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THE MEASUREMENT OF AREAL DENSITY OF COMPOSITE ARMOR

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ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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13. ABSTRACT

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Details of illustrations in this document may be better studied on microfiche

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THE MEASUREMENT OF AREAL DENSITY OF COMPOSITE ARMOR

ABSTRACT

A technique for measuring the areal density of composite armor (ceramic face and woven roving backup) was investigated. The technique consisted of taking cores of one square inch in area from the ceramic plate and measuring the density by two methods, the dry weight method and water displacement method. The effect of the spall shield on the areal density is discussed, together with various methods of machining the ceramic cores.

INTRODUCTION

With the Army's emphasis on mobility, the use of lightweight armor for personnel, aircraft and vehicles is required. In several applications, ceramic-faced armor meets the protection requirements at the lowest possible weight.

One area which requires improvement for more effective specifications is the measurement of areal density of the composite armor (ceramic face, adhesive, and backup material). The areal density is an expression of the weight carried when the area covered by the armor is known. Lightweight armor is used in weight-critical applications; hence, careful specification of areal density is required. Areal density determinations are critical to (1) effective characterization of the material in terms of ballistic protection which leads to (2) more accurate specifications of requirements.

SPECIMEN PREPARATION AND MACHINING

The method selected for computing the areal density of the armor material consists of taking precision cores from the tile such that the area of the core is one square inch. One of the early problems encountered was in machining the materials to the desired configurations. Four materials were selected for testing: 85% Al_2O_3, a hot-pressed B_4C, a silicon-modified B_4C, and SiC. These materials each have different machining characteristics, and no one technique is adequate for all the selected materials. Initially, a rotary ultrasonic grinding technique was considered, but this technique failed in the penetration of the hot-pressed B_4C. Electrical discharge machining (EDM) was considered next; however, the successful use of this technique is dependent upon the electrical conductivity characteristics of the material being cored. The Al_2O_3 and hot-pressed B_4C are electrical insulators which thereby prohibit the use of EDM on these materials. EDM was very successful in coring the silicon-modified B_4C since the silicon additions enhanced the electrical conductivity of this material. Results of EDM on this material are shown in Figure 1. Diamond core drilling was considered next; however, preliminary investigation revealed that this method would be too costly.

Discussions were then held with representatives of various ceramic suppliers since these organizations are prime suppliers of ceramic materials and have considerable experience in machining these materials. Results of these discussions formed the basis of the machining technique utilized for all the material. This technique consisted of running a Norton SD-120-R100 diamond cutoff wheel at 8000 sfm (surface feet per minute) and feeding the work through at about two ipm. The tile was stripped into sections of one-and-one-half-inch width; these sections were further cut into one-and-one-half-inch squares, and the corners cut off the squares so that an octagon remained. The octagons were then glued together into a stack of 10 specimens and ground circular to the desired diameter of 1.1283 inches. After final grinding, the stack of specimens was heated and the glue dissipated. The

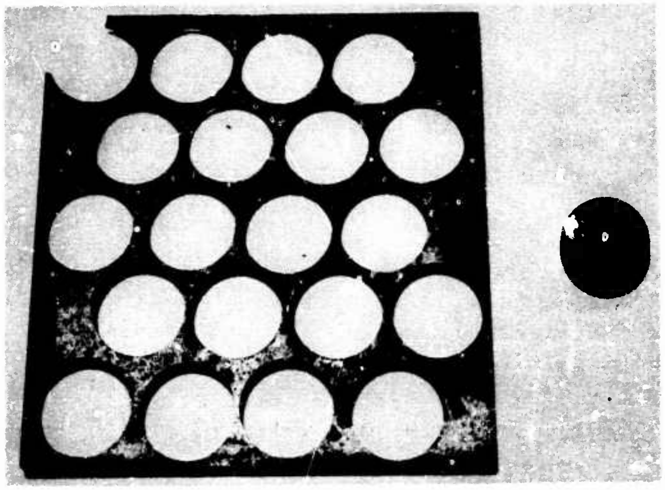

Figure 1. EDM of Si Modified B_4C

progressive steps involved in this operation are shown in Figure 2. The time required to produce a single specimen was computed to be one-half hour; 16 specimens were obtained from each six-by-six-inch tile. This is considered adequate for determining the percent coefficient of variation for the density of the sample population.

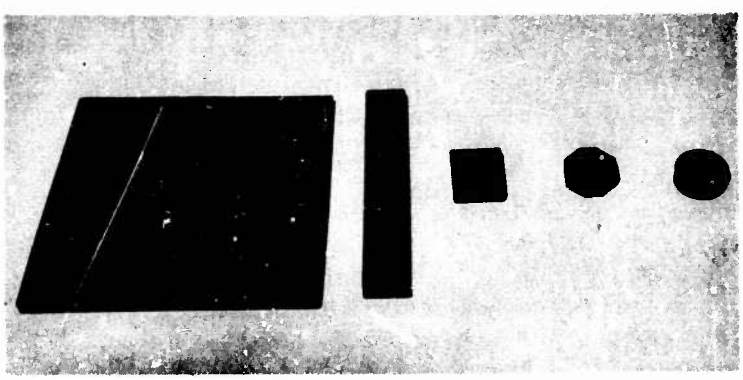

Figure 2. Progressive Steps in Machining Cores

It does not necessarily follow that the circular specimen is the best shape; for instance, a square of one inch on a side would also be adequate, the only requirement being that the specimen to be tested have an area equivalent to unity to simplify the density calculations. The selection of the desirable shape should be the prerogative of the personnel conducting the test; however, grinding a group of specimens into circular shapes was more convenient than grinding squares to the desired area. Additional studies to determine optimum machining techniques are being conducted.

TEST PROCEDURE

After the specimens are machined so that the area is equal to one square inch, the next step is to determine the density of the material. The procedure for determining the density is outlined in the standard form shown in the Appendix. The equipment for measuring density consists of a Mettler Balance (Figure 3) having a digital readout accurate to four decimal places. Readout is in the cgs system.

The process consists of weighing the sample in air, spraying a clear plastic over the sample to prevent water absorption during the displacement measurement, suspending the sample in water as shown in Figure 3, and determining the volume and weight of the sample.

The areal density may be calculated using the specimen dry weight. Since the area is one square inch, the areal density is known and may be converted to the desired area by the appropriate conversion factors. The areal density may also be calculated by converting the density obtained by the water displacement technique to the areal density through the appropriate calculations discussed in the following section.

Figure 3. Test Equipment for Density Measurement

TEST RESULTS

The densities of the individual cores for each material tested are listed in Table I of the Appendix. Standard methods of statistical analysis were utilized in evaluating the data. The specific formulas employed are listed below:

The average value is

$$\overline{X} = \frac{\Sigma X_i}{n} , \qquad (1)$$

where X_i = individual values

n = the total number of values.

The standard deviation is

$$S = \sqrt{\frac{\Sigma (X_i - \overline{X})^2}{n - 1}} \quad , \tag{2}$$

and the percent coefficient of variation is

$$\nu = 100S/\overline{X} \quad . \tag{3}$$

Employing the above formulas, the results are:

85% Al_2O_3	(B) B_4C	(A) B_4C	SiC
$\overline{X}$ = 3.4406 g/cc	$\overline{X}$ = 2.6190 g/cc	$\overline{X}$ = 2.5067 g/cc	$\overline{X}$ = 3.0915 g/cc
S = 0.0085	S = 0.0048	S = 0.0035	S = 0.0366
ν = 0.2480%	ν = 0.1816%	ν = 0.1412%	ν = 1.1833%

It can be seen from the above data that the coefficient of variation of the sample population within the tile is quite small. Minor variations in the density are most likely due to dispersed phases within the material.

The areal density is computed from the above data by the formula, Areal Density = Density x Conversion Factors.

Since the thickness was not measured, it may be calculated from the volume and area of the core specimen. By design, the area is equal to one square inch; therefore, the thickness is numerically equal to the volume of the specimen. The data required for calculating the areal density is known, and a sample calculation follows. Areal density measured of ceramic alone:

85% Al_2O_3

$$A.D. = 3.4406 \frac{g}{cm^3} \times \frac{4.9079 cm^3}{1 \ in^2} \times \frac{1 \ lb}{453.6 g} \times \frac{144 \ in^2}{1 \ ft^2}$$

A.D. = 5.3607 psf

(B) B_4C

$$A.D. = 2.6190 \frac{g}{cm^3} \times \frac{5.2984 cm^3}{1 \ in^2} \times \frac{1 \ lb}{453.6 g} \times \frac{144 \ in^2}{1 \ ft^2}$$

A.D. = 4.4052 psf

(A) B_4C

$$A.D. = 2.5067\ \frac{g}{cm^3} \times \frac{4.7989 cm^3}{1\ in^2} \times \frac{1\ lb}{453.6 g} \times \frac{144\ in^2}{1\ ft^2}$$

A.D. = 3.8189 psf

SiC

$$A.D. = 3.0915\ \frac{g}{cm^3} \times \frac{5.6672 cm^3}{1\ in^2} \times \frac{1\ lb}{453.6 g} \times \frac{144\ in^2}{1\ ft^2}$$

A.D. = 5.5620 psf

Composite Armor of SiC + 1/4-inch woven roving GRP

$$A.D. = 2.6143\ \frac{g}{cm^3} \times \frac{9.8339 cm^3}{1\ in^2} \times \frac{1\ lb}{453.6 g} \times \frac{144\ in^2}{1\ ft^2}$$

A.D. = 8.1615 psf

The areal density at any location of any configuration may be obtained by using the last two calculations on the density measurement sheet, i.e., H and I, volume and density. It is therefore possible to obtain a random sampling of areal density for quality assurance purposes.

Whether or not the spall shield should or should not be included in the areal densities was also considered. A nylon spall shield was added to each of the 14 silicon carbides plus woven roving GRP backup specimens. The results are reported in Table II of the Appendix. The mean value of the areal density of the composite armor is 8.235 psf. This was determined by using two techniques.

The measurement of areal density with spall shield can be accomplished by either the dry or water displacement technique. Care must be exercised in applying the spall shield so that the cement makes a good bond. This prevents air from being trapped between the armor and spall shield during water displacement measurements. Thus, there is no difference in the areal density measured by either the dry or water displacement technique in the measurements made above.

Measuring the areal density of the silicon carbide armor and woven roving GRP produced an areal density of 8.162 psf; the areal density of the nylon spall shield measured 0.111 psf. If this value is added to the composite armor, 8.162 + 0.111 = 8.273 psf is the result. This result is well within a standard deviation of 0.057 psf.

From the foregoing it may be concluded that measuring the areal density by either technique, with or without the spall shield, will give satisfactory results.

SUMMARY

A technique has been developed for measuring the areal density of armor plate. This technique consists of taking cores from the material so that the area of the core is precisely one square inch. The volume and density of the sample are determined by the water displacement method utilizing a digital readout balance accurate to the fourth decimal place.

This technique eliminates the necessity for taking physical measurements of the thickness of the sample, since the sample thickness is equivalent to volume/area with the area being in effect unity; the thickness is therefore numerically equal to the volume of the sample. Machining and testing of each sample requires approximately 45 minutes when the machining is accomplished in groups of 10 specimens.

The areal density is computed from the data by

$$\text{Areal Density} = \text{Density (g/cc)} \times \frac{\text{volume (cc)}}{\text{area (in)}^2} \times \frac{1\ \text{lb}}{453.6\text{g}} \times \frac{144\ \text{in}^2}{1\ \text{ft}^2} .$$

Addition of the nylon spall shield plus adhesive adds approximately 0.111 psf to the areal density. This may be added to the areal density of ceramic face plus woven roving GRP backup material to arrive at the areal density of the total system. This compares quite favorably to taking areal densities of the complete package by the dry or water displacement techniques.