TECHNICAL REPORT

68-46-AD

SILICATE FOAM FOR AIRDROP CUSHIONING

by

E. Jack Baker, Jr. & William A. Mallow

Southwest Research Institute

San Antonio, Texas

Contract No. DAAG17-67-C-0114

May [illegible]

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Airdrop Engineering Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

FOREWORD

This work was performed during the period March 1967 to March 1968 under U. S. Army Natick Laboratories Contract No. DAAG 17-67-C-0114. The Department of Army Project No. is 1F121401D195 entitled "Exploratory Development of Airdrop Systems, Task 13 Impact Phenomena."

The program is part of continuing investigations directed toward obtaining an improved, low-cost, expendable material for mitigating ground impact shock on Army materiel delivered by parachute from an aircraft in flight.

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ABSTRACT

Sodium silicate foam was proposed as a possible substitute for paper honeycomb as an airdrop cushion. Experimental efforts to implement silicate foam panels using a 2-kilowatt microwave energy source proved inadequate. Larger energy input with a more uniform flux appeared to be necessary to accommodate the size of panels desired.

A sodium silicate/perlite aggregate formulation was found to fulfill most of the product specifications. Areas for improvement include collapsed to expanded ratio, maximum strain level, rectangularity of stress-strain curve, product density and friability.

The silicate/perlite formulation and foamed sodium silicate formulations allow a wide latitude of variation and control. It is believed that optimization of formulation and heating equipment can be realized.

SILICATE FOAM FOR AIRDROP CUSHIONING

I. Introduction

This report covers the work performed by Southwest Research Institute and includes the results of laboratory evaluations conducted by SwRI personnel and the dynamic test results performed at the U. S. Army Natick Laboratories on sodium silicate airdrop cushioning materials. The purpose of this project was to study the feasibility of using sodium silicate foam as an energy absorbing airdrop cushioning material.

Many different materials have been evaluated for the ability to absorb kinetic energy of an object that is airdropped using parachutes. In practice, this energy is absorbed by the cushioning material that is permanently deformed during impact. As a result, these cushions are considered single-shot energy absorbers. The prime purpose of the cushioning material is to offer a reduced deceleration to the package which has been airdropped. The energy absorbed is three to ten times greater for an airdrop load than for typical transportation shocks. This increased energy is usually absorbed by having a large deflection of the cushioning material rather than increasing the unit load.

For an airdrop cushion to be an effective energy dissipater, it must have a number of desired characteristics. Among these characteristics are the following:

a. Capable of being stored and shipped in the collapsed state for economy in storage and shipment; a minimum ratio of 1 to 15 collapsed to expanded volume is desired.

b. Capable of withstanding temperature extremes of -65°F to +125°F in storage and use, and unaffected by direct contact with water.

c. Provide an approximately rectangular force-deformation curve to 80% deformation when force is dynamically applied at initial impact velocities ranging from 20 fps to 90 fps.

d. Average crushing force under condition c. above should be 6300 psf + 10%.

e. Capable of being easily prepared and used in the field with a minimum of auxiliary equipment and personnel.

f. Limit rebound energy, or resilience, to less than 5% of total energy dissipated to 80% deformation.

g. Limit cost of dissipater material to less than $0.15/1,000 ft lb of energy dissipated.

h. The material and supporting supplies shall not possess explosive, mechanical, biological, toxicological, or electromagnetic radiation effects which could be hazardous from a health or safety standpoint to using personnel.

The material presently being used for the airdrop cushions is paper honeycomb. As a possible alternative to the paper honeycomb material, Southwest Research Institute proposed the use of sodium silicate foam as an airdrop cushion after working with this material for several years. Silicate foam has many attractive features, among which are: low cost, ready availability of raw materials, ease of handling, nontoxicity and nonflammable characteristic.

The mechanism by which liquid sodium silicate, or water glass, is foamed is as follows: Sodium silicate is approximately 40% solids and 60% water by weight. If the solution is heated to the boiling point, the water is driven off. When a sufficient amount of heat is applied to the liquid, rapid boiling occurs. When approximately 10% of the original water is left in the solution, a viscous solution is obtained. As this small amount of remaining water attempts to leave the sodium silicate solution, the viscosity of the solution is high enough that a part of it expands and thus forms a foamlike matrix. This expanded volume can reach a level 10 to 15 times the original volume.

The resulting foam has a very low thermal-conductivity; as a result, it has been found that great difficulty arises when attempting to fabricate thick foam sections by use of conventional heating methods. However, we have discovered that microwave heating is a very efficient and economical method of fabricating foam sections in virtually any thickness. Because microwave heating operates by exciting the water molecule in the solution, it therefore operates without regard of the distance from the wall of the containing vessel. During the program, the only sodium silicate used had a ratio of 3.22 silica to 1.00 sodium oxide.

II. Use of Sodium Silicate as an Airdrop Cushioning Material

Initially, the sodium silicate panels were produced in 6 × 6 × 1-in. gypsum board molds using a 2-kilowatt microwave oven. These panels were tested using an Instron testing machine. The load-deformation curve obtained from the Instron testing machine at a deformation rate of 20 in. per min indicated that regular sodium silicate foam did not have the required strength for the airdrop cushion. Therefore, several additives were compounded with sodium silicate to increase its compressive strength.

In addition to the static compression tests that were conducted at SwRI, a dynamic drop test was performed. The SwRI dead-weight drop tester consists of a 60-lb weight that was dropped 14 ft. The impact velocity was 30 ft/sec. Therefore, the kinetic energy of the hammer just before impact was 840 ft-lb. Since the desired energy absorption of the foam is approximately 4410 ft-lb/ft^3, the required volume to absorb the 840 ft-lb of energy would be 0.19 ft^3. This volume was used on each of the SwRI tests.

There was no instrumentation on the SwRI deadweight drop tester; so the tests were used to obtain a visual indication of the ability of the given foam formulation to absorb the kinetic energy of the drop hammer. The results of these dynamic tests as well as the static tests on several foam formulations are shown in Tables I through IV of the Appendix.

Like most rigid foams, sodium silicate foams exhibited some blowout of the foam on impact. This blowout, or explosion of the foam, is caused by the compression of the trapped air in the cells and insufficient mechanical strength of the cell walls to withstand the increased pressure. In order to overcome this tendency to explode on impact, some plasticizers, such as powdered polyethylene and Elvax* were added to the sodium silicate solution before foaming.

Both the powdered polyethylene and the Elvax waxes reduced the blowout of the foam panels when impacted. Due to the lower cost of powdered polyethylene, this plasticizer was selected for additional evaluation with the 16 × 18 × 3-in. foam panels.

The larger panels were fabricated using gypsum-board molds and the 2-kilowatt microwave oven. Some difficulty was encountered in producing a completely uniform 16 × 18 × 3-in. panel. The surface of these panels had many irregularities. In some areas of the panel, the mold was completely filled, and, in other areas, the mold was either under-filled or over-filled. Other complications involved rather large, up to 3-in. diameter, blow holes that formed in the panels during fabrication.

*Trademark for a series of ethylene/vinyl acetate copolymers.

Both of these problems were traced to nonuniform flux distribution in the microwave oven. The under-filled section of the mold was receiving very little heat, and the sections that were over-filled in which blow holes formed, received excessive amounts of heat. These difficulties were overcome by periodic rotation of the mold during the heating cycle.

Samples containing 90% sodium silicate and 10% powdered polyethylene were prepared in the 16 × 18 × 3-in. mold. These panels were taken to the University of Texas, Balcones Research Laboratory, for dynamic test. The University of Texas drop-test fixture was built for the U. S. Army Natick Laboratories under contract, and has been used to evaluate paper honeycomb and several other potential airdrop cushioning materials.

The drop fixture consists of a 561-lb weight that is guided on each corner. An accelerometer is mounted on the weight. The weight is lifted 9.1 ft and allowed to drop. The maximum velocity is approximately 24 ft/sec. Approximately 12 in. above the bottom of the test fixture, a slide wire is contacted by a pickup that is mounted on the 561-lb weight. The output from the slide wire is displayed as the abscissa, and the output from the accelerometer is displayed as the ordinate on an x-y oscilloscope. A photograph of the trace is taken during the test then, with the proper calibration factors, the load-deformation curve can be obtained.

The results of these initial dynamic tests at the University of Texas indicated that the foamed sodium silicate began to fail at approximately 3000 psf. The unit load increased linearly up to about 10,000 psf at 70% deformation. This shaped curve was not the rectangular profile desired.

An attempt was made to reduce the time required to fabricate the large foam panels in the microwave oven. A search for a larger microwave oven in the San Antonio area was unsuccessful. Next, an attempt was made to predry the liquid solution before placing it in the molds and microwave oven. This predrying process was accomplished by spraying the sodium silicate solution in thin layers on polyethylene sheets. These thin layers of solution dried rapidly, and the material was placed into the molds in this predried state. The amount of time to foam the material in the microwave oven was reduced from 2 to 3 to 3/4 of an hr. The large foam panels were still poorly expanded, had large convolutions, and were generally unattractive.

A number of the 6 × 6 × 1-in. smaller panels were fabricated and bonded to make one large 16 × 18 × 3-in. panel. This proved to be very slow, laborious, and ineffectual since a large percent of the volume of the large panel was occupied by the adhesive. Therefore, this effort was abandoned because it was felt that the results of a sample made from many smaller samples bonded together would not be representative of a panel fabricated in a single pass.

Alternate paths involving extending the sodium silicate with inert, low density materials, such as perlite, vermiculite, fiberglass, excelsior, cotton linters, hemp jute cuttings, and several others were investigated. Of these, perlite and vermiculite offered the most promise. We fabricated eight panels of sodium silicate/perlite and two panels of sodium silicate/vermiculite that measured 16 × 18 × 3 in. and shipped them to Natick Laboratories for dynamic test and evaluation. The formulation of these was the following:

Sodium Silicate/Perlite

Sodium Silicate	59%
Perlite	41%

Density = 18-20 lb/ft^3

Sodium Silicate/Vermiculite

Sodium Silicate	64%
Vermiculite	36%

Density = 18-20 lb/ft^3

The sodium silicate and perlite or vermiculite were mixed together in a large container. Then, enough of the mixture to fill the 16 × 18 × 3-in. mold was loosely packed into the large gypsum-board mold. The mold was then placed in the microwave oven for 30 min. The panel was then removed from the mold, and another panel was fabricated in like manner.

The results of the sodium silicate/perlite tests conducted at Natick Laboratories 25 October 1967 are shown in Figure 1. The data indicated an initial stress of 45,000 to 55,000 psf within the first 10% of the deflection. Then, the unit stress rapidly reduced to approximately 10,000 psf and the stress increased to 25,000 to 30,000 psf at about 50% strain.

The results of the sodium silicate/vermiculite also conducted on 25 October 1967 are shown in Figure 2. The stress slowly increased to approximately 20,000 psf at about 25% deflection. The tabulated results for these tests are shown in Table I on page 8.

These test results indicated that the average unit loading, or stress level, was three to four times higher on the average than the desired level. These tests also indicated that the initial onset of failure of the panels was

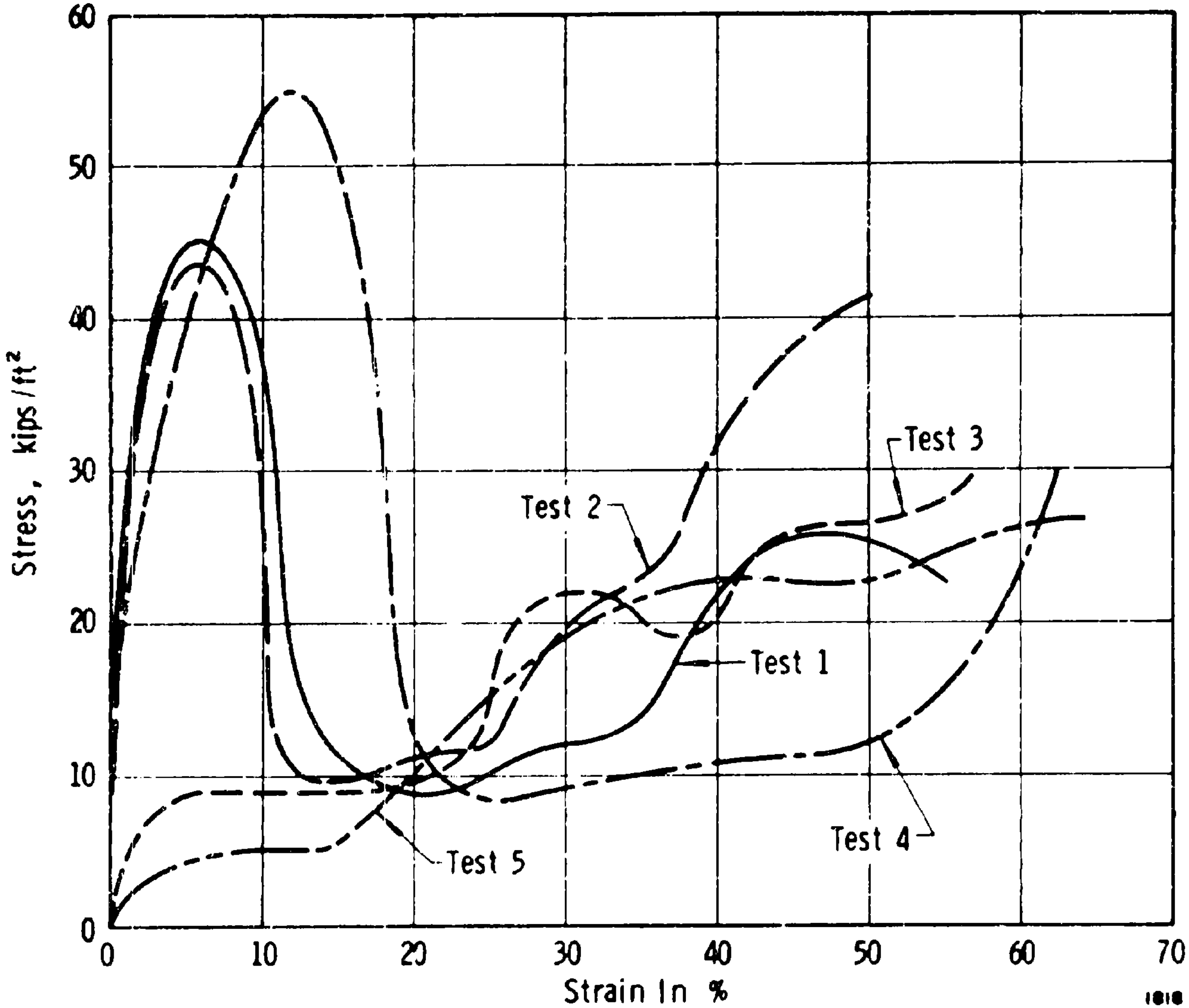

Figure 1. Sodium Silicate/Perlite Test Data
NLAB 25 Oct 1967

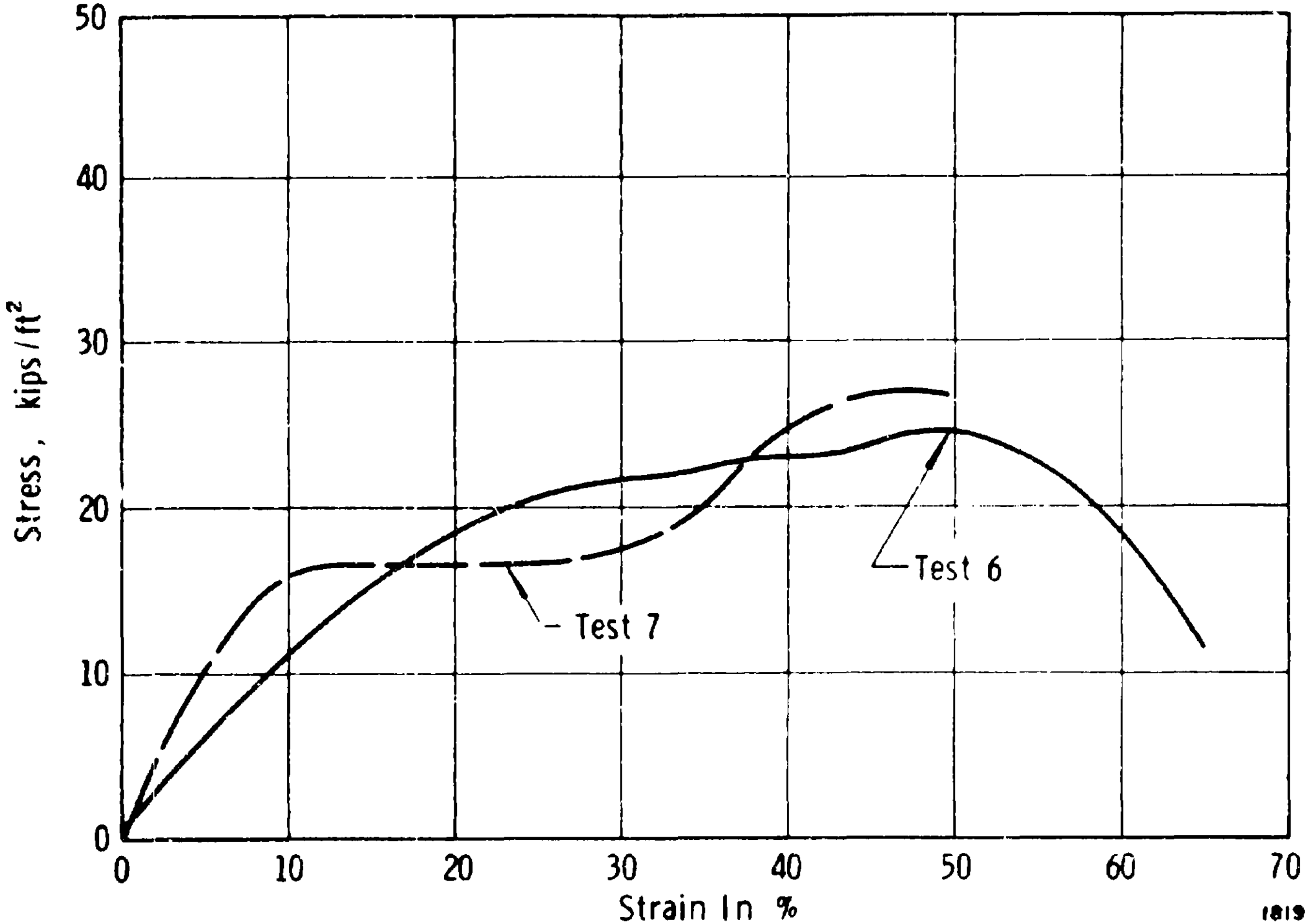

Figure 2. Sodium Silicate/Vermiculite Test Data
NLAB 25 Oct 1967

TABLE I

RESULTS OF NLABS TEST ON 25 OCTOBER 1967

Test	Type of Panel	Density (lb/ft^3)	Impact Velocity (fps)	Average Dynamic Crushing Stress (lb/ft^2)	Panel Thickness (in.)
1	Sodium silicate/ perlite	20.19	42.2	21,400	6
2	Sodium silicate/ perlite	18.80	42.2	25,430	6
3	Sodium silicate/ perlite	19.27	37.6	17,400	6
4	Sodium silicate/ perlite	20.50	30.6	17,455	3
5	Sodium silicate/ perlite	20.44	23.6	18,305	3
6	Sodium silicate/ vermiculite	19.94	34.4	19,190	3
7	Sodium silicate/ vermiculite	17.70	26.6	21 750	3

much higher than desired. In addition to these facts, we were aware of the fact that the density of the cushion was too high, and the panels were slightly friable.

To reduce the high-average stress and density and to eliminate the high-initial stress, it was decided to build the panel with voids. These voids were in the shape of a truncated cone and measured 3 in. at their major diameter, 2 in. at their minor diameter, and were 3 in. in length.

The male section of the mold was made of styrofoam coffee cups. The cups were equally spaced and mounted on a plywood board 16 X 18 X 3-inches. Several different spacings were evaluated, they were 18, 25, and 30 voids per panel.

The mold was inverted and placed over the plywood form with the styrofoam cups in place on the board. The mold was then filled with the various formulations of sodium silicate and perlite. The bottom of the mold was placed in position, and the mold and plywood form were turned over. With the plywood form on top, it was easily removed from the mold. Sufficient adhesive power was developed between the perlite and the sodium silicate so that when the cups were removed none of the mixture fell into the void. The top was then placed on the mold, and the mold was placed in the microwave oven for 20 to 30 min.

Several formulations with different numbers of voids were fabricated. This was done to study the effect of the voids, and the effect of formulations, on the stress-strain data. Samples of several of the panels were evaluated at the University of Texas, Balcones Research Center. Along with the cored samples, we also evaluated a solid panel of the same formulation as the sodium silicate/perlite samples tested at Natick. Data from the University of Texas indicated that the initial failure occurred at approximately 4000 psf. The loading remained constant to approximately 35% strain, and then the unit load slowly increased to about 12,000 psf at 75% strain. This is considerably different than the Natick data for the same material. But, this may be due to the fact that Natick Laboratories tests are conducted in a horizontal plane, and the University of Texas tests were conducted in a vertical plane.

As a result of these tests, it was decided to submit eight panels for the second set of tests at Natick Laboratories on 4 December 1967. These panels had 25 cores as described above and had the following formulation:

Sodium Silicate Solution	59%
Perlite	35%
Powdered Polyethylene	6%

The stress-strain data are plotted in Figure 3. The stress was considerably lower on the second set of tests than on the first set. In fact, the stress during the first 30 to 40% strain was so low that approximately 50% of the kinetic energy was still available at 50% strain. Therefore, the stress level increased rapidly between 50% strain and 70% strain.

The tabulated results are shown in Table II on page 11.

The results of this second set of dynamic tests indicated that a major step had been made in improving the properties of the sodium silicate/perlite panels. Not only was the density of the material reduced by a factor of almost 2, but the initial high-stress level was not evident and the average stress was near the desired level.

The first half of the stress-strain level was lower than desired. Therefore, a firmer foam panel was fabricated for the third set of airdrop cushions to be evaluated at Natick Laboratories.

The third formulation consisted of the following items and percentages:

Sodium Silicate	62.5%
Perlite	31.3%
Calcium Carbonate	6.2%

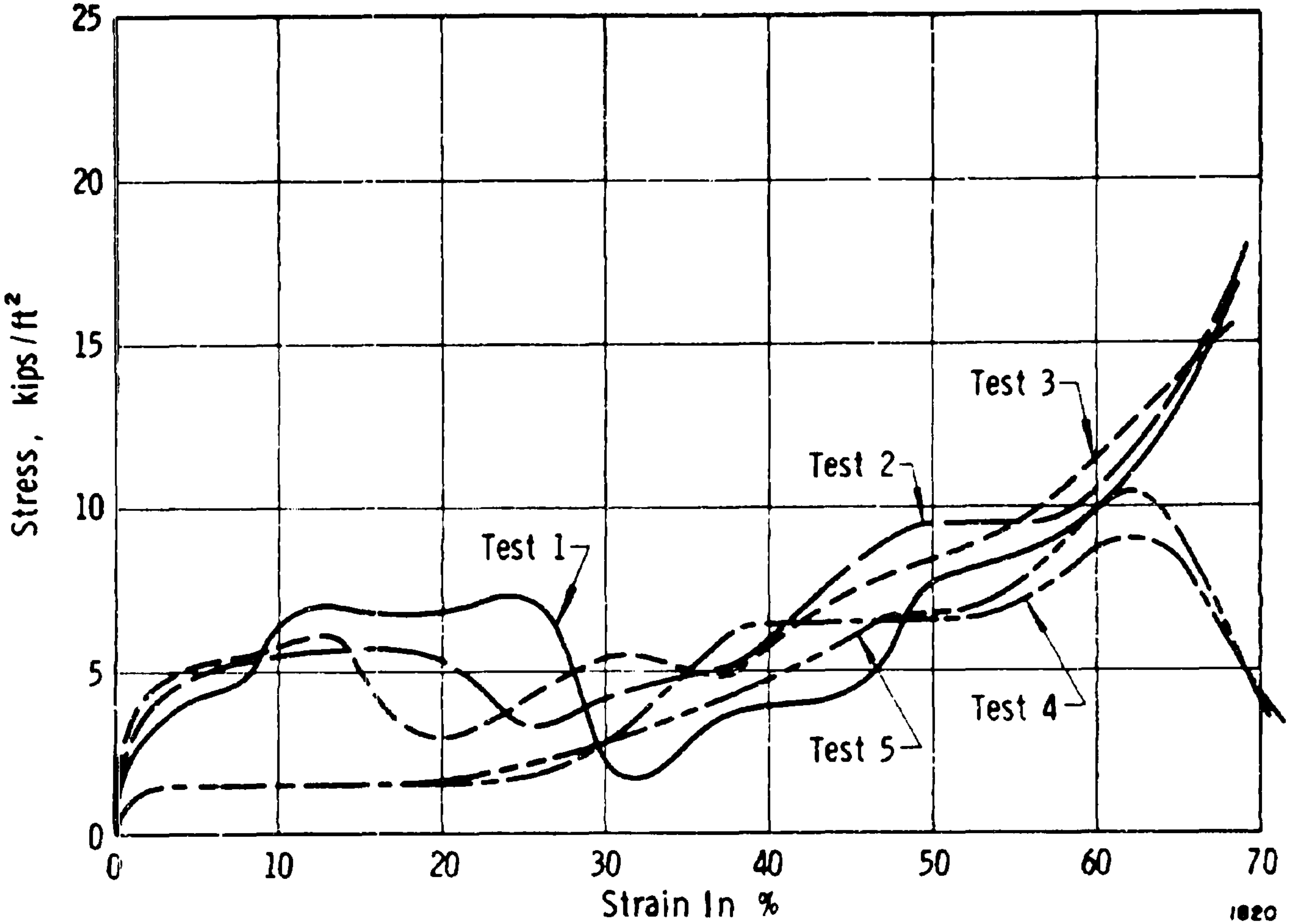

Figure 3. Sodium Silicate / Perlite Test Data
NLAB 4 Dec 1967

TABLE II

RESULTS OF NLABS TEST ON 4 DECEMBER 1967

Test	Type of Panel	Density (lb/ft^3)	Impact Velocity (fps)	Average Dynamic Crushing Strain (lb/ft^2 Average 70%)	Panel Thickness (in.)
1	Sodium silicate/ perlite	10.72	28.5	7550	6
2	Sodium silicate/ perlite	9.85	28.5	7700	6
3	Sodium silicate/ perlite	10.23	44.0	7650	6
4	Sodium silicate/ perlite	10.6	28.5	4900	3
5	Sodium silicate/ perlite	10.83	28.5	5200	3

This material was put into the mold with 25 truncated cone-shaped voids and baked for 20 to 30 min in the 2-kilowatt microwave oven.

The results of the dynamic tests conducted at Natick Laboratories on 25 January 1968 are shown in Figure 4. The stress-strain data on these tests indicated an oscillatory tendency for the panels. The average stress was higher on the third set, primarily as a result of the increased stress in the first half of the stress-strain curve.

The tabulated results for the third set of dynamic tests at Natick Laboratories are shown in Table III on page 13.

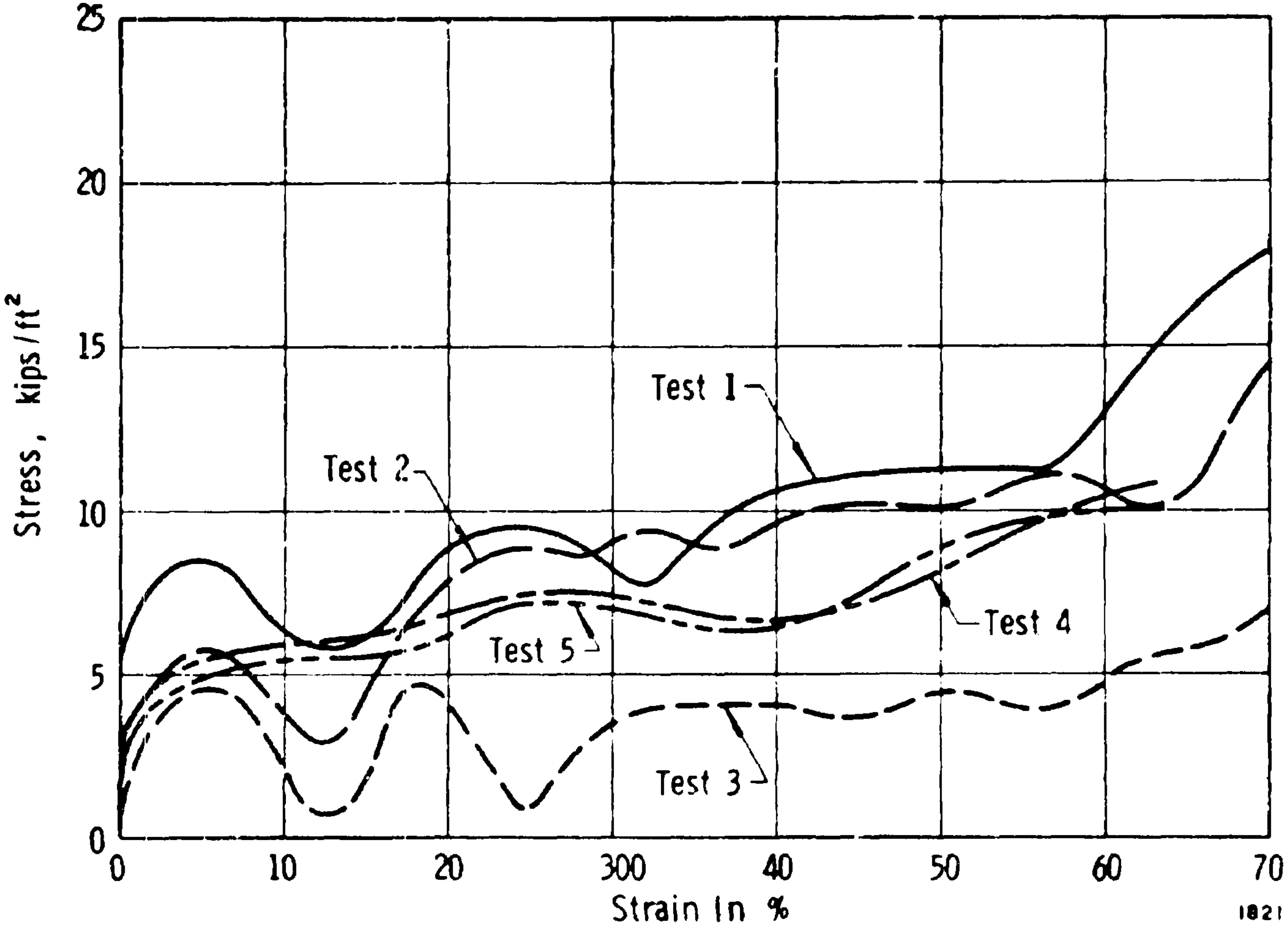

Figure 4. Sodium Silicate/Perlite Test Data
NLAB 25 Jan 1968

TABLE III

RESULTS OF NLABS TEST ON 25 JANUARY 1968

Test	Type of Panel	Density (lb/ft^3)	Impact Velocity (fps)	Average Dynamic Crushing Stress (lb/ft^2)	Panel Thickness (in.)
1	Sodium silicate/ perlite	12.45	28.5	10,000	6
2	Sodium silicate/ perlite	12.37	28.5	9,050	6
3	Sodium silicate/ perlite	12.25	46.0	4,200	6
4	Sodium silicate/ perlite	13.65	28.5	7,750	3
5	Sodium silicate/ perlite	13.25	28.5	7,815	3

III. Comparison of Sodium Silicate/Perlite System with Desired Characteristics

Eight desired characteristics were outlined for an improved energy dissipater. The following discussion states what each of the desired characteristics are and how well the third sodium silicate/perlite system meets the desired characteristics.

A. Capable of being stored and shipped in the collapsed state for economy in storage and shipment; a minimum ratio of 1 to 15 collapsed to expanded volume is desired.

The third system has a collapsed-to-expanded ratio of 1:2, which is not as good as previously expected, but it is better than the 1:1 ratio for preexpanded paper honeycomb.

B. Capable of withstanding temperature extremes of -65°F to +125°F in storage and use, and unaffected by direct contact with water.

These temperature extremes will not affect the sodium silicate/perlite panels. In fact, the upper temperature limit of the sodium silicate/perlite panel is approximately 1800°F. Even though sodium silicate is normally water soluble, there are several chemicals that make the sodium silicate completely insoluble in water.

C. Provide an approximately rectangular force-deformation curve to 80% deformation when force is dynamically applied at initial impact velocities ranging from 20 fps to 90 fps.

The data indicate that the stress-strain curve hardens after about 60% strain. Up to that point, the curve is basically rectangular. Sufficient data have not been taken to determine the strain-rate sensitivity of the material, but, from the limited data taken, the sodium silicate/perlite system appears to be insensitive to strain rate.

D. Average crushing force under condition C above should be 6300 psf + 10%.

The average crushing force was slightly above the desired level. But, it has been demonstrated in this program that the stress-strain curve can be affected in several ways; therefore, we feel that this goal can be reached.

E. Capable of being easily prepared and used in the field with a minimum of auxiliary equipment and personnel.

The sodium silicate/perlite airdrop panels can be easily prepared in the field with only a few men and several molds by allowing the panels to air cure at ambient temperatures. If conventional or microwave ovens are available, fewer molds would be required and the cure time shortened.

F. Limit rebound energy, or resilience, to less than 5% of total energy dissipated to 80% deformation.

Since the sodium silicate/perlite panels fail by crushing rather than by plastic deformation, the rebound energy is virtually zero. Under no condition has the rebound energy been measured as high as 2%.

G. Limit cost of dissipater material to less than $0.15/1000 ft-lb of energy dissipated.

Using the average energy dissipated in the third set of dynamic tests, the cost of the dissipater material would be $0.069/1000 ft-lb of energy dissipated. If the desired 6300 ft-lb level is used for the calculation, $0.085/1000 ft-lb would be the cost figure. In either case, the cost of the sodium silicate/perlite air cushion compared favorably with the desired value.

H. The material and supporting supplies shall not possess explosive, mechanical, biological, toxicological, or electromagnetic radiation effects which could be hazardous from a health or safety standpoint to using personnel.

The sodium silicate/perlite system does not possess any property listed above that could be hazardous to the health or safety of personnel using the airdrop cushions.

IV. Conclusions and Recommendations

It is concluded that the sodium silicate/perlite system meets or approaches all goals. This system has several attractive features: these include low cost (as low as $0.07/1000 ft-lb of energy dissipated), ease of handling, nontoxicity, nonflammable characteristic, insensitivity to temperature extremes, has no rebound after impact, and can be used as an airdrop cushion many times by remolding the materials.

There are some areas that could be improved; these are: to increase the present 1:2 collapsed-to-expanded ratio, extend the maximum strain level, smooth and flatten the stress-strain curve to a more rectangular curve, decrease the density and in turn the cost, and reduce the friability.

It is recommended that additional work be carried out to investigate the use of sodium silicate and sodium silicate/perlite panels for airdrop cushions. The first step in a new investigation should be to determine the feasibility of using large microwave units in the field. Since these units are being considered by the Army for use as kitchen equipment, they may also be available for preparation of airdrop cushions. If this proves feasible, then the foamed panels should be reevaluated.

In the area of sodium silicate/perlite panels, the formulations should be modified to reduce the average stress level, flatten the stress-strain curve, increase the maximum strain level, and reduce the density.

APPENDIX

CHEMICAL FORMULATIONS AND EVALUATIONS

TABLE A.1

6 × 6 × 1-IN. PANELS USED FOR PRELIMINARY EVALUATION OF FORMULATIONS

Component	Composition (% by wt)	Charged in Mold (gms)	Comments
Sodium Silicate*	73.5	220	Uniform cells, 9-lb/ft^3 density. Some blowout resulted from the drop test.
Borax	9.5		
Sodium Metaborate	3.7		
Water	13.3		
Sodium Silicate	71.5	220	Uniform cells, 9-lb/ft^3 density. Less blowout with drop tests than Sample No. 1.
Borax	7.15		
Sodium Metaborate	3.55		
Powdered Polyethylene	7.15		
Water	10.65		
Sodium Silicate	87.0	230	Uniform cells, 12-lb/ft^3 density. Some blowout in drop tests.
Powdered Polyethylene	13.0		
Sodium Silicate	95.0	230	Uniform cells, 10-lb/ft^3 density. Good "legs." On impact, only slight blow-out.
Elvax 210 (33% solution)	5.0 (solids)		
Sodium Silicate	93.0	248	Uniform cells, 11-lb/ft^3 density. Negligible blow-out. Force curve was near-rectangular.
Elvax 40 (33% solution)	7.0 (solids)		
Sodium Silicate	72.6	220	Uniform cells, 9-lb/ft^3 density. Some blowout resulted from the drop test.
Sodium Metaborate	5.5		
Borax	7.3		
Water	14.5		
Sodium Silicate		200	Cotton charred. Poor expansion of silicate.
Cotton Linters (6 × 6 × 1-in. loosely packed)			

*Sodium silicate listings indicate a solution of 40% solids by weight in water; 3.22 to 1 ratio SiO_2/Na_2O.

TABLE A.1 (Cont'd)

6 × 6 × 1-IN. PANELS USED FOR PRELIMINARY EVALUATION OF FORMULATIONS

Component	Composition (% by wt)	Charged in Mold (gms)	Comments
Sodium Silicate Fiber Glass ($36-in^3$ volume loosely packed into mold)		200	Poor expansion. Glass compacted and stratified.
Sodium Silicate Hemp Fiber ($36-in^3$ volume)		200	Charred. Suppressed foam.
Sodium Silicate Jute Fiber ($36-in^3$ volume)		200	Charred. Suppressed foam.
Sodium Silicate Excelsior ($36-in^3$ volume)		200	Charred. Suppressed foam.
Sodium Silicate Vinyl Foam ($36-in^3$ volume)		200	Charred. Suppressed foam.
Sodium Silicate Powdered Silica ($36-in^3$ volume)		200	Suppressed foam.
Sodium Silicate Reticular Urethane Foam ($36-in^3$ volume)		200	Uniform distribution of silicate foam through urethane matrix. Reduced blowout to minimal. Urethane partially embrittled by local overheating.
Sodium Silicate Vermiculite	66-2/3 33-1/3	240	Uniform dimensions and reproducible. Moderate blowout on impact.

TABLE A.1 (Cont'd)

6 X 6 X 1-IN. PANELS USED FOR PRELIMINARY EVALUATION OF FORMULATIONS

Component	Composition (% by wt)	Charged in Mold (gms)	Comments
Sodium Silicate Perlite	58.0 42.0	240	Uniform dimensions, reproducible. Moderate blowout on impact.
Sodium Silicate Vermiculite Powdered Polyethylene	62.5 31.25 6.25	256	Polyethylene tends to pyrolize in this medium upon excessive heating.
Sodium Silicate Perlite Powdered Polyethylene	55.0 39.5 5.5	254	Attractive, strong aggregate panel. Moderate blowoutout. Elevated compression strength (120 psi).

TABLE A.II

16 X 18 X 3-IN. PANELS. INVESTIGATION OF THE ADAPTABILITY OF FORMULATIONS AND EQUIPMENT TO LARGE PANEL PREPARATION

Component	Composition (% by wt)	Charged in Mold (lb)	Comments
Sodium Silicate	74.0	11.5	Irregular surface. Non-uniform expansion.
Sodium Metaborate	5.6		
Borax	7.4		
Water	13.0		
Sodium Silicate	74.0	Predried to 6.6	Improved surface uniformity and uniformity of expansion. Stress cracks throughout panel.
Sodium Metaborate	5.6		
Borax	7.4		
Water	13.0		
Sodium Silicate	90.0	10.75 (wet)	Nonuniform expansion.
Powdered Polyethylene	10.0	6.7 (dried)	
Sodium Silicate	95.0	11.0 (wet)	Nonuniform expansion.
Elvax 210 (33% solution)	5.0 (solids)	6.5 (dried)	
Crushed Foam (Formulation No. 1)	33-1/3	15	Density, 23 pcf. Panel badly stress cracked and friable.
Sodium Silicate Solution (Formulation No. 1)	66-2/3		
Crushed Foam (100% sodium silicate)	33-1/3	15	No coherent integrity.
Sodium Silicate Solution (100%)	66-2/3		
Sodium Silicate	61.0	12	Good dimensional uniformity. Slightly fragile, friable.
Vermiculite*	33.0		
Calcium Carbonate	6.0		
Sodium Silicate	61.0	10	Very friable.
Vermiculite†	33.0		
Calcium Carbonate	6.0		
Perlite‡	33-1/3	15	Fair to good. Density ~ 20 pcf.
Sodium Silicate	66-2/3		

*Grade No. 3
†Grade No. 2
‡Horticultural grade, low density (6-7 pcf).

TABLE A.III

16 × 18 × 3-IN. PANELS TESTED AT UNIVERSITY OF TEXAS

Component	Composition (% by wt)	Density (lb/cu ft)	Comments
Sodium Silicate Perlite	59 41	16.7	Solid sample. 1/2 panel, 9 × 16 × 3-inches. Compressed to 1/2 inch.
Sodium Silicate Perlite	59 41	18.6	9 × 16 × 6 in., two each half-panels stacked together. Compressed to 3/4 inch.
Borax Sodium Silicate Perlite	5.25 55.5 39.25	11.5	25 voids, 2 panels (16 × 18 × 6-in.) stacked with 3-in. openings facing down. Compressed width 1-3/4 inches.
Borax Sodium Silicate Perlite	5.25 55.5 39.25	12	25 voids, 2 panels (16 × 18 × 6-in.) stacked with 3-in. openings facing down. Compressed width, 2-1/4 inches.
Powdered Polyethylene Sodium Silicate Perlite	6.45 55.0 38.55	11.8	25 voids, 2 panels (16 × 18 × 6-in.) stacked with 3-in. openings facing down. Compressed width 2-1/2 inches.
Powdered Polyethylene Sodium Silicate Perlite	6.45 55.0 38.55	11.5	25 voids, 2 panels (16 × 18 × 6-in.) stacked with 3-in. openings facing down. Compressed width 2-1/8 inches.
Sodium Silicate Perlite	59.0 41.0	9.6	25 voids, 2 panels (16 × 18 × 6-in.) stacked with 3-in. openings facing down. Compressed width 7/8 inch.
Sodium Silicate Perlite	59.0 41.0	13.7	2 solid panels (16 × 18 × 6-in.). Compressed width, 2.3 inches.

TABLE A.III (Cont'd)

16 × 18 × 3-IN. PANELS TESTED AT UNIVERSITY OF TEXAS

Component	Composition (% by wt)	Density (lb/cu ft)	Comments
Sodium Silicate	59.0	10.5	25 voids, 2 panels (16 × 18 × 6-in.) stacked with 3-in. openings center-faced. Compressed width 1.9 inches.
Perlite	41.0		
Sodium Silicate	53.0	12.2	25 voids, 2 panels (16 × 18 × 6-in.) stacked with 3-in. openings center-faced. Compressed width 2.6 inches.
Perlite	37.6		
Powdered Polyethylene	9.4		
Sodium Silicate	51.5	12.0	25 voids, 2 panels (16 × 18 × 6-in.) stacked with 3-in. openings center-faced. Compressed width 2.6 inches. Friable.
Perlite	36.3		
Powdered Polyethylene	12.2		
Sodium Silicate	55.0	9.4	30 voids, 2 panels (16 × 18 × 6-in.) stacked with 3-in. openings center-faced. Compressed width 1.4 inches.
Perlite	39		
Powdered Polyethylene	6		
Sodium Silicate	53.0	10	30 voids, 2 panels sandwiched (16 × 18 × 6-in.) with 3-in. openings center-faced. Compressed width 2.1 inches.
Perlite	38		
Powdered Polyethylene	9		
Sodium Silicate	59	13.7	Screened low density. Perlite for formulation.
Perlite	41		

TABLE A.IV

16 × 18 × 3-IN. PANELS TESTED AT U.S. ARMY NATICK LABORATORIES

Component	Composition (% by wt)	Density (lb/cu ft)	Comments
Sodium Silicate	59	18-20	8 samples tested at U.S. Army Natick Laboratories, 25 October 1967.
Perlite	41		
Sodium Silicate	64	18-20	2 samples tested at U.S. Army Natick Laboratories, 25 October 1967.
Vermiculite	36		
Sodium Silicate	59	11	Prepared 8 each and delivered to U.S. Army Natick Laboratories facility. 25 hole panels (16 × 17 × 3-in.) each, 4 December 1967.
Perlite	34.8		
Powdered Polyethylene	6.8		
Sodium Silicate	62.5	12-13	Prepared 8 panels for shipment to U.S. Army Natick Laboratories facility on 22 December 1967. 25 holes, evaluated on 25 January 1968.
Perlite	31.25		
Calcium Carbinate	6.25		

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13. ABSTRACT

Sodium silicate foam was proposed as a possible substitute for paper honeycomb as an airdrop cushion. Experimental efforts to implement silicate foam panels using a 2 kilowatt microwave energy source proved inadequate. Larger energy input with a more uniform flux appeared to be necessary to accommodate the size of panels desired.

A sodium silicate/perlite aggregate formulation was found to fulfill most of the product specifications. Areas for improvement include collapsed to expanded ratio, maximum strain level, rectangularity of stress-strain curve, product density and friability.

The silicate/perlite formulation and foamed sodium silicate formulations allow a wide latitude of variation and control. It is believed that optimization of formulation and heating equipment can be realized.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Impact strength	8					
Energy	8		9			
Absorption	8		8			
Dissipation	8		8			
Impact shock	1					
Sodium silicate	10		10		9	
Foams	10		10		9	
Perlite	10		10		9	
Vermiculite	10		10		9	
Airdrop operations	4		4		4	
Stress-strain measurements					8	