 were used to compute specimen volume V at each experimental temperature. The results were compared with those obtained using an equation, attributed to J.L. Brandt in Ref. 4, which gives for the length L of an aluminum specimen of 99.996 percent purity

$$L = L_o[1 + C(22.17\ t + 0.012\ t^2)\ 10^{-6}] \qquad [5]$$

where L_o is its length at 0^oC, C is a constant which for pure aluminum is equal to unity, and t is the temperature in degrees Celsius within the range -60 to 100^oC. We applied eq. 5 to both length and diameter in computing the "known" volume of the aluminum specimen for comparison with our experimental values.

In using buoyancy measurements to determine the volume of a composite explosive, account must be taken of the fluid displaced by the protective film with which the specimens are coated. The volume V of the explosive itself is given by an equation of the form of eq. 3 with one additional term, V_p, the volume of this film.

$$\rho_{oil} = \frac{W_{air} - W_i}{V + V_c + V_p} \qquad [6]$$

Values of V_p were computed using our previously determined value of the specific volume of the film at each temperature at which buoyancy measurements on the explosive were made.

4.0 RESULTS AND DISCUSSION

4.1 Density of the Oil

Dimensions of the nilvar block, measured at 296 K, were found to be 10.344 x 1.925 x 0.315 cm and its weight in air was 50.93630 g. The entire 0.305-mm-diameter copper wire weighed 0.20870 g; it was immersed to a length of 7.609 cm, measured at 296 K. Nilvar and copper were assumed to have a coefficient of linear expansion of 1.26×10^{-6} and 16.6×10^{-6} K^{-1} respectively. The immersed weights at 22 different temperatures are presented in Table I along with the computed density of the oil at each temperature. These densities as a function of temperature are also presented graphically in Fig. 4, in which it can be seen that the plotted points deviate from a straight line. The cubic equation which best fits these points (least squares) is

$$\rho_{oil} = C_o + C_1 T + C_2 T^2 + C_3 T^3 \qquad [7]$$

where $C_o = 1.28656$
$C_1 = 1.28122 \times 10^{-3}$
$C_2 = 8.60806 \times 10^{-7}$
and $C_3 = 4.98146 \times 10^{-10}$.

4.2 Protective Film

Buoyancy and other measurements made on six specimens of protective film are presented in Table II. The immersed weight was measured at five different temperatures, for each of which the specimen volume was computed using eqs. 3 and 4. The copper wire weighed 0.21745 g; during buoyancy measurements it was partly immersed in oil to the extent of 8.424 cm of its length as measured at 296 K.

TABLE I

Density of the silicone oil at several temperatures

Temperature [K]	Weight of nilvar, immersed in oil [g]	Computed oil density [g/cm^3]
248.1	44.78810	1.01375
249.8	44.79148	1.01320
253.6	44.81966	1.00869
254.7	44.82485	1.00786
258.9	44.85092	1.00369
262.9	44.87388	1.00001
268.4	44.90515	0.99500
273.1	44.93389	0.99040
278.0	44.95900	0.98638
282.4	44.98435	0.98232
287.0	45.01140	0.97799
289.6	45.02785	0.97536
295.4	45.05875	0.97041
296.3	45.06210	0.96987
302.0	45.09590	0.96446
312.4	45.15465	0.95506
322.4	45.20910	0.94634
333.2	45.26842	0.93685
342.5	45.31950	0.92867
352.6	45.37475	0.91983
362.5	45.42700	0.91146
373.2	45.48327	0.90246

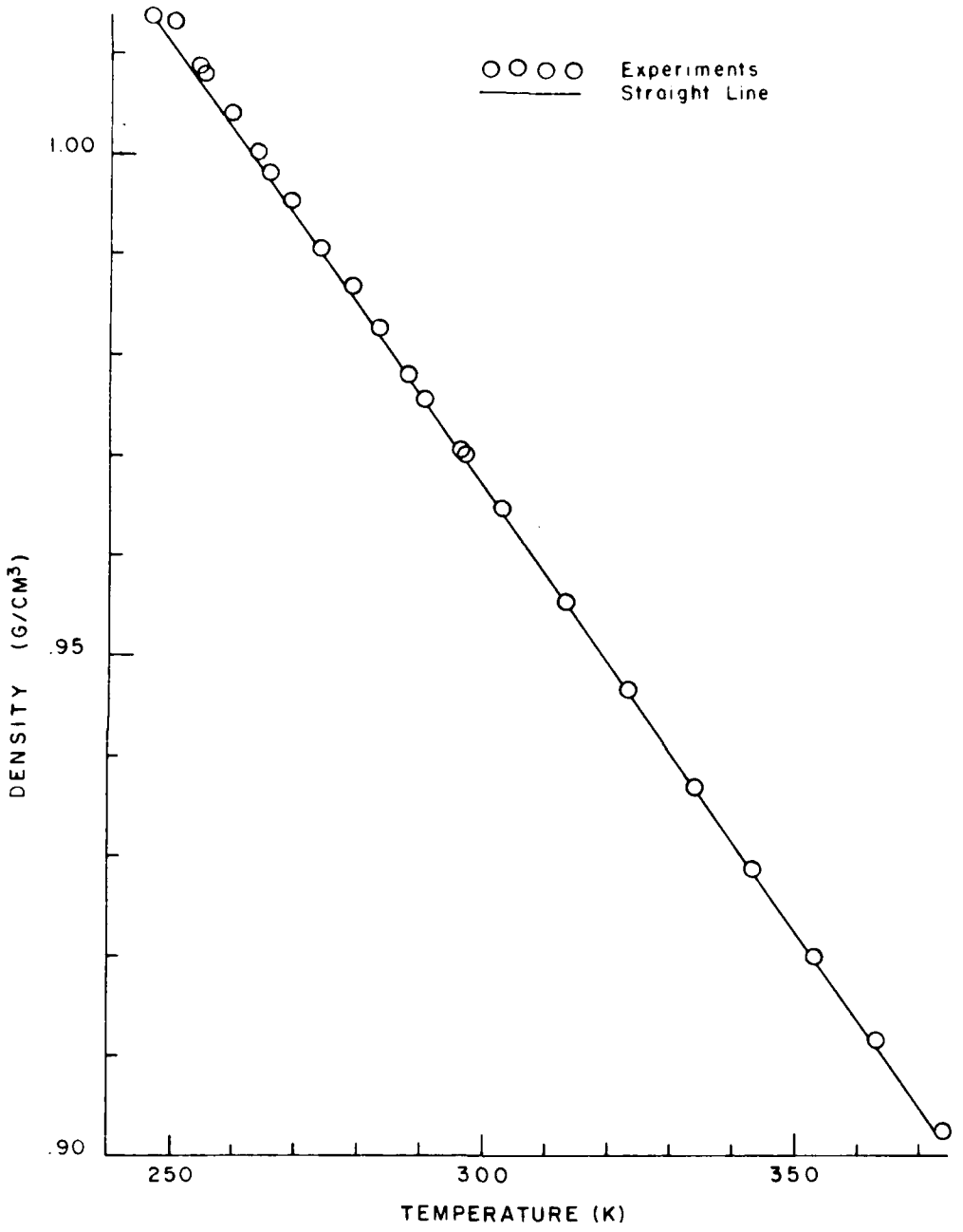


FIGURE 4 - Density of the silicone oil at several temperatures

TABLE II

Protective film volume ac several temperatures

	Temperature [K]	Immersed weight [g]	Computed volume [cm^3]	Coefficient of cubical expansion at 296 K (β) [K^{-1}]
Specimen # 1, weight = 13.12890 g	249.7	3.02550	10.1871	5.08×10^{-4}
	272.9	3.14930	10.2824	
	294.6	3.25130	10.3881	
	317.4	3.33970	10.5180	
	342.7	3.39240	10.7136	
Specimen # 2, weight = 13.64959 g	251.9	3.14990	10.5920	5.31×10^{-4}
	272.8	3.26698	10.6929	
	296.2	3.37010	10.8175	
	316.9	3.45290	10.9420	
	342.2	3.51912	11.1320	
Specimen # 3, weight = 13.62578 g	247.8	3.11994	10.5661	5.36×10^{-4}
	272.7	3.25209	10.6789	
	297.0	3.35746	10.8144	
	316.9	3.43882	10.9312	
	342.6	3.51067	11.1201	
Specimen # 4, weight = 13.61923 g	247.6	3.13574	10.5419	4.96×10^{-4}
	272.8	3.26461	10.6570	
	294.0	3.37484	10.7602	
	316.8	3.46531	10.8960	
	342.0	3.51248	11.1048	
Specimen # 5, weight = 13.60681 g	247.5	3.12132	10.5428	4.92×10^{-4}
	272.3	3.26297	10.6450	
	294.7	3.33770	10.7518	
	316.8	3.46670	10.8809	
	341.9	3.50751	11.0956	
Specimen # 6, weight = 13.64165 g	247.6	3.12831	10.5718	5.05×10^{-4}
	272.3	3.26961	10.6734	
	295.4	3.38689	10.7848	
	316.8	3.46957	10.9145	
	341.9	3.51657	11.1239	

Our values of volume at each temperature for the six specimens are presented graphically in Fig. 5. These 30 values of V are fitted, using least squares, to the cubic equation

$$V_p = W(C_o + C_1T + C_2T^2 + C_3T^3) \qquad [8]$$

where the constants were found to have the following values:

$C_1 = 0.44941$

$C_2 = 3.23165 \times 10^{-3}$

$C_3 = 1.14768 \times 10^{-5}$

$C_4 = 1.50803 \times 10^{-8}$.

From eqs. 1 and 8 the value of the coefficient of cubical expansion β at 296 K was found to be 5.05×10^{-4} K^{-1}. Values of β for each specimen, given in the last column of Table II, were obtained in a similar fashion from a cubic equation fitted to the results for each.

4.3 Accuracy of Measuring Technique

The aluminum specimen subjected to buoyancy measurements to provide an estimate of the degree of precision of our other results was 3.1717 cm long and 1.9101 cm in diameter, measured at 296 K. In air it weighed 24.56061 g; immersed in oil the weights, recorded at 14 different temperatures, were as presented in Table III. The copper wire weighed 0.21745 g; during buoyancy measurements it was partly immersed in oil to the extent of 8.424 cm of its length as measured at 296 K.

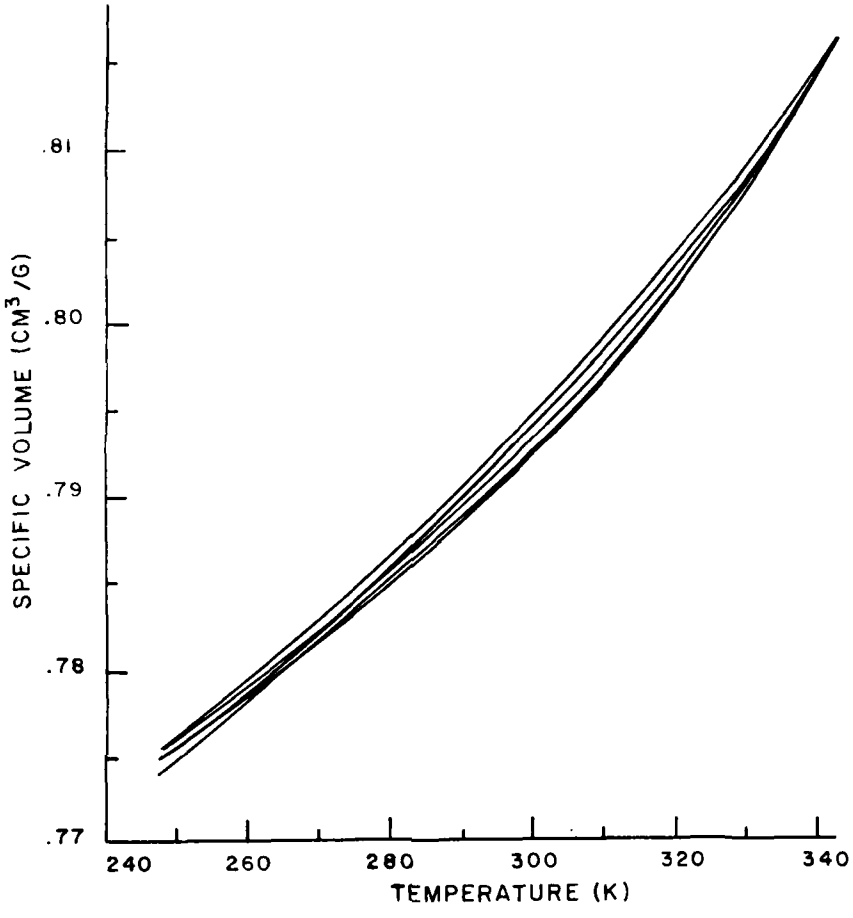


FIGURE 5 - Specific volume of 6 specimens of the protective film

TABLE III

Volume of the aluminum specimen at several temperatures

Temperature [K]	Aluminum weight, immersed in oil [g]	Computed volume [cm^3]	Volume, from eq. 5 [cm^3]
248.1	15.58397	9.0602	9.0590
254.2	15.63550	9.0614	9.0627
262.4	15.69843	9.0678	9.0675
271.9	15.77327	9.0730	9.0732
282.6	15.85554	9.0798	9.0797
295.1	15.95232	9.0869	9.0874
302.1	16.00302	9.0933	9.0917
312.6	16.08395	9.0979	9.0983
322.7	16.15874	9.1055	9.1047
333.5	16.23773	9.1131	9.1116
343.6	16.31032	9.1208	9.1182
353.6	16.38382	9.1265	9.1247
364.2	16.45858	9.1355	9.1317
371.6	16.51062	9.1419	9.1367

The volume of the aluminum at each temperature, computed using eqs. 3 and 4, is presented in the third column of Table III and also plotted in Fig. 6. Along with these experimental volumes, we have also plotted in this figure the "known" volume at each temperature as computed from the measured dimensions using eq. 5.

Our experimental volumes were fitted to a cubic equation from which, in conjunction with eq. 1, the coefficient of cubical expansion β at 296 K was computed. This value, $\beta = 69.61 \times 10^{-6}\ K^{-1}$, can be compared with the "known" value of β obtained from eqs. 1 and 5, that is, $\beta = 68.24 \times 10^{-6}\ K^{-1}$. These two values of β differ by about two percent. It is not known to what extent this discrepancy is systematic or random.

4.4 Composite Explosive

Buoyancy and other measurements made on 16 specimens of a composite explosive, each completely covered by the protective film developed especially for this purpose, are presented in Table IV. The immersed weight was measured at five different temperatures, for each of which the volume of the explosive alone was computed using eqs. 4 and 6. The copper wire weighed 0.21745 g; during buoyancy measurements it was partly immersed in oil to the extent of 8.424 cm of its length as measured at 296 K.

The dependance of volume upon temperature for these 16 specimens is illustrated in Figs. 7 - 11 where specific volumes are plotted as ordinates. For each specimen a cubic equation was fitted to the results, then each equation in conjunction with eq. 1 was used to compute the corresponding value of β given in the last column of Table IV. The mean value of β for each batch is also given in the last column of Table IV.

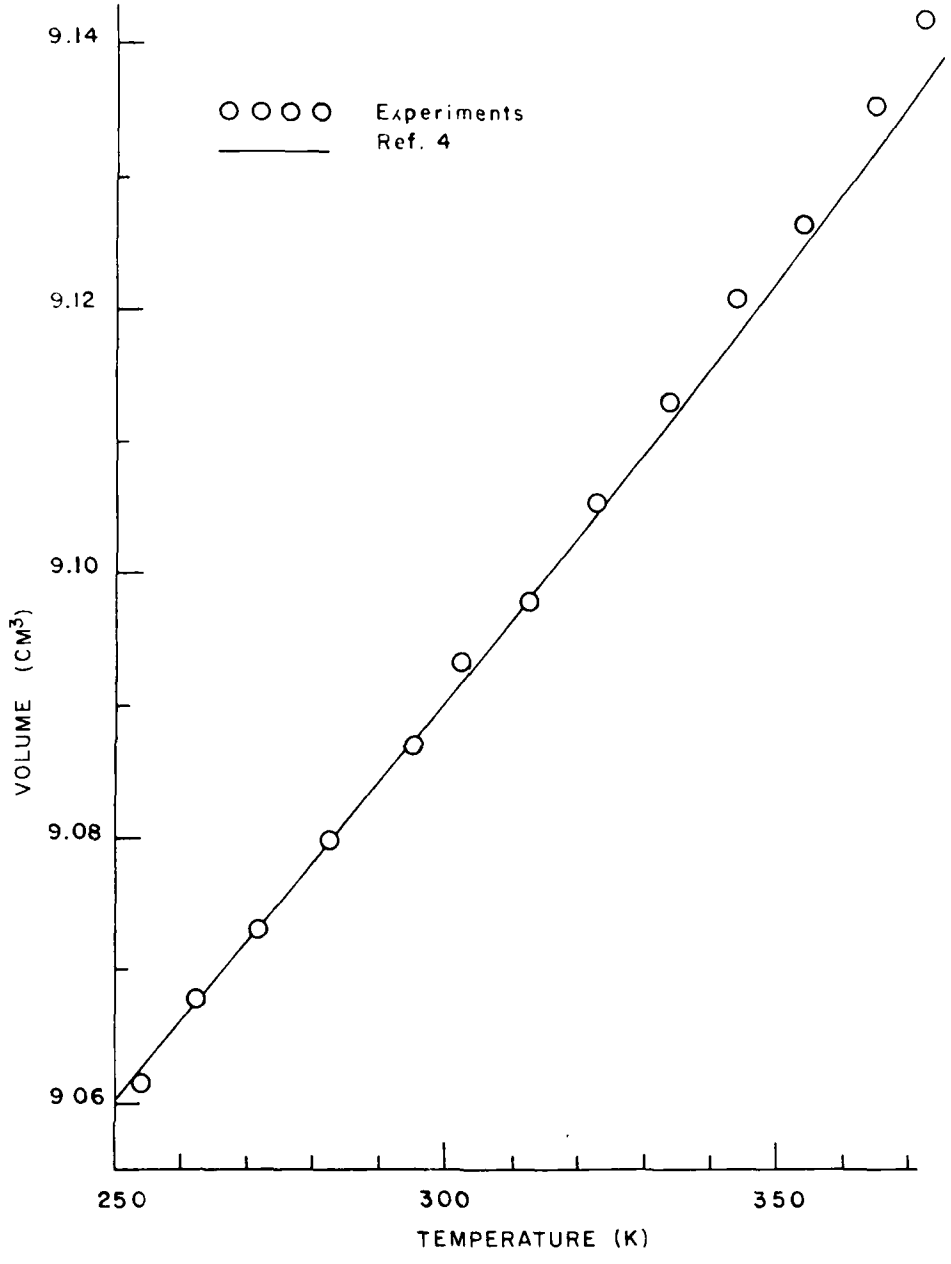


FIGURE 6 - Volume of the aluminum specimen at several temperatures

TABLE IV

Composite explosive buoyancy results

Specimen No.	Batch No.	Bare explosive weight [g]	Protective film weight [g]	Temp. [K]	Immersed weight [g]	Computed explosive volume [cm^3]	Coefficient of cubical expansion at 296 K (β) [K^{-1}]	
1	1	13.93420	0.25959	247.8	5.21668	8.8578		
				272.3	5.35138	8.9277		
				294.5	5.46629	8.9968	$3.51 \cdot 10^{-4}$	
				316.7	5.58138	9.0668		
				342.0	5.70259	9.1545		
2	1	14.30517	0.24187	247.6	5.35677	9.0802		
				272.2	5.49376	9.1536		
				294.6	5.61430	9.2240	$3.49 \cdot 10^{-4}$	
				316.9	5.73130	9.2961		mean = $3.59 \cdot 10^{-4}$
				342.1	5.85735	9.3835		
3	1	12.84594	0.38179	248.0	4.73283	8.2894		SD = $0.10 \cdot 10^{-4}$
				272.3	4.85204	8.3612		
				294.6	4.95690	8.4317	$3.69 \cdot 10^{-4}$	
				316.8	5.06305	8.4992		
				342.0	5.17197	8.5866		
4	1	13.55088	0.33858	247.8	4.99690	8.7136		
				272.3	5.12342	8.7887		
				294.3	5.23312	8.8600	$3.67 \cdot 10^{-4}$	
				316.5	5.34416	8.9311		
				336.7	5.44021	9.0001		
5	2	13.66780	0.31701	248.8	5.12188	8.7088		
				272.4	5.24723	8.7773		
				294.5	5.36030	8.8462	$3.63 \cdot 10^{-4}$	
				316.3	5.46842	8.9166		
				337.3	5.56997	8.9854		
6	2	13.77824	0.29955	249.4	5.16372	8.7779		
				272.8	5.28912	8.8462		
				294.2	5.40112	8.9114	$3.49 \cdot 10^{-4}$	
				316.9	5.51706	8.9823		mean = $3.55 \cdot 10^{-4}$
				337.5	5.61849	9.0491		
7	2	13.84384	0.33030	247.8	5.17643	8.8232		SD = $0.06 \cdot 10^{-4}$
				272.6	5.30968	8.8968		
				295.3	5.42781	8.9677	$3.56 \cdot 10^{-4}$	
				316.9	5.53784	9.0371		
				337.5	5.63909	9.1053		

TABLE IV

(Continued)

Specimen No.	Batch No.	Bare explosive weight [g]	Protective film weight [g]	Temp. [K]	Immersed weight [g]	Computed explosive volume [cm^3]	Coefficient of cubical expansion at 296 K (β) [K^{-1}]	
8	2	13.87439	0.30153	248.2	5.19436	8.8324		
				272.6	5.32615	8.9045		
				294.4	5.44130	8.9713	$3.54 \cdot 10^{-4}$	
				317.0	5.55512	9.0448		
				337.5	5.65450	9.1146		
9	3	14.15744	0.22020	249.2	5.30331	8.9958		
				272.7	5.43199	9.0658		
				293.9	5.54692	9.1298	$3.50 \cdot 10^{-4}$	
				317.3	5.66620	9.2072		
				337.6	5.76789	9.2760		
10	3	14.13567	0.22587	248.8	5.29867	8.9773		
				273.7	5.42894	9.0487		mean = $3.64 \cdot 10^{-4}$
				295.2	5.54786	9.1187	$3.55 \cdot 10^{-4}$	
				317.0	5.65936	9.1905		SD = $0.20 \cdot 10^{-4}$
				337.3	5.76048	9.2595		
11	3	13.77464	0.27494	248.3	5.17938	8.7450		
				272.6	5.30910	9.8150		
				294.6	5.42373	9.8818	$3.86 \cdot 10^{-4}$	
				317.0	5.53606	9.9634		
				337.6	5.63389	9.0233		
12	4	14.01138	0.25582	248.6	5.25191	8.9052		
				272.6	5.38219	8.9758		
				293.7	5.49479	9.0407	$3.51 \cdot 10^{-4}$	
				317.1	5.61374	9.1162		
				337.4	5.71324	9.1856		
13	4	14.00323	0.43082	248.2	5.23766	8.9450		
				272.2	5.36907	9.0161		mean = $3.58 \cdot 10^{-4}$
				295.6	5.49490	9.0896	$3.64 \cdot 10^{-4}$	
				316.9	5.60085	9.1630		SD = $0.07 \cdot 10^{-4}$
				337.7	5.70194	9.2363		
14	4	14.15298	0.36308	248.6	5.29775	9.0219		
				272.4	5.43036	9.0933		
				295.1	5.55241	9.1642	$3.58 \cdot 10^{-4}$	
				316.9	5.66331	9.2379		
				337.4	5.76456	9.3104		

TABLE IV

(Continued)

Specimen No.	Batch No.	Bare explosive weight [g]	Protective film weight [g]	Temp. [K]	Immersed weight [g]	Computed explosive volume [cm^3]	Coefficient of cubical expansion at 296 K (K^{-1})	
15	5	14.09492	0.44288	249.1	5.28056	9.0932		
				272.2	5.40878	9.0726		
				295.0	5.53172	9.1458	$5.61 \cdot 10^{-4}$	
				317.0	5.64325	9.2189		mean =
				337.4	5.74319	9.2916		$5.57 \cdot 10^{-4}$
16	5	14.17857	0.32855	249.1	5.30171	9.0492		SD =
				272.3	5.43136	9.1094		$0.06 \cdot 10^{-4}$
				294.9	5.55431	9.1789	$5.53 \cdot 10^{-4}$	
				316.7	5.66598	9.2519		
				337.3	5.76705	9.3245		

Let us consider the possible existence of batch-to-batch variations in β. If each is weighed equally their overall mean is 3.584 x 10^{-4} K^{-1}, with a standard deviation (SD) of 0.0297 x 10^{-4} K^{-1}. The SD for the specimens within each batch ranges from 0.06 to 0.20 x 10^{-4} K^{-1}, therefore we may infer that no batch differs from any other with respect to β, insofar as our experiments can detect such differences. In other words, we shall tentatively consider each of our 16 measurements of β in like fashion, as single measurements of equal validity. This intuitive decision is supported by the results obtained using Snedecor's F-test for the analysis of variance, where the F ratio confirms that our intuitive assumption has a probability greater than 99 percent of being valid.

Now let us consider our proposal to discard the greatest of these 16 values of β, namely, that for specimen No. 11. Whether it should be discarded or not can be judged using a criterion for testing outlying observations suggested by Grubbs (Ref. 5). This test uses the ratio of the sum of the squares of deviations from their mean for the N-1 unsuspected values over the same sum for the N values including the suspected one. For N = 16 this ratio must be smaller than 0.4634 to be significant at the one-percent level. Since the observed ratio is 0.4358 for our sample of 16 specimens, the probability is less than 0.01 that the measured β for specimen No. 11 comes from the same normal distribution as those for the other 15 values.

The origin of the abnormally large value of β for specimen No. 11 is perhaps apparent from Fig. 9. The curve for specimen No. 11 lies below the others at low temperatures and above them at high temperatures, but coincides with them near 296 K and also at both extremes. That is, the slope of the curve at 296 K, near the point of inflection, differs greatly from that of a straight line joining its end points because of this reversal of curvature.

Two further values of β were retained in spite of several indications that they were suspect, namely, those for specimens Nos. 3 and 4. It is apparent in Fig. 7 that their specific volume is appreciably greater than that of all other specimens. Also, their values of β are the two largest of the 15 valid measurements.

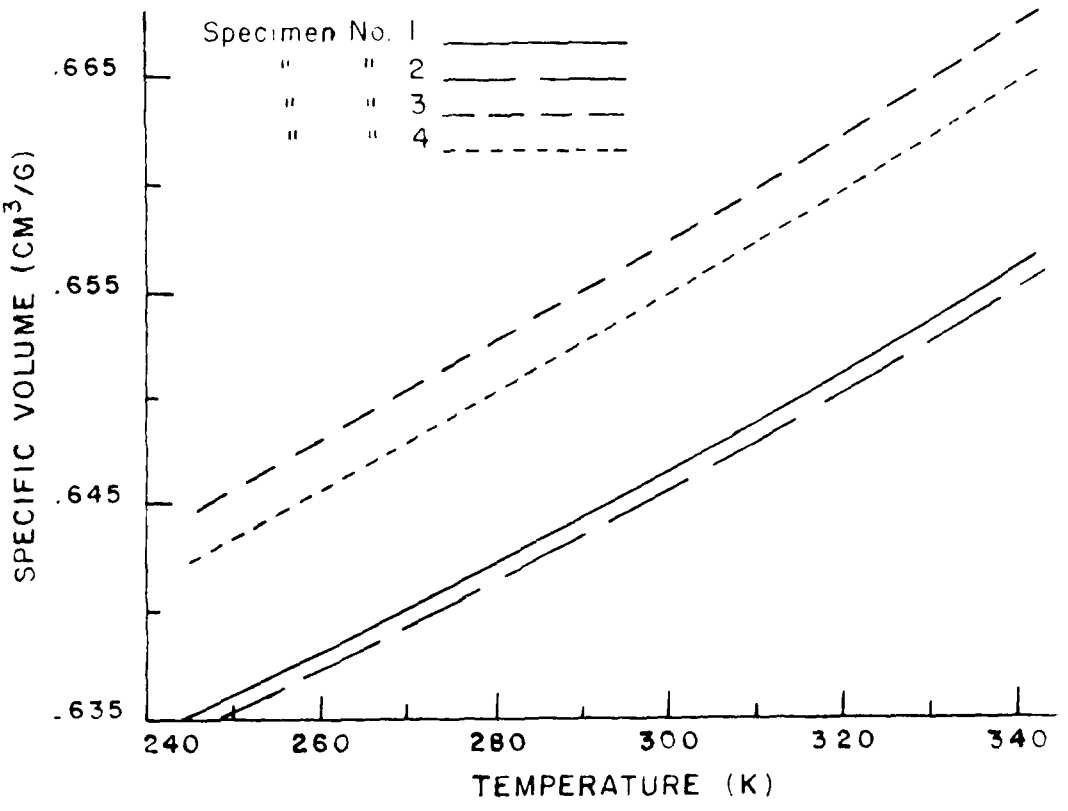


FIGURE 7 - Specific volume of composite explosive, batch No. 1

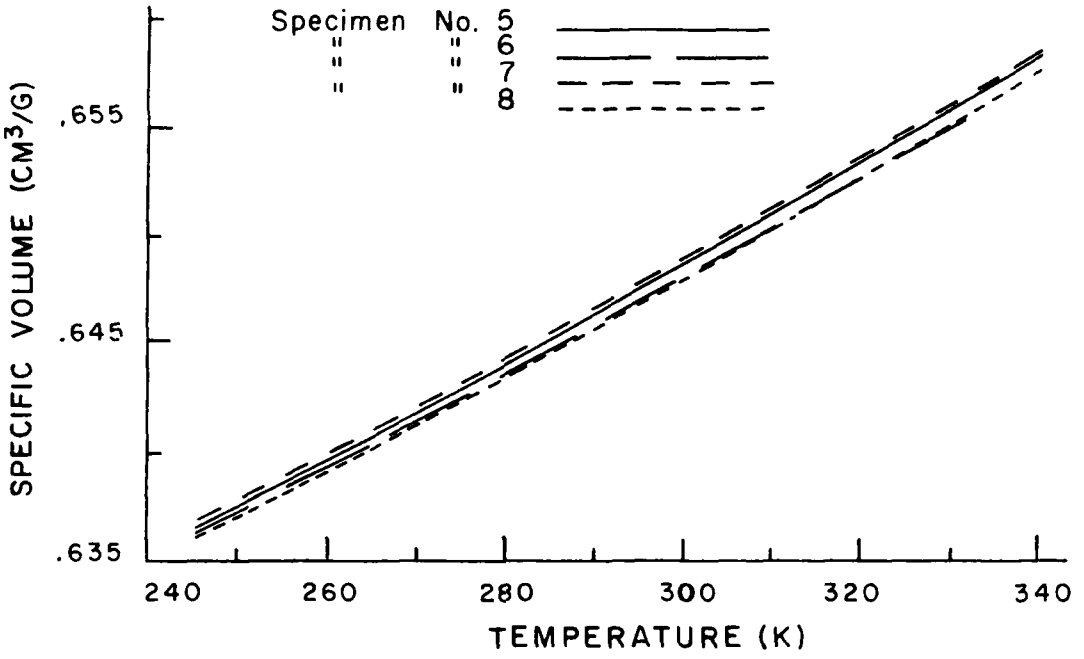


FIGURE 8 - Specific volume of composite explosive, batch No. 2

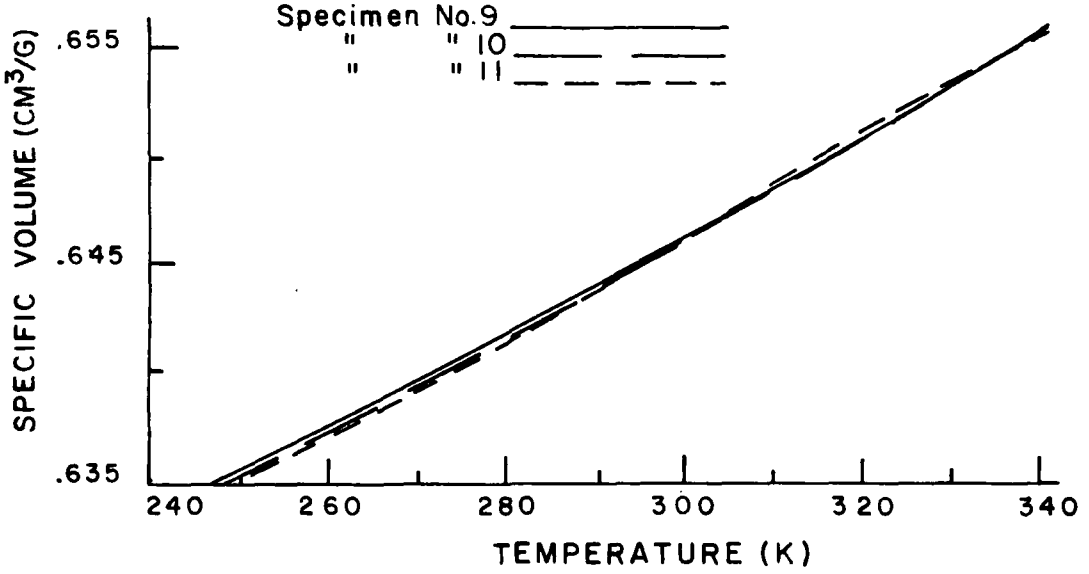


FIGURE 9 - Specific volume of composite explosive, batch No. 3

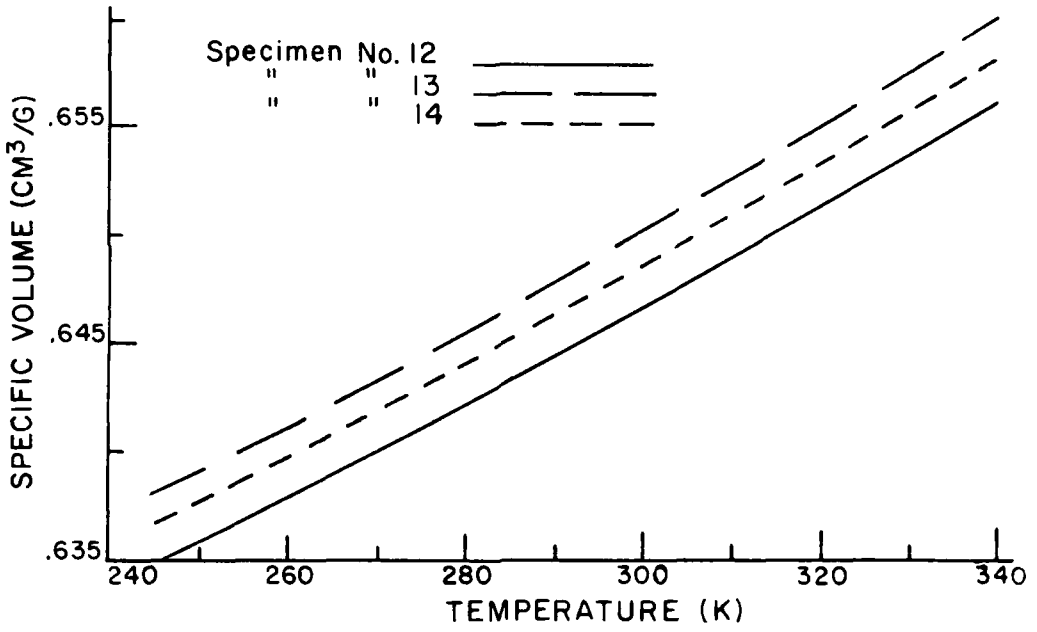


FIGURE 10 - Specific volume of composite explosive, batch No. 4

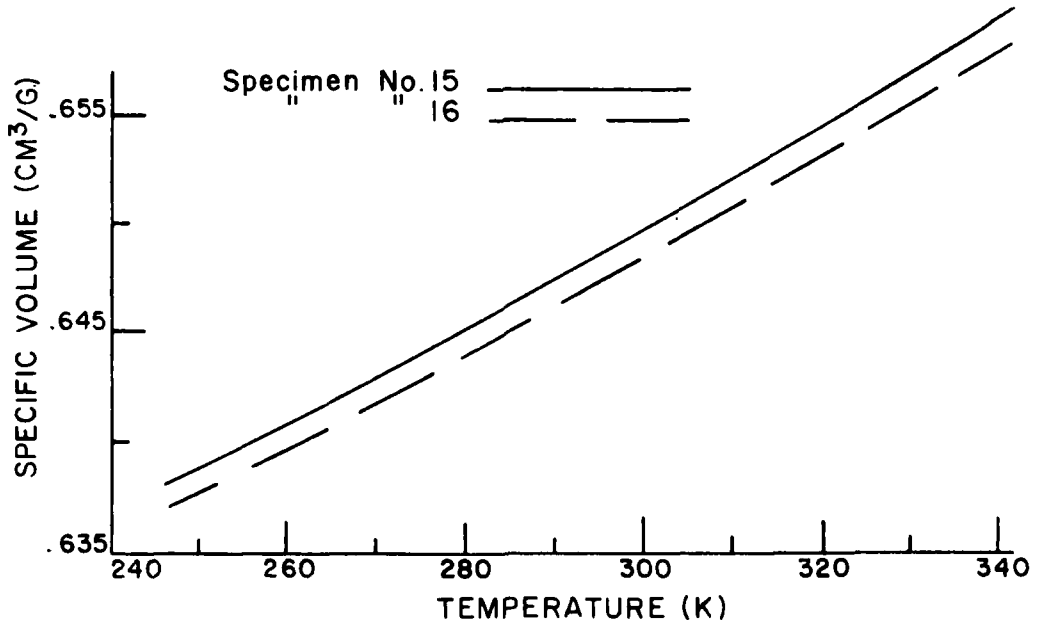


FIGURE 11 - Specific volume of composite explosive, batch No. 5

5.0 CONCLUSIONS

A technique has been developed and applied to the measurement of the specific volume of a composite explosive (RDX/binder-83/17) at temperatures ranging from 248 to 338 K. From these results the coefficient of cubical expansion β can be computed at any intervening temperature or over any range within this interval. At 296 K it was found to have the mean value of 3.57×10^{-4} K^{-1} from 15 separate measurements. A similar technique applied to an aluminum specimen, for which β is known, gave a value about 2.0 percent too large.

The standard deviation of the measurements made on this composite explosive provides some evidence of its good batch-to-batch uniformity. The coefficient of cubical expansion for 15 specimens from five separate batches has a standard deviation of 1.9 percent (0.066×10^{-4} K^{-1}) which is comparable to the values 0.10, 0.06, 0.05, 0.07 and 0.06 x 10^{-4} K^{-1} for intra-batch specimens.

6.0 ACKNOWLEDGEMENTS

Mr. J.G. Mélançon carried out much of the experimental work. Mr. G.R. Walker participated in many technical discussions with the author of an earlier report in French covering this experimental program and had invaluable advice from Mr. G.J. McLaughlin on the statistical analysis presented here; this collaboration led to a number of substantial changes in the final report.

7.0 REFERENCES

1. Drolet, J.F., "Thermal Conductivity of DREV Composite Explosives", DREV TN-1986/71, December 1971, UNCLASSIFIED

2. Christie, F.A. and Drolet, J.F., "Castable Composite Explosives: Evaluation of Thermophysical Properties", DREV TN-2057/73, April 1973, UNCLASSIFIED

3. Pasman, H.J., Walker, G.R. and Matte, Y., "Castable Composite Explosives: Evaluation of Output by the Standard Cylinder Test", DREV R-4094/78, May 1978, UNCLASSIFIED

4. Engineers, Scientists and Metallurgists and Aluminium Company of America, "Aluminium, Properties, Physical Metallurgy and Phase Diagrams", Vol. 1, Edited by Kent R. Von Horn, American Society for Metals, Ohio, 1967

5. Grubbs, Frank, "Sample Criteria for Testing Outlying Observations", Annals of Mathematical Statistics, p. 27, 1950

DREV R-4169/80 (UNCLASSIFIED)

Research and Development Branch, DND, Canada.
DREV, P.O. Box 880, Courcelette, Que. GOA 1RO

"A Castable Composite Explosive: The Coefficient of Cubical Expansion
by C. Bélanger, F. Bedford and A. Ouellet

The volume of a composite explosive (RDX/binder-83/17) has been measured at temperatures from 248 to 338 K using Archimedes' principle. The specimens were covered with a protective film specially developed to prevent the binder from dissolving in the fluid, a silicone oil. From the results the coefficient of cubical expansion of the explosive at 296 K is 3.57×10^{-4} K^{-1} as the mean of 15 measurements having a standard deviation of 0.066×10^{-4} K^{-1}. A similar technique applied to an aluminum specimen whose coefficient is known gave a value about 2.0 percent too large. (U)

DREV R-4169/80 (UNCLASSIFIED)

Research and Development Branch, DND, Canada.
DREV, P.O. Box 880, Courcelette, Que. GOA 1RO

"A Castable Composite Explosive: The Coefficient of Cubical Expansion
by C. Bélanger, F. Bedford and A. Ouellet

The volume of a composite explosive (RDX/binder-83/17) has been measured at temperatures from 248 to 338 K using Archimedes' principle. The specimens were covered with a protective film specially developed to prevent the binder from dissolving in the fluid, a silicone oil. From the results the coefficient of cubical expansion of the explosive at 296 K is 3.57×10^{-4} K^{-1} as the mean of 15 measurements having a standard deviation of 0.066×10^{-4} K^{-1}. A similar technique applied to an aluminum specimen whose coefficient is known gave a value about 2.0 percent too large. (U)

DREV R-4169/80 (UNCLASSIFIED)

Research and Development Branch, DND, Canada.
DREV, P.O. Box 880, Courcelette, Que. GOA 1RO

"A Castable Composite Explosive: The Coefficient of Cubical Expansion
by C. Bélanger, F. Bedford and A. Ouellet

The volume of a composite explosive (RDX/binder-83/17) has been measured at temperatures from 248 to 338 K using Archimedes' principle. The specimens were covered with a protective film specially developed to prevent the binder from dissolving in the fluid, a silicone oil. From the results the coefficient of cubical expansion of the explosive at 296 K is 3.57×10^{-4} K^{-1} as the mean of 15 measurements having a standard deviation of 0.066×10^{-4} K^{-1}. A similar technique applied to an aluminum specimen whose coefficient is known gave a value about 2.0 percent too large. (U)

DREV R-4169/80 (UNCLASSIFIED)

Research and Development Branch, DND, Canada.
DREV, P.O. Box 880, Courcelette, Que. GOA 1RO

"A Castable Composite Explosive: The Coefficient of Cubical Expansion
by C. Bélanger, F. Bedford and A. Ouellet

The volume of a composite explosive (RDX/binder-83/17) has been measured at temperatures from 248 to 338 K using Archimedes' principle. The specimens were covered with a protective film specially developed to prevent the binder from dissolving in the fluid, a silicone oil. From the results the coefficient of cubical expansion of the explosive at 296 K is 3.57×10^{-4} K^{-1} as the mean of 15 measurements having a standard deviation of 0.066×10^{-4} K^{-1}. A similar technique applied to an aluminum specimen whose coefficient is known gave a value about 2.0 percent too large. (U)

CRDV R-4169/80 (NON CLASSIFIE)

Bureau - Recherche et Développement, MDN, Canada.
CRDV, C.P. 880, Courcelette, Qué. G0A 1R0

"Un explosif composite coulable: Coefficient de dilatation cubique"
by C. Bélanger, F. Bedford and A. Ouellet

Le volume d'un échantillon d'explosif composite (RDX/liant-83/17) a été mesuré dans une gamme de températures comprise entre 248 et 338 K en utilisant le principe d'Archimède. Les échantillons étaient enrobés d'un film protecteur développé spécialement pour éviter la dissolution du liant dans l'huile de silicone utilisée comme liquide d'immersion. Les résultats ont montré que la moyenne de 15 mesures du coefficient de dilatation cubique de l'explosif à 296 K est $3.57 \times 10^{-4}\ K^{-1}$ avec un écart type de $0.066 \times 10^{-4}\ K^{-1}$. Une technique similaire appliquée à un échantillon d'aluminium, dont le coefficient est connu, a donné une valeur de 2.0 pour cent supérieure. (NC)

CRDV R-4169/80 (NON CLASSIFIE)

Bureau - Recherche et Développement, MDN, Canada.
CRDV, C.P. 880, Courcelette, Qué. G0A 1R0

"Un explosif composite coulable: Coefficient de dilatation cubique"
by C. Bélanger, F. Bedford and A. Ouellet

Le volume d'un échantillon d'explosif composite (RDX/liant-83/17) a été mesuré dans une gamme de températures comprise entre 248 et 338 K en utilisant le principe d'Archimède. Les échantillons étaient enrobés d'un film protecteur développé spécialement pour éviter la dissolution du liant dans l'huile de silicone utilisée comme liquide d'immersion. Les résultats ont montré que la moyenne de 15 mesures du coefficient de dilatation cubique de l'explosif à 296 K est $3.57 \times 10^{-4}\ K^{-1}$ avec un écart type de $0.066 \times 10^{-4}\ K^{-1}$. Une technique similaire appliquée à un échantillon d'aluminium, dont le coefficient est connu, a donné une valeur de 2.0 pour cent supérieure. (NC)

CRDV R-4169/80 (NON CLASSIFIE)

Bureau - Recherche et Développement, MDN, Canada.
CRDV, C.P. 880, Courcelette, Qué. G0A 1R0

"Un explosif composite coulable: Coefficient de dilatation cubique"
by C. Bélanger, F. Bedford and A. Ouellet

Le volume d'un échantillon d'explosif composite (RDX/liant-83/17) a été mesuré dans une gamme de températures comprise entre 248 et 338 K en utilisant le principe d'Archimède. Les échantillons étaient enrobés d'un film protecteur développé spécialement pour éviter la dissolution du liant dans l'huile de silicone utilisée comme liquide d'immersion. Les résultats ont montré que la moyenne de 15 mesures du coefficient de dilatation cubique de l'explosif à 296 K est $3.57 \times 10^{-4}\ K^{-1}$ avec un écart type de $0.066 \times 10^{-4}\ K^{-1}$. Une technique similaire appliquée à un échantillon d'aluminium, dont le coefficient est connu, a donné une valeur de 2.0 pour cent supérieure. (NC)

CRDV R-4169/80 (NON CLASSIFIE)

Bureau - Recherche et Développement, MDN, Canada.
CRDV, C.P. 880, Courcelette, Qué. G0A 1R0

"Un explosif composite coulable: Coefficient de dilatation cubique"
by C. Bélanger, F. Bedford and A. Ouellet

Le volume d'un échantillon d'explosif composite (RDX/liant-83/17) a été mesuré dans une gamme de températures comprise entre 248 et 338 K en utilisant le principe d'Archimède. Les échantillons étaient enrobés d'un film protecteur développé spécialement pour éviter la dissolution du liant dans l'huile de silicone utilisée comme liquide d'immersion. Les résultats ont montré que la moyenne de 15 mesures du coefficient de dilatation cubique de l'explosif à 296 K est $3.57 \times 10^{-4}\ K^{-1}$ avec un écart type de $0.066 \times 10^{-4}\ K^{-1}$. Une technique similaire appliquée à un échantillon d'aluminium, dont le coefficient est connu, a donné une valeur de 2.0 pour cent supérieure. (NC)


LME