Y/DW-1661

Y-12

OAK RIDGE
Y-12
PLANT

LOCKHEED MARTIN

MECHANICAL PROPERTIES OF A LOW DENSITY CONCRETE FOR THE NEW ES-2 SHIPPING/STORAGE CONTAINER INSULATION, IMPACT MITIGATION MEDIA AND NEUTRON ABSORBER

Raymon E. Oakes, Jr.
Development Division
Oak Ridge Y-12 Plant

April 10, 1997

LOCKHEED MARTIN

This document has been reviewed by a Y-12 DC/UCNI-RO and has been determined to be UNCLASSIFIED and contains no UCNI. This review does not constitute clearance for Public Release.

Name: Stan Thomas **Date:** 09/23/09

Prepared by the
Oak Ridge Y-12 Plant
Oak Ridge, Tennessee 37831
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.,
for the
U.S. DEPARTMENT OF ENERGY
Under contract DE-AC05-84OR21400

MANAGED BY
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

INTRODUCTION

The design, analysis and testing of new Shipping/Storage container design for enriched uranium, labeled ES-2, is underway at the Oak Ridge Y-12 Plant. To assure greater containment during an accidental impact or fire, a better insulating/energy-absorbing material is being sought for the outermost filler. A replacement for the presently used Celotex$^{(R)}$, a low density wood product, and plywood is desirable. A more fire retardant material with otherwise equal or better impact energy and neutron absorption is being sought.

Kaolite$^{(R)}$ 1600, a castable Portland cement-based product by Thermal Ceramics, contains vermiculite (expanded mica) instead of gravel or other high density aggregates. It is a low density, high temperature insulating material with non-recoverable impact energy absorption capabilities. The major components of Kaolite 1600 according to the manufacturers Product Information sheet are:

Alumina	Al_2O_3	9.6%
Silica	SiO_2	31.5%
Ferric Oxide	Fe_2O_3	6.7%
Titanium Oxide	TiO_2	1.0%
Calcium Oxide	CaO	29.8%
Magnesium Oxide	MgO	11.9%
Alkalies,as	Na_2O	1.8%

The purpose of this work is to quantify the mechanical properties of this product for a variety of thermal cures, test temperatures and neutron absorbing additives in a form useable for data input for finite element analysis of a variety of potential accident scenarios.

EXPERIMENTAL WORK

Test Types_ Four properties tests are conducted on the Kaolite 1600 material, Flexural Tensile Strength, Unconstrained Compressive Strength, Constrained Compressive Strength and Density.

All specimens are cast in containers the shape of the desired specimen. The vendors wet mix ratio of water/Kaolite, 36 quarts water to 50 lb Kaolite 1600 is used exclusively (473 cc water/315 g Kaolite used in laboratory size specimens). After mixing and packing in the molds, mild impacts from a plastic hammer against the mold sides are made until air bubbles ceased to rise to the top.

An electrically heated, liquid nitrogen cooled convection oven with +/-2EF control is used for elevated temperature cures and testing.

Tensile Strength_ Nine tensile strength values are obtained from cast and tested quarter-point, four-point bend specimens, 1 in wide x 1 in high x 8 in long. Each are tested over a 6-in support span and 3-in compression span, having the following very low outer fiber tensile strength and density:

average tensile strength = 19.4 psi, standard deviation 4.7 psi, and
average density = 21.2 lb/ft^3, standard deviation 1.0 lb/ft^3.

Low tensile strengths should not be detrimental in this application where the predominate failure mode is constrained compression.

Cure for the tensile specimens is 24 hr at 72EF plus 24 hr at 220EF, high enough to drive off free water but retain the water of hydration. Water of hydration is loosely bound to a number of cement components and can be driven off at elevated temperatures either by using elevated temperature curing or could occur in a hypothetical long term fire environment.

Unconstrained Compressive Strength_ Unconstrained or uniaxial compression test specimens are molded, cured and tested in 3-in diam polyurethane coated paper mailing tubes cut to 6-in heights with one end sealed. The cure is 24 hr at 72EF + 24 hr at 220EF. The tubes are thin and weak enough to add little strength to the specimen. Figure 1 shows the stress-strain curves and initial densities for three tests each at different test rates, including impact conditions (200 in/s). The increased strength values of the two highest test rates probably result from air entrapment in the cells. Also shown is the minor strength contribution of an empty paper mold.

Three deformation stages are associated with compression of low density materials containing voids (vermiculite is considered to be a void as well as any remaining air entrapments). First, the matrix surrounding the voids buckles, shown as the steep initial portion of the curves in Figure 1. The buckling stage is followed by a large strain region of compaction with minor stiffness increase. In the unconstrained compression tests large-scale shear failures occur across the sample prior to full compaction. Specimen buckling and gross shear failures forced the tests to be terminated. Constrained compression tests will show the steeper rise of more densified material.

Figure 2 is the integrated area under each of the three stress-strain curves of Figure 1, the cumulative work or energy per unit volume absorbed by the material as a function of strain.

Constrained, Hydrostatic Compression Tests_ Constrained compression tests simulate the deformation mode of accident conditions in the material as it is used in the ES-2 container. The material is constrained by filling the outer stainless steel drum. In the event of an accident the inner container and its contents must remain intact. In the absence of vacant volume compaction or hydrostatic compression is the only deformation mode available. Laboratory simulations require compressing a specimen in a rigid, tight closed-ended cylinder with a tight fitting piston. A 20k pound testing machine loads the piston. The cylinders are four-inch ID thick-walled pipe and the specimens are cast, cured and tested in the cylinder. The specimen height is 4.5 in.

This test is used to provide primary input to the Finite Element Analysis as well as a relevant means to evaluate repeatability, cures , test temperature and additive effects on properties.

Note that percent compressive strain and percent volume change values are equivalent for all constrained compression tests.

Repeatability The five stress-strain curves of Figure 3 represent material cured for 24 hr at 72EF + 24 hr at 220EF + 48 hr at 500EF. Each specimen is individually mixed and cast. Initial measured densities are shown for each specimen. Repeatability of density and the stress-strain curves are good for this type material. Note the three stages of deformation, cell buckling , densification and the beginning of compression of densified material are present. Load limitations of the test machine prevent reaching full compaction, a near vertical rise in the curve.

Cure Effects Both cure time and temperature have major effects on the constrained compressive properties of Kaolite 1600, Figures 4 and 5. Cures at higher temperatures and/or longer cure times remove the most water as noted by decreasing density. Material strength increases in proportion to the degree of water loss. Cure time/temperature would be volume dependent so these cures may only represent the limiting cure for the much larger ES-2 container.

Test Temperature Effects Decreasing test temperature in well cured specimens, Figures 6 and 7, lowers both strength and energy absorption only slightly.

Neutron Absorbing Additives_ Residual water, free or as hydrates, is the primary neutron absorber in Kaolite. Adequate water or other neutron absorber must be present before, during and after all ES-2 container accident scenarios. The 500EF cure should eliminate most of the free water and part of the water of hydration, at least in specimen sized lots where equilibrium temperatures are reached throughout the material. Higher temperatures are required to release all the water of hydration of two of the basic Portland cement components:

$$\begin{array}{ll} Fe_2O_3\cdot xH_2O & (660\text{-}750^0F) \\ CaO_2\cdot 8H_2O & (400^0F)\,. \end{array}$$

These hydrates during curing actually form very complex and unique hydrates. The disassociation temperatures for these complex hydrates are unique for each cement formulation and are unknown for Kaolite 1600. One requirement for the ES-2 container is survival in a fire environment of 1470EF for 0.5 hr without loss of seal of the inner container. Certainly loss of criticality protection must be assured in the same scenario.

Measured Kaolite densities cast and cured in ES-2 containers is about 29 lb/ft^3 when cured at 200EF for 48 hr. followed by 500EF for 48 hr. This is much higher than 21-22 lb/ft^3 in similarly cured laboratory samples, indicating either considerable residual water is retained in the ES-2 containers or large differences in compaction exist or both. Under long term fire conditions the amount of residual water and its distribution throughout the container is unknown.

Boron is a nonvolatile neutron absorber available in numerous chemical forms. Two forms, borax ($Na_2B_4O_7.10H_2O$) and boron carbide (B_4C), are investigated as potential neutron absorbers. The required amount according to criticality calculations is 2.5% natural boron. Weight percentages of 11.3% borax or 3.0% boron carbide meet this requirement. Note that natural boron implies the isotopic ratio found in nature. Not all boron in the market meets this criteria.

Figure 8 and 9 show that borax degrades both the strength and energy absorption an unacceptable amount. Due to the high molecular weight of borax the amount of material needed to provide adequate boron is excessive.

Unlike borax, boron carbide is predominately boron and Figures 8 and 9 show that the needed amount and even double the needed amount does not degrade the Kaolite and would be an acceptable, nonvolatile neutron absorbing additive.

Bibliography

(1) *Handbook of Chemistry and Physics*, 60th Edition, Robert C. Weast, ed., CRC Press, Inc., Boca Raton, Florida 33431.

(2) *Concrete Admixtures Handbook, Properties, Science , and Technology*, V. S. Ramachandran, ed., Noyes Publications, Park Ridge, New Jersey.

Ka16fig1.xlc

Figure 1_Kaolite 1600 Compressive Stress-Strain vs Strain Rate

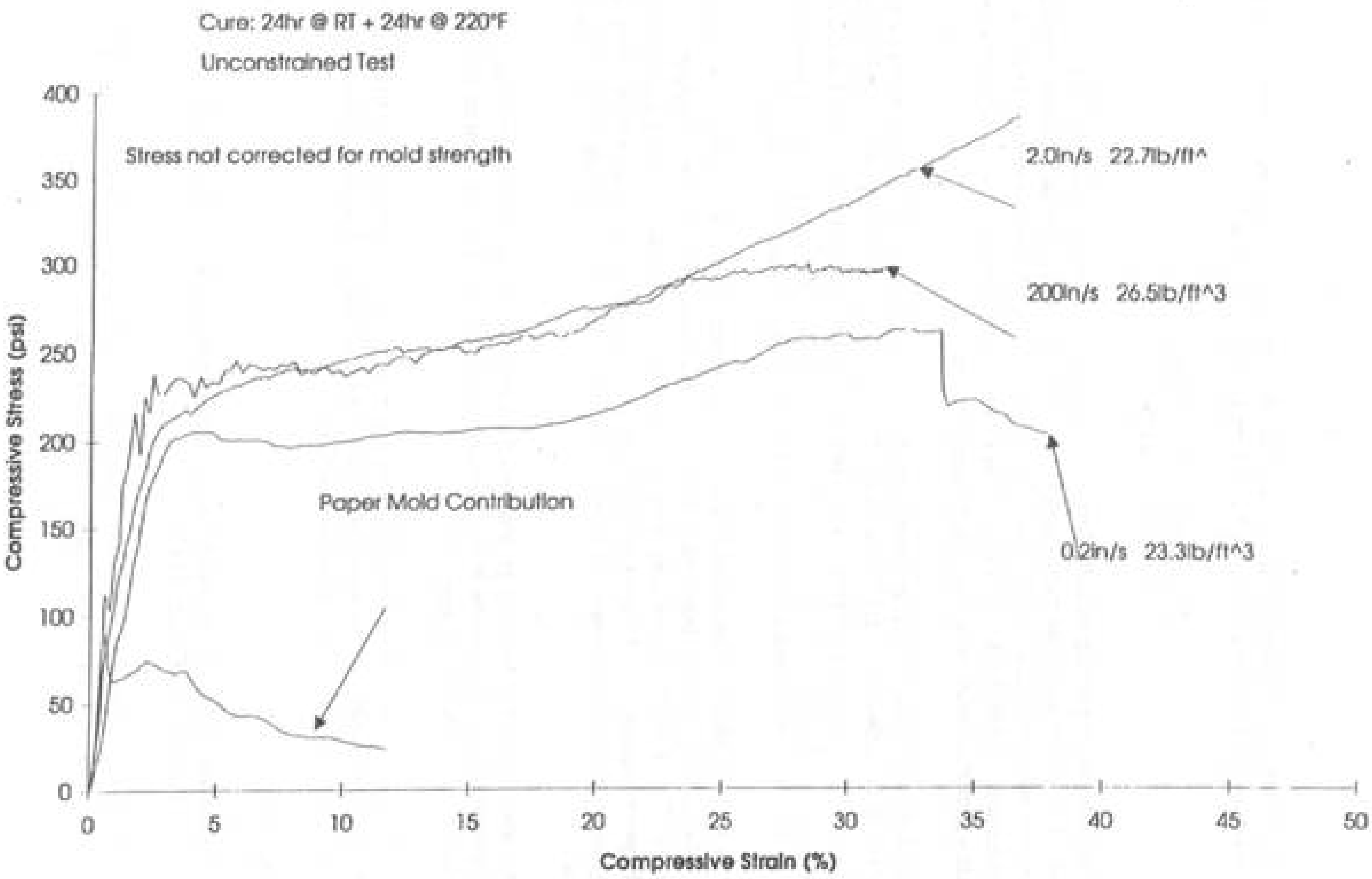
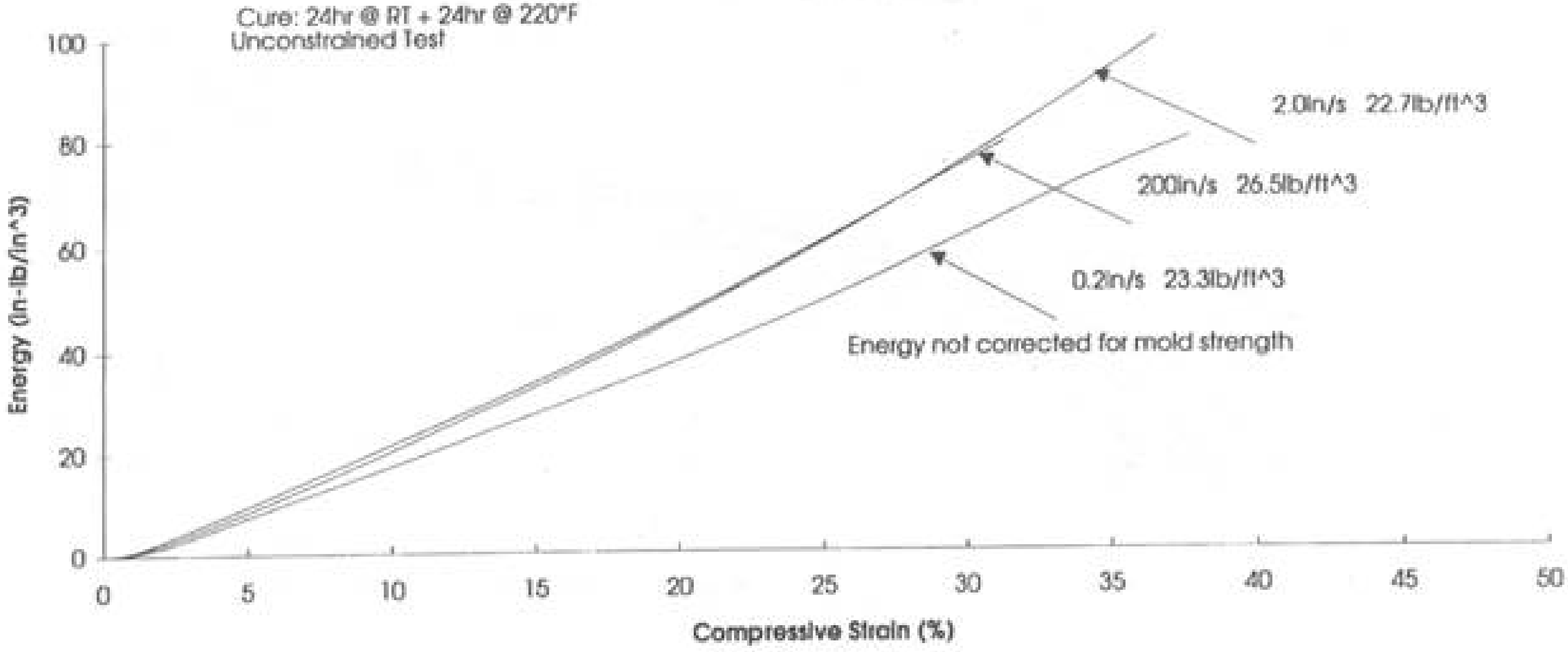
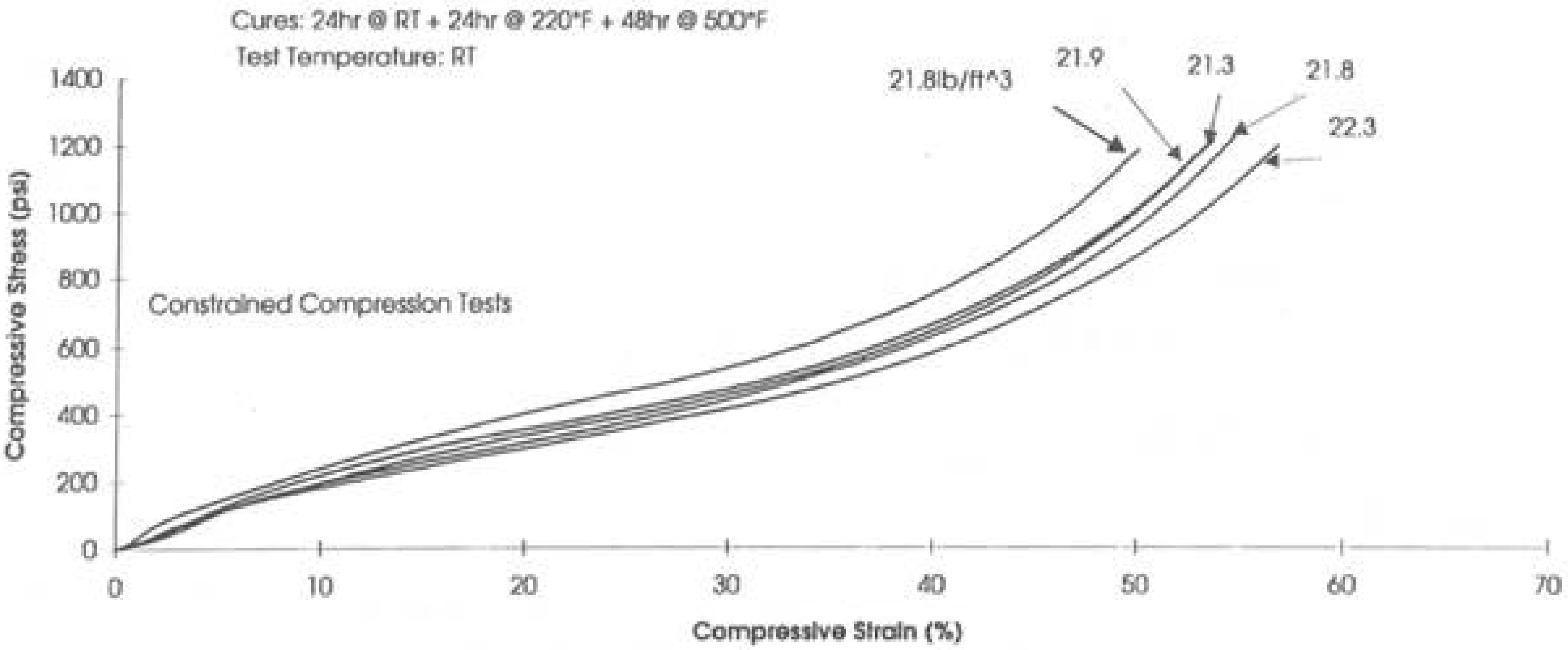


Figure 2_Kaolite 1600 Energy/Unit Volume vs Strain and Strain Rate



Ka16fig3.xlc

Figure 3_Kaolite 1600 Stress-Strain Curves, Repeatability Tests



Cures: 24hr @ RT + 24hr @ 220°F + 48hr @ 500°F
Test Temperature: RT

Constrained Compression Tests

Figure 4_Kaolite 1600 Stress-Strain Curves for Different Cures

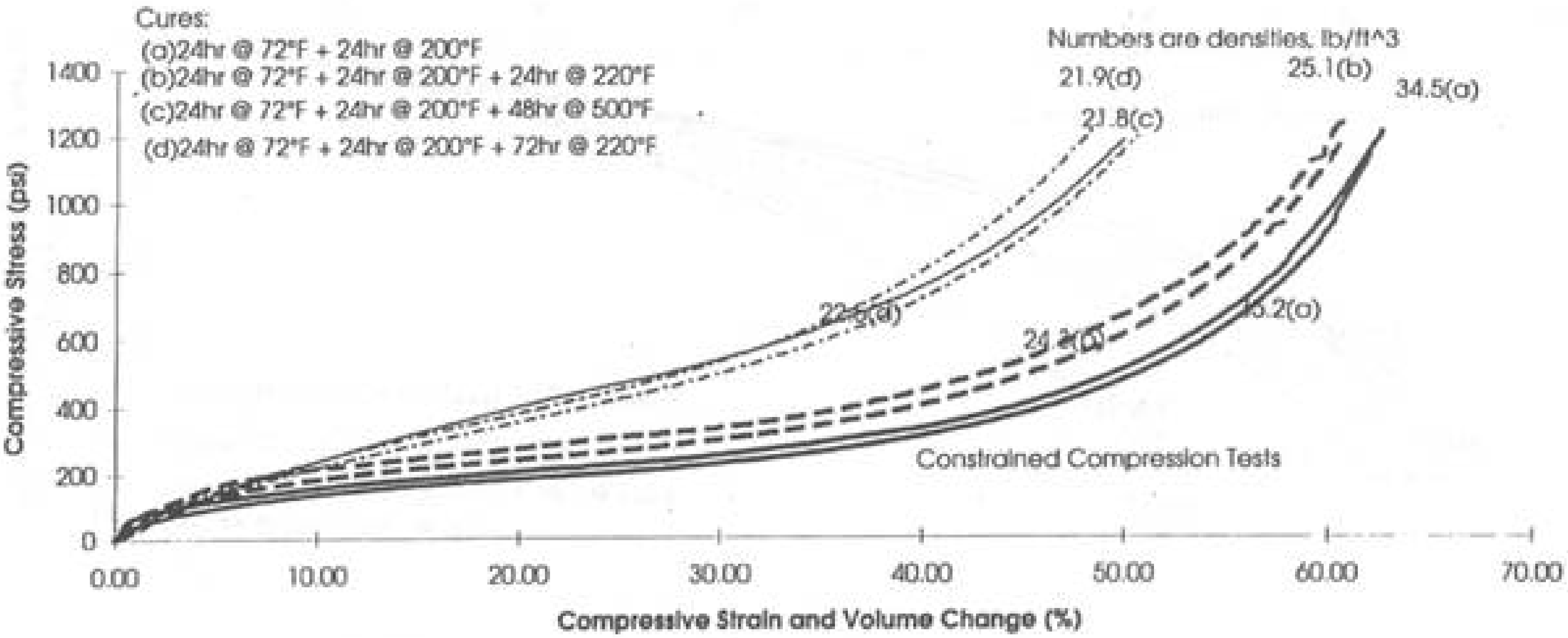


Figure 5_Kaolite 1600 Energy-Strain Curves for Different Cures

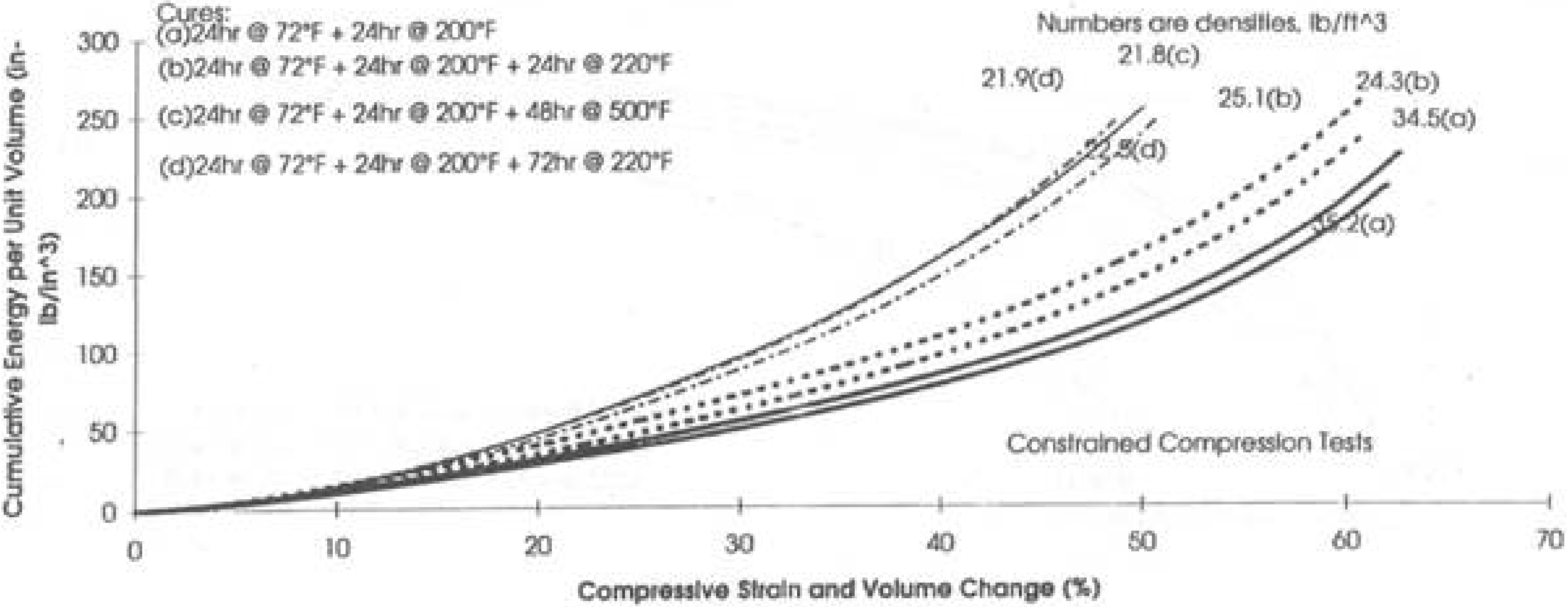


Figure 6_Kaolite 1600 Stress-Strain Curves for Different Test Temperatures

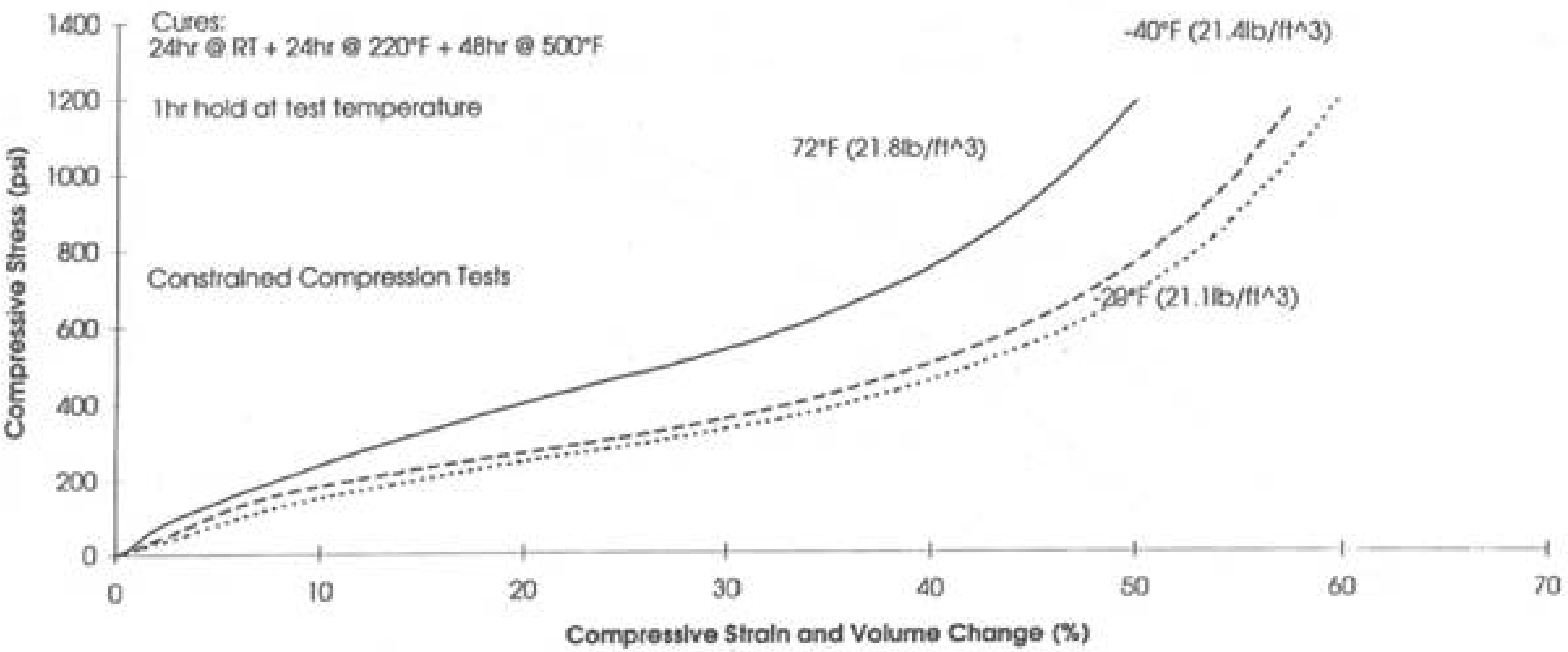


Figure 7_Kaolite 1600 Energy-Strain Curves for Different Test Temperatures