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FOAMED SULFUR FOR AIRDROP CUSHIONING

John M. Dale, et al

Southwest Research Institute
San Antonio, Texas

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FOAMED SULFUR FOR AIRDROP CUSHIONING

by

John M. Dale
Allen C. Ludwig

Southwest Research Institute
San Antonio, Texas

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AIRDROP ENGINEERING LABORATORY
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

This work was performed during the period April 1967 to April 1968 under U. S. Army Natick Laboratories Contract No. DAAG-17-67-C-0115. The Department of the Army Project No. is 1M121401D195 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.

JAMES G. BENNETT
Colonel, QMC
Director, Airdrop Engineering Laboratory

APPROVED:

DALE H. SIELING, Ph. D.
Scientific Director

FELIX J. GERACE
Brigadier General, USA
Commanding

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ABSTRACT

Investigation of foamed sulfur as an improved energy dissipator to prevent damage to military equipment in airdrop applications has shown this material to have such desired project target characteristics as:

A capacity for withstanding temperature extremes of -65° to +125°F in storage and during use, and being unaffected by direct contact with water.

Providing an approximately rectangular force-deformation curve to 80 percent deformation when the forces are dynamically applied at initial impact velocities ranging from 20 to 46 fps (46 fps was the highest impact velocity actually used).

Limiting rebound energy or resilience to less than 5 percent of total energy dissipated to 80 percent deformation.

Having a material cost of less than $0.15/1000 ft·lb of energy dissipated.

Four additional target requirements which met with qualifications were:

Being easily prepared and used in the field with a minimum of auxiliary equipment and personnel (protective clothing and ventilation provisions are required).

A collapsed to expanded volume ratio of 1 to 15.

An average crushing force of 6300 psf plus or minus 10 percent.

Supporting supplies, foaming process and resultant foam shall not be hazardous to health or safety of using personnel.

The qualifications for the second and third requirements were that while it was possible to obtain expansion ratios of 1 to 13, the characteristics of sulfur foam were such that desired physical properties were best achieved at expansion ratios between 1 to 8 and 1 to 10. The target crushing force was attained with the two single 3-inch thick specimens from the final series. The 6-inch specimens prepared by using two 3-inch thick specimens had slightly higher crushing strengths than did the single 3-inch specimens.

Supplies must be stored in proper containers to eliminate or contain hazardous hydrogen sulfide gas and related obnoxious odor generation. Phosphoric acid is to be contained and handled with precautions normal for acids, and the foaming process conducted in a well ventilated atmosphere to protect personnel from generation of hydrogen sulfide gas.

FOAMED SULFUR FOR AIRDROP CUSHIONING

I. INTRODUCTION

Sulfur foams are a relatively new material having been conceived and developed at Southwest Research Institute and are described in the recently issued United States Patent No. 3, 337, 355 These foams were initially developed for shock isolation applications. Sulfur foams consist essentially of sulfur which has been modified with viscosity and surface tension improvers. A blowing agent is added to the molten formulation which is contained in a pressure vessel. When the formulation is released from the vessel, the blowing agent expands the molten liquid into a froth which subsequently cools and solidifies into a rigid cellular material. The mechanical properties of this foam are primarily a function of the foam density and formulation, and can be varied substantially.

Cursory examination of the shock isolation or energy absorption characteristics of sulfur foam indicated that it had an attractive potential as an airdrop cushioning. An approved energy dissipator for airdrop applications, however, must have a variety of characteristics. It was the objective of this program to determine to what degree rigid sulfur foam could meet the desired or target characteristics as specified by the U. S. Army Natick Laboratories for an improved energy dissipator for airdrop use.

Laboratory experimentation in the area of foam development was followed by the scaling up of sulfur foam production procedures and the preparation of a preliminary set of samples. These samples were dynamically tested at the Balcones Research Center of the University of Texas, which is under a research contract to Natick Laboratories which includes evaluation of energy dissipating materials. Following this, modifications were made in the formulation, and the first series of eight specimens were prepared and submitted to the Natick Laboratories for dynamic testing. The test data received from Natick Laboratories were analyzed, alterations were made in the formulation, and a second series of eight specimens was submitted to Natick Laboratories for dynamic testing. Test data received from Natick Laboratories were analyzed, alterations were again made in the formulations, and a third and final set of eight specimens was submitted to Natick for dynamic testing.

I. OPTIMIZING RIGID SULFUR FOAM FOR USE AS AIRDROP ENERGY DISSIPATION MATERIAL

The quantities of foam required for this program were substantially greater than the facilities were capable of producing at one time. For this program, a steam jacketed, 100-gal capacity pressure vessel was converted to produce sulfur foam. This vessel was thermally insulated and modified for foam production. A 25-ft flexible rubber discharge line was attached to this vessel to provide mobility in placement of the foam.

Metal skin molds were fabricated to produce sulfur foam boards 3 in. thick by 18 in. high by 8 ft in length. Two such molds allowed for the production of sufficient foam board to supply the Natick Laboratories with eight samples, each 3 in. by 16 in. by 18 in., as well as provide several additional specimens for static testing at Southwest Research Institute. Figure 1 shows a typical batch of sulfur foam being deposited into one of the molds. The foam specimens which solidified in approximately 1 hr were removed from the molds and cut to size for testing and shipment to the sponsor. A

FIGURE 1. SULFUR FOAM BEING POURED INTO A FORM

handsaw was employed to cut and shape the foam. Figure 2 shows a typical specimen after removal from the mold.

FIGURE 2. SULFUR FOAM PLANK

A considerable amount of time was devoted to lining out the equipment and preparing the preliminary series of test specimens. Impact tests on the foam specimens that were prepared the previous day were conducted at the Balcones Research Center of the University of Texas at Austin. The rigid sulfur foam specimens provided a rectangular force deformation curve as was desired. The force deformation curves indicate an amount of ringing, and it was not possible to determine precisely whether this was occurring in the test equipment or was a property of the foam. Figure 3 is a reproduction of one of the force deformation curves for the sulfur foam specimen obtained at an impact velocity of 24 fps. The horizontal section of this curve occurred at a stress leveling of approximately 30,100 lb/ft^2, and the deformation before packing was approximately 75 to 80 percent. The rebound energy was less than 5 percent of the total energy dissipated. From these tests, it was indicated that further development work would be directed to lowering the compressive strength of the foam.

The first series of official specimens was prepared and forwarded to Natick Laboratories for dynamic testing.

Static tests of constrained specimens at Southwest Research Institute indicated that the compressive strength of this foam was high. These specimens were dynamically tested at Natick Laboratories, and the results of these

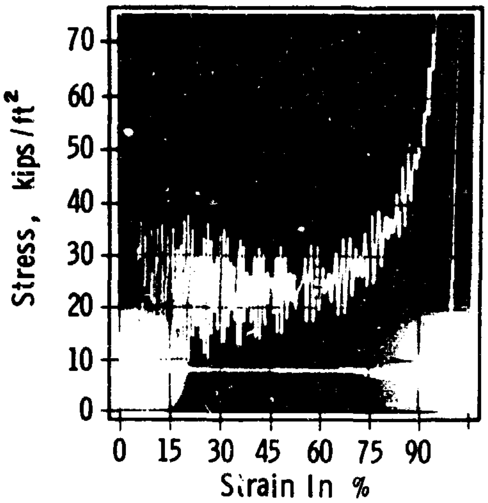


FIGURE 3. DYNAMIC CRUSHING CHARACTERISTICS AS MEASURED BY THE BALCONES RESEARCH CENTER UNIVERSITY OF TEXAS AT AUSTIN

tests were transmitted to Southwest Research Institute. The following table shows the dynamic stress characteristics measured by the Natick Laboratories. Figure 4(a) shows a typical force-deformation curve for one of the specimens of this series. The dynamic and static force-deformation curves for all of the specimens tested can be found in the Appendix. From these data, it was indicated that the sulfur foam material had a dynamic crushing

TABLE I. SUMMARY OF IMPACT DATA ON FIRST SERIES OF SPECIMENS

Test No.	Impact Velocity (ft/sec)	Thickness (in.)	Density (lb/ft^3)	Dynamic Crushing Stress (lb/ft^2) (Average)	Remarks
1	28.1	3	19.44	16,150	
2	21.8	3	20.26	14,950	
3	31.2	3	20.40	17,500	
4		3	21.22	-	No data due to poor film
5	30.0	6	23.03	13,300	
6	37.0	6	25.31	19,100	

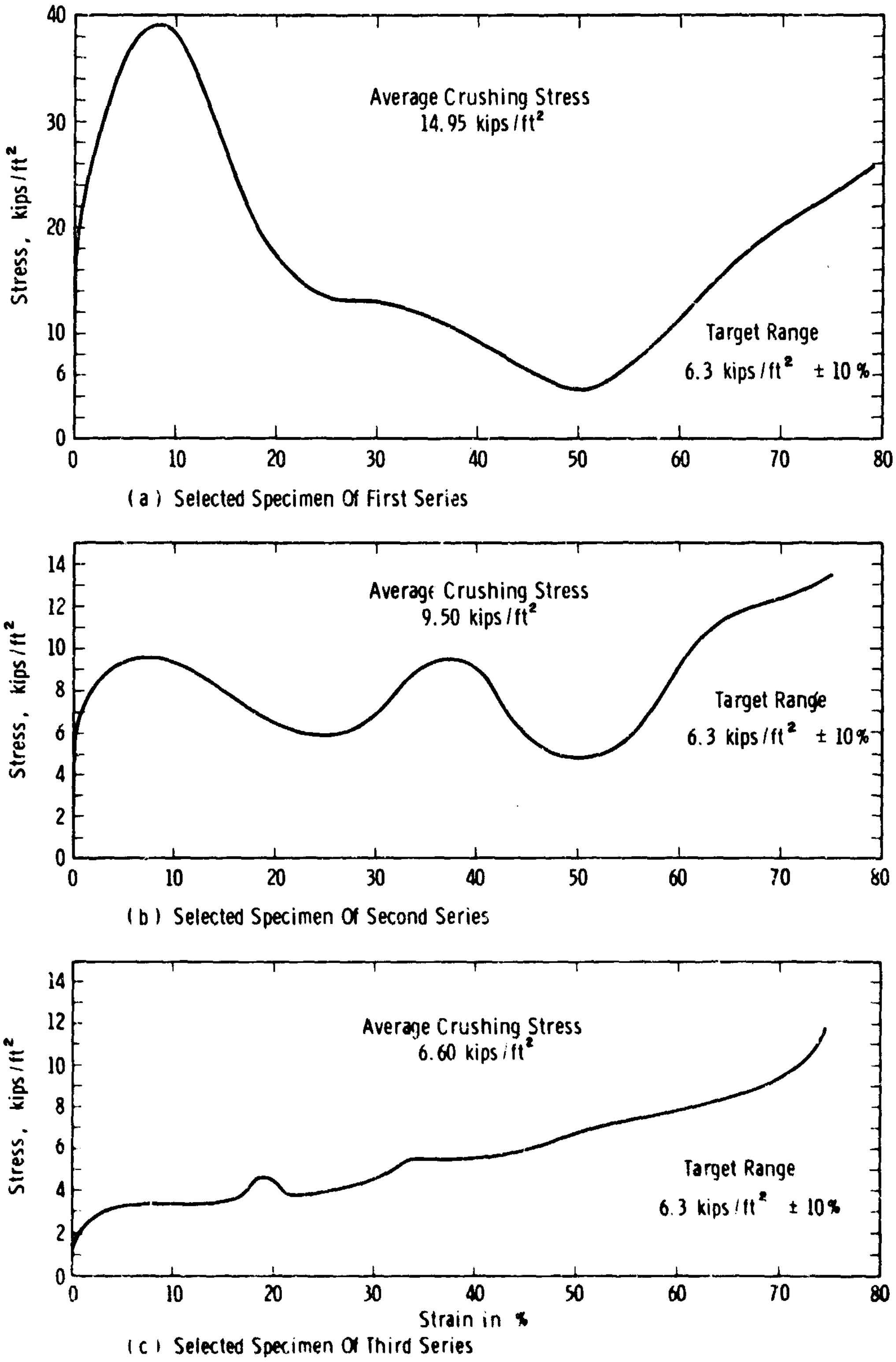


FIGURE 4. TYPICAL FORCE-DEFORMATION CURVES FOR SELECTED SPECIMENS OF FIRST, SECOND AND THIRD SERIES OF SPECIMENS SUBMITTED TO NATICK LABS FOR TESTING

strength of approximately two to three times that which was desired and a peaking of the force-deformation curve at the onset of loading. Examination of specimens prepared at the same time as those forwarded to Natick for testing and retained at Southwest Research Institute indicated a small celled, dense foam structure along the outer surfaces of the foam as compared to a less dense foam cell structure in the center of the specimens. Thus, attention was focused on lowering of the strength of the foam and improving the uniformity of the foam structure, from surface to surface.

A second series of rigid sulfur foam specimens was prepared and forwarded to Natick Laboratories for testing. Static tests of constrained specimens at Southwest Research Institute indicated that the compressive strength of this foam was within the target limits. Dynamic test results were returned to the Institute. The results, as measured by Natick Laboratories, are presented in Table II below. Figure 4(b) shows a typical force-deformation curve for one of the specimens of this series.

TABLE II. SUMMARY OF IMPACT DATA ON SECOND SERIES OF SPECIMENS

Test No.	Impact Velocity (ft/sec)	Thickness (in.)	Density (lb/ft^3)	Dynamic Crushing Stress (lb/ft^2)
1	28.5	3	16.50	10,660
2	28.5	3	16.30	9,500
3	28.5	6	16.75	4,290
4	28.5	6	14.70	3,400
5	46.0	6	14.30	4,900

A substantial lowering of the density of this series of specimens resulted in a significant lowering of the dynamic crushing stress. Unexplained was the fact that the 6-in. thick specimens had approximately half the dynamic crushing strength of that of the 3-in. thick specimens of foam of the same density and formulation. This was believed to be due to the fact that the area under test on the 6-in. thick specimens was drastically reduced when part of the test material was blown out at the onset of loading.

A third and final set of specimens was prepared and shipped to Natick Laboratories for testing. Again, static tests of constrained specimens at Southwest Research Institute indicated compressive strengths within the target limits. To overcome the edge rupturing of the specimens upon impact, the specimens were constrained by wrapping the edges with two thicknesses of masking tape. The results on this series of specimens are presented in Table III. Figure 4(c) shows a typical force deformation curve for one of the specimens of this series, and it is to be noted that it falls within the designated target range.

TABLE III. SUMMARY OF IMPACT DATA ON THIRD SERIES OF SPECIMENS

Test No.	Impact Velocity (ft/sec)	Thickness (in.)	Density (lb/ft^3)	Dynamic Crushing Stress (lb/ft^2)
1	28.5	3	16.9	6675
2	28.5	3	16.9	6600
3	46.0	6	16.9	7220
4	28.5	6	16.8	7350
5	28.5	6	17.0	7620

The formulations employed in preparing the three series of specimens are shown in Table IV.

TABLE IV. FOAM FORMULATION FOR EACH BATCH SUBMITTED

Component	Parts by Weight		
	1st Batch	2nd Batch	3rd Batch
Sulfur	100.00	100.00	100.00
Talc	10.00	10.00	10.00
1, 5-Cyclooctadiene	3.00	3.00	3.00
P_2S_5	3.00	5.00	5.00
$CaCO_3$	3.00	-	-
H_3PO_4	3.00	5.00	5.00
FeS_2	1.00	1.00	-
TCP	0.25	0.25	0.25

III. DISCUSSION

The characteristics of rigid sulfur foam as an improved energy dissipator for airdrop applications are discussed in the sequence of the target characteristics as required.

A. Expansion Ratio

While the ratio of 1 to 13 collapsed to expanded volume was achieved in terms of core densities, overall expansion ratios on the order of 1 to 8 and 1 to 10 were found to have stress levels more in keeping with the target strength of the foam. Considerable time was expended in scaling up the operation to produce specimens of the size and type required for this project, and additional future effort could profitably be expended in improving the expansion ratios.

B. Environmental Resistance

Specimens of the sulfur foam were stored at temperatures of -65° and +125°F. In addition, specimens were submerged in water for 48 hr at 70°F. These specimens were then tested in compression, and the results are compared against specimens held at room temperature as follows:

TABLE V. COMPRESSIVE STRENGTH OF SPECIMENS SUBJECTED TO VARIOUS TEST CONDITIONS

Test Condition (°F)	Compressive Strength (psf)	Density (lb/ft^3)
-65 Dry	5040	16.8
+70 Dry	5760	16.5
+70 Wet	5040	17.1
+125 Dry	5040	17.3

The minor variations in properties found indicate that sulfur foam has environmental resistance sufficient for this application.

C. Force-Deformation Characteristics

The sulfur foam provided horizontal force-deformation curves to 70 percent deformation when the force was dynamically applied at initial impact velocities between 21.8 to 46.0 fps obtained with the dynamic tester at Natick Laboratories. The Natick Laboratories test data did not show response beyond 70 percent; however, preliminary tests at Balcones Research Center indicated deformation to 80 percent and a rectangular dynamic force deformation curve.

D. Average Compressive Strength

The average crushing force of the sulfur foams had a target value of 6300 psf ±10 percent. Several of the sulfur foam specimens had strengths that fell within this range when tested statically. When identical specimens of the same foams were tested dynamically, the strengths fell outside the desired range. As was discussed earlier this was believed due to the rigid foam being blown out at the moment of impact, thus reducing the test area. This problem was greatly minimized by using constrained specimens on the third batch which were sent to Natick for testing. The single 3-in. thick specimens had strengths only 5 percent greater than the target value of 6300 psf, and the two samples had a 1 percent spread. With further additional development work, it is believed that the desired crushing force could be obtained with lower density foams.

E. Field Preparation

The ability to prepare rigid sulfur foam in the field has already been demonstrated by the use of a self-contained portable foam generator which was completely self-sufficient with the exception of fuel and foam formulation. This generator is shown in Figure 5.

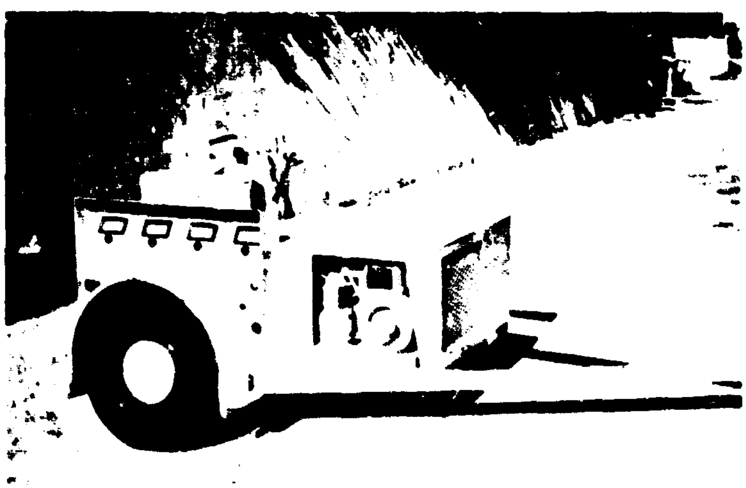


FIGURE 5. PORTABLE FIELD FOAM GENERATOR

F. Rebound Energy

Sulfur foams are rigid brittle materials having essentially no elasticity, and, as such, rebound has never been encountered when testing any of the formulations prepared to date. Any rebound associated with sulfur foams is certainly well below 5 percent.

G. Cost of Material

The cost of the sulfur foams averages about $0.037/lb. The formulation submitted to Natick for testing in the third series of specimens had the cost breakdown shown on Table VI. The current materials costs of the sulfur foams are well below the limits set at $0.15/1000 ft-lb of energy absorbed.

H. Other Characteristics

In regard to the contract requirement that the materials and supporting supplies for preparing sulfur foams do not possess explosive, mechanical, biological, or electromagnetic radiation effects: The phosphorus pentasulfide when exposed to moisture can generate slight quantities of hydrogen sulfide; however, when stored in the supplied containers, no problem is encountered. When the phosphorus pentasulfide is contacted with the phosphoric acid in the foam formulation, hydrogen sulfide is formed. The odor dissipates rapidly upon solidification so that the only requirement is that foams be poured in a well-ventilated atmosphere. The phosphoric acid should be handled with the same caution normally given acids. The 1, 5-cyclooctadiene is a hydrocarbon and as such should be handled accordingly.

Observations at Natick Laboratories during dynamic testing of foam samples showed that fine sulfur dust that settled on metals combined with moisture in the air and caused corrosion.

TABLE VI. FORMULATION AND ENERGY DISSIPATION COST BREAKDOWN

	Formulation Cost*			Unit Energy Dissipation Cost			
Component	Parts by wt	Cost (cents/lb)	Cost/Part (cents)	Foam Density (lb/ft^3)	Cost ($cents/ft^3$)	Energy Absorbed ($ft\text{-}lb/ft^3$)	Cost (cents/1000 ft-lb)
Sulfur	100.00	1.7	170				
Talc	10.00	3.5	35				
1,5-cyclooctadiene†	3.00	50.0	150			**	
P_2S_5	5.00	13.0	65	17	63.0	6300 × .75	13.3
TCP	0.25	31.0	8			= 4725	
H_3PO_4	5.00	6.0	30				
Total Parts	123.25						
	Total Cost		458				

$$\text{Cost/lb} = \frac{458}{123} = 3.7¢ \text{ per pound}$$

*Oil, Paint and Drug Reporter, February 28, 1968.
†Estimate from Manufacturer.
**Distance at crush to bottoming.

IV. CONCLUSIONS

The problems encountered in scaling up for the production of foams with the low densities which produced the desired dynamic properties were considerably more difficult and required more time than was expected. As such, not as much effort was devoted to formulation development as was desired to produce foams with higher strength-to-weight ratios. Nevertheless, the present foam formulations appear to be attractive energy dissipating materials for the following reasons:

(1) Low density sulfur foams can be prepared and poured in large quantities with conventional equipment under field conditions.

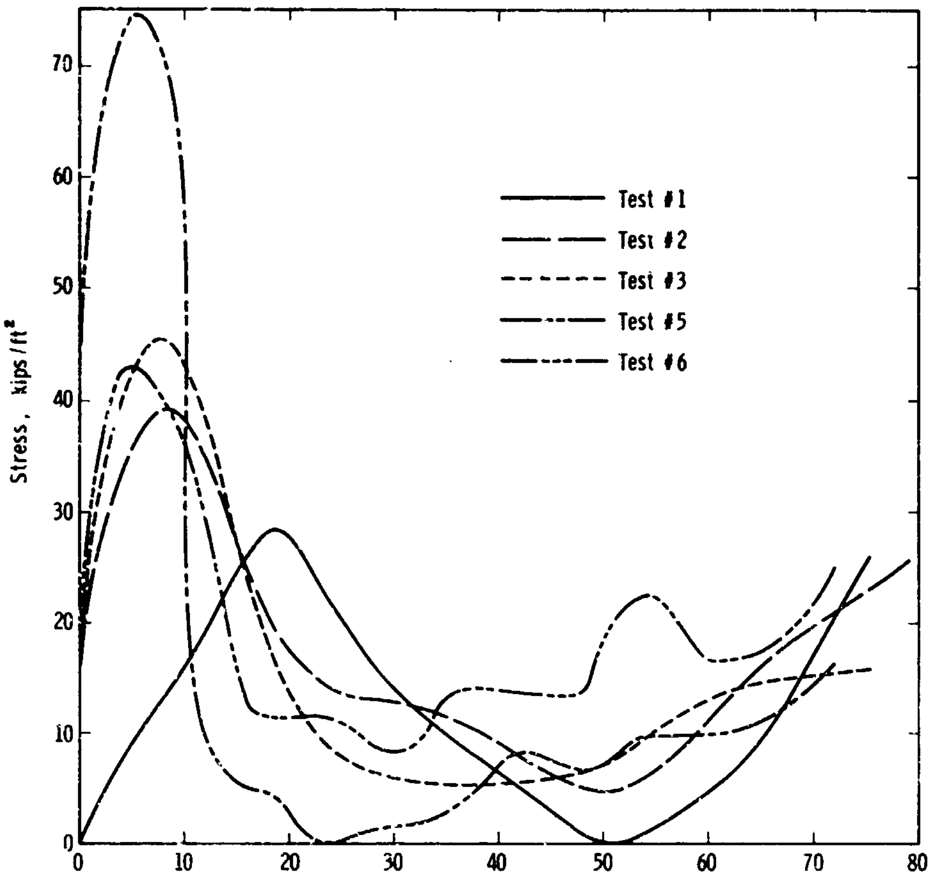
(2) The dynamic crushing stress of these foams can be controlled principally by foam formulation and density.

(3) The target dynamic characteristics for the ideal desired energy absorbing material can presently be obtained with sulfur foams by having a density of 17 lb/ft^3.

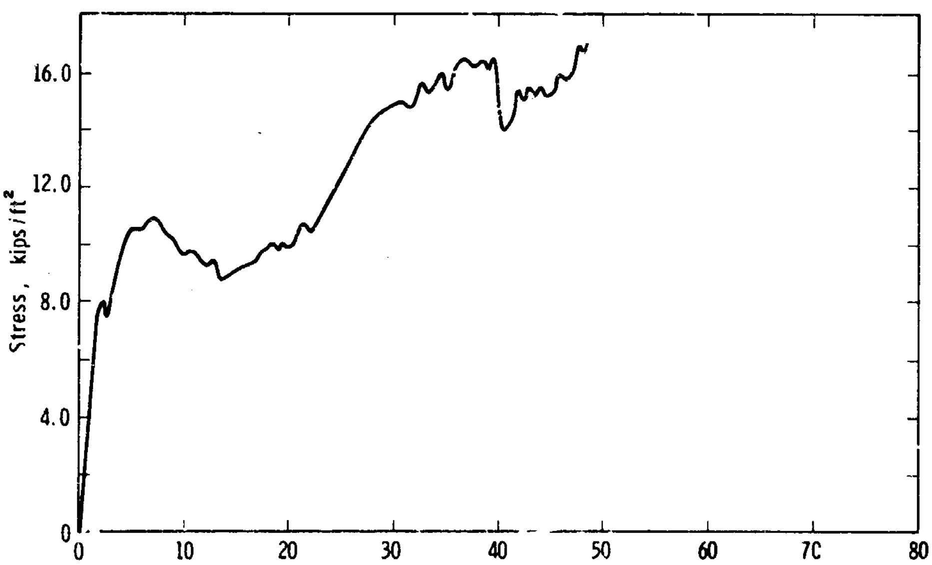
To meet the desired expansion ratio of 1 to 15, further development in improving the strength-to-weight ratio of sulfur foams would be desirable.

APPENDIX

DYNAMIC AND STATIC FORCE-DEFORMATION CURVES FOR FIRST, SECOND, AND THIRD SERIES OF SPECIMENS

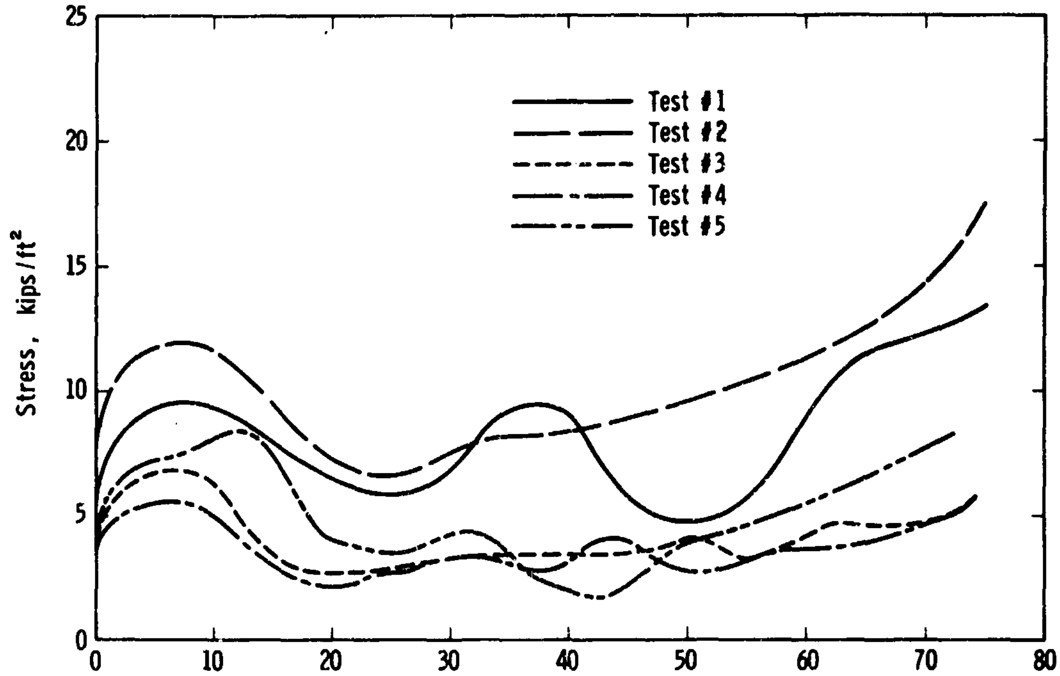


(a) Dynamic Force-Deformation Curves For 1st Series Of Specimens Submitted To Natick Labs

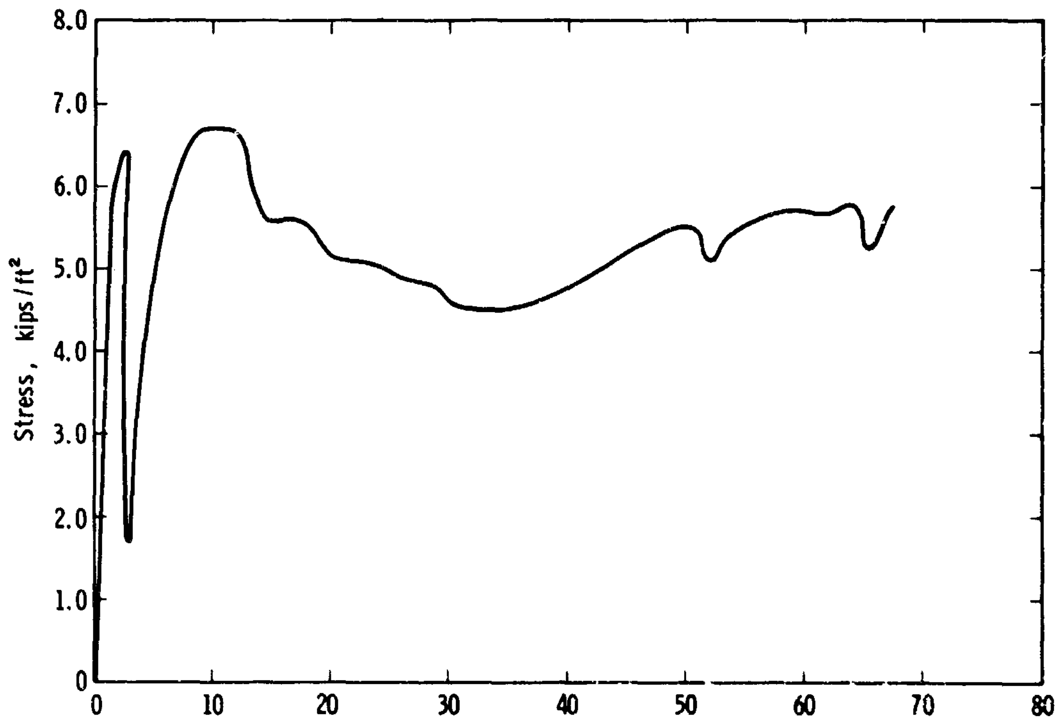


(b) Static Force-Deformation Curve For 1st Series Specimen Tested At Southwest Research Institute

FIGURE A.1. DYNAMIC AND STATIC FORCE-DEFORMATION CURVES FOR FIRST SERIES OF SPECIMENS

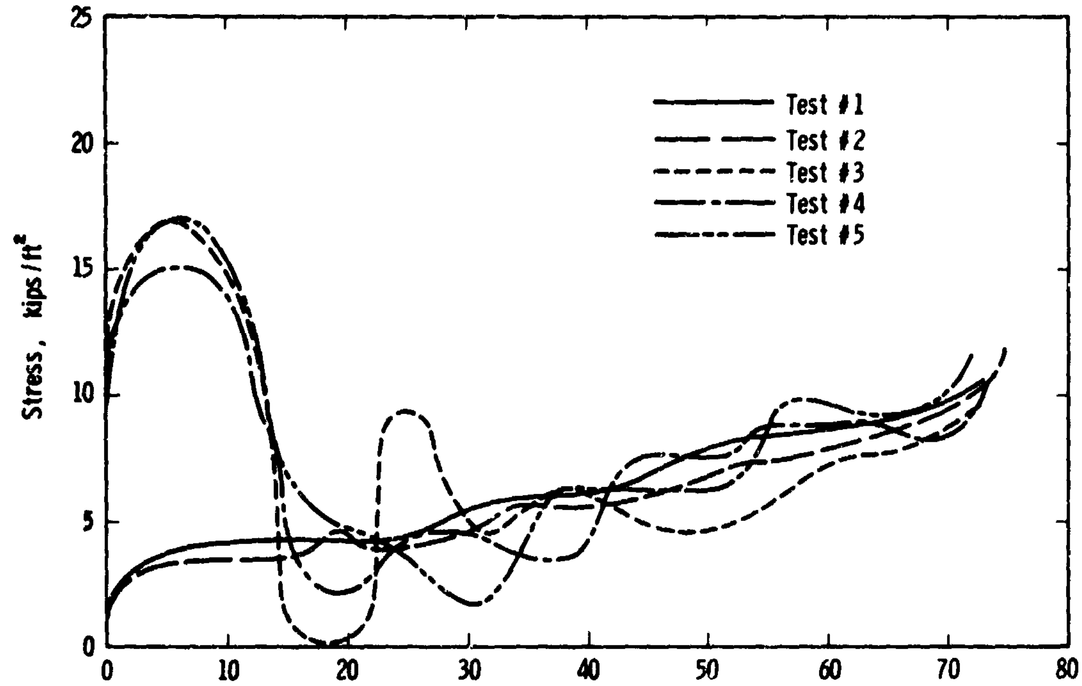


(a) Dynamic Force-Deformation Curves For 2nd Series Of Specimens Submitted To Natick Labs



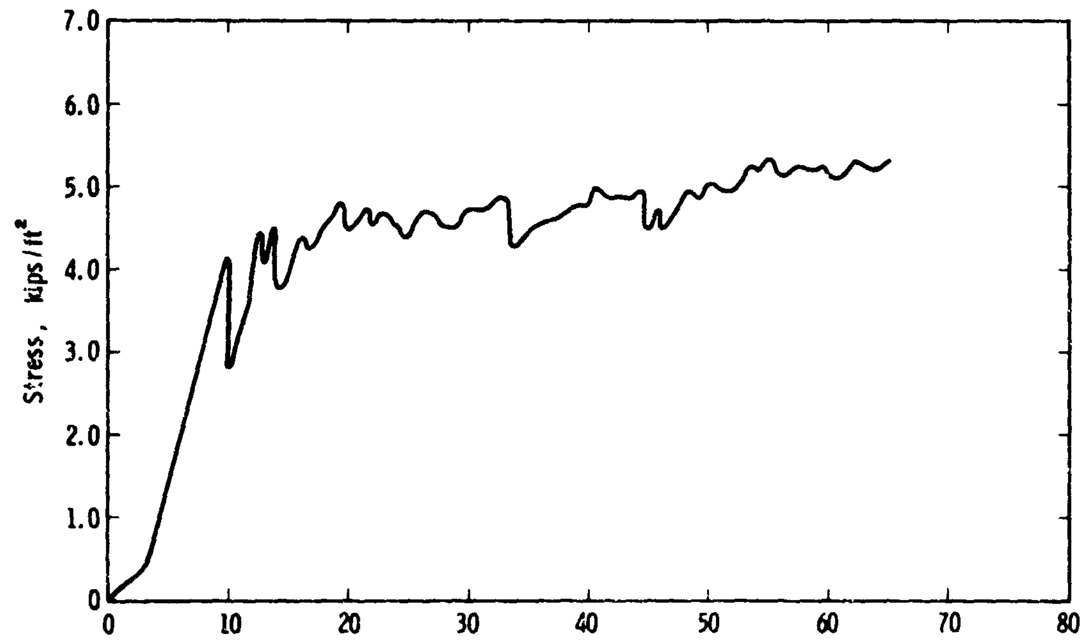
(b) Static Force-Deformation Curve For 2nd Series Specimen Tested At Southwest Research Institute

FIGURE A.2. DYNAMIC AND STATIC FORCE-DEFORMATION CURVES FOR SECOND SERIES OF SPECIMENS



Strain In %

(a) Dynamic Force-Deformation Curves For 3rd Series Of Specimens Submitted To Natick Labs



Strain In %

(b) Static Force-Deformation Curve For 3rd Series Specimen Tested At Southwest Research Institute

FIGURE A.3. DYNAMIC AND STATIC FORCE-DEFORMATION CURVES FOR THIRD SERIES OF SPECIMENS

13. Abstract (cont'd)

single 3-inch thick specimens from the final series. The 6-inch specimens prepared by using two 3-inch thick specimens had slightly higher crushing strengths than did the single 3-inch specimens.

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13. ABSTRACT Investigation of foamed sulfur as an improved energy dissipator to prevent damage to military equipment in airdrop applications has shown this material to have such desired project target characteristics as:

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An average crushing force of 6300 psf plus or minus 10 percent.

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The qualifications for the second and third requirements were that while it was possible to obtain expansion ratios of 1 to 13, the characteristics of sulfur foam were such that desired physical properties were best achieved at expansion ratios between 1 to 8 and 1 to 10. The target crushing force was attained with the two (cont'd)

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Impact strength	8					
Compressive properties	8					
Deformation	8					
Cost	8					
Expanded plastics	9					
Sulfur	9					
Foams	9					
Airdrop operations	4					