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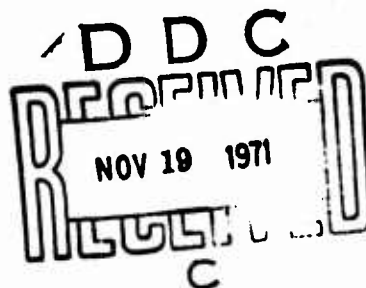
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DEVELOPMENT OF A WATER-SOLUBLE SODIUM SILICATE
FOAM FOR FRAGMENT RETRIEVAL

Prepared by

Southwest Research Institute
San Antonio, Texas

October 1971



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FINAL REPORT

Richard A. Owen

Prepared By:

Southwest Research Institute

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RAOwen
Aberdeen Proving Ground, Md.
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ABSTRACT

A new recovery material for use in fragmentation studies is described. The material, a sodium silicate foam, is water soluble which greatly facilitates fragment retrieval. Also, the material can be produced in any desired shape, on site, thereby reducing handling problems. The material can also be produced in a wide range of densities and other applications are suggested.

Results are presented that show the foamed sodium silicate substantially reduces secondary breakup of long slender fragments produced by thin wall shells.

A cost comparison of the sodium silicate foam with fiberboard for a 105mm panel test is presented.

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INTRODUCTION

The recovery of fragmented material is important to determine the lethality of a munition because it is necessary to know what fragments the shell produces and what is the distribution of these fragments. To gather this information, the fragments must be captured without extensive damage to the metal, and a repeatable distribution pattern must be maintained by the catcher material.

The present system of retrieval, which uses fiberboard as the catcher material, has several disadvantages. It is a laborious procedure to dig through fiberboards to find each piece of metal, and there is also reason to suspect that, by its nature, fiberboard causes extensive damage to the fragments. Due to its properties, fiberboard packs in front of the fragment as it travels through the board. The result of this compacting of fiber is the formation of large stresses on the projectile, thus causing greater damage.

SwRI has developed a technology to produce a foamed-in-place, sodium silicate foam which can be made water soluble during application. Hence, it was proposed that a fragment retrieval system, using sodium silicate foam, would be superior because the foamed material would permit easy retrieval by allowing the fragments to drop from the foam. Also, there would be reduced metal damage due to reduced packing effects on the fragments.

The foam offers other advantages, among which is the ability to produce it in any desired shape, on site, thereby reducing handling problems. Another advantage is the availability of any range of densities, to enable variations in recovery techniques.

DISCUSSION

The use of fiberboard is widely accepted as a means to recover fragments from all types of shrapnel-producing projectiles. One reason for its use is the availability of fiberboard in 4 ft X 8 ft X 1/2-in. sheets. These sheets are trimmed to the desired size and stacked to a depth sufficient to stop all the fragments. It is assumed that fiberboard is uniform throughout its mass and therefore will perform identically each time it is used.

When a metal fragment penetrates fiberboard at high velocities, it tends to rupture the adhesive bond between the wood particles at different rates. Pieces of the wood fiber are carried into the next sheet by the fragment. This creates a large drag on the fragment which, in turn, causes nonuniformity in compressive forces on the fragment. The consequence of this effect is a breakup of the fragment during penetration.

If X-ray photography is applied to study fragment formation at the moment of explosion, data can be obtained to indicate what should be retrieved from the catcher material. An example of this is provided in Figure 1 which is an X-ray photograph made by BRL at the point of explosion of a 20-mm shell. It shows that the metal casing is being fractured to produce strips of fragments having an approximate length to width ratio of 5:1 or 6:1. Numerous small fragments are combined with these larger fragments.

Recovery data for this same shell from fiberboard gives an entirely different picture of the distribution, dimensions, and mass of the fragments. Figure 2 is a compilation of data obtained from a 20-mm shell, where the fragments were retrieved from both fiberboard and sodium silicate foam. It can be observed that the weight distribution of fragments captured in Celotex is not in good agreement with the observed weight distribution in the X-ray photograph. The curve on the graph for Celotex indicates that nearly 40 percent of the total weight is in the weight interval of 8 grains or less. Such a weight distribution could only occur if the larger particles were broken down during capture. It is thus apparent that the lethality measurements from data obtained by recovery in fiberboard do not give a true picture of a given shell's lethal potential.

The normal procedure for recovery of fragments buried in fiberboard involves the use of one or more persons adept at inspecting and recovering small bits of metal from the fibrous mat. This is a tedious procedure where an error can be costly in giving a proper evaluation to

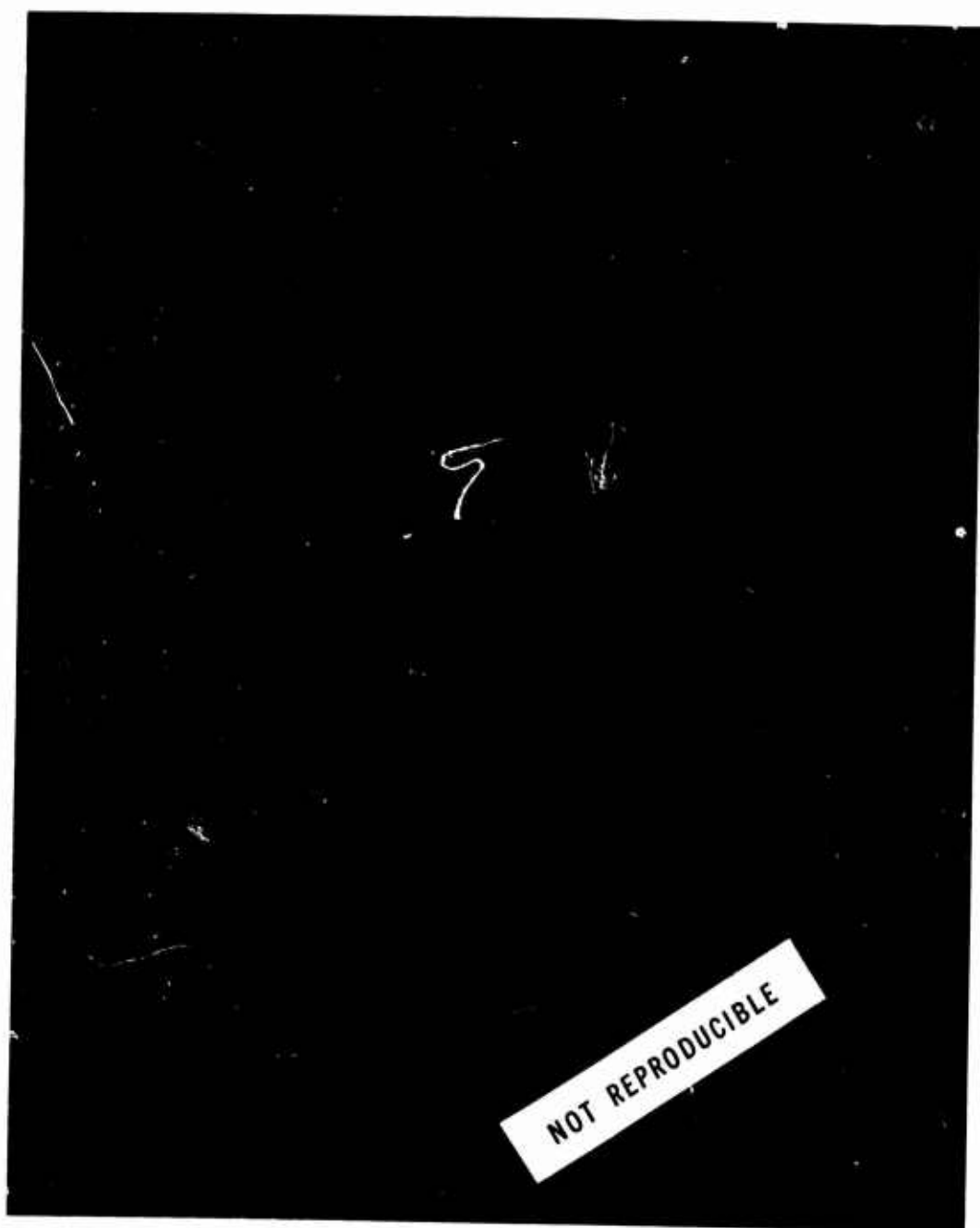


FIGURE 1. X-RAY PHOTOGRAPH OF 20-MM PROJECTILE
64.2 μ SEC AFTER INITIATION

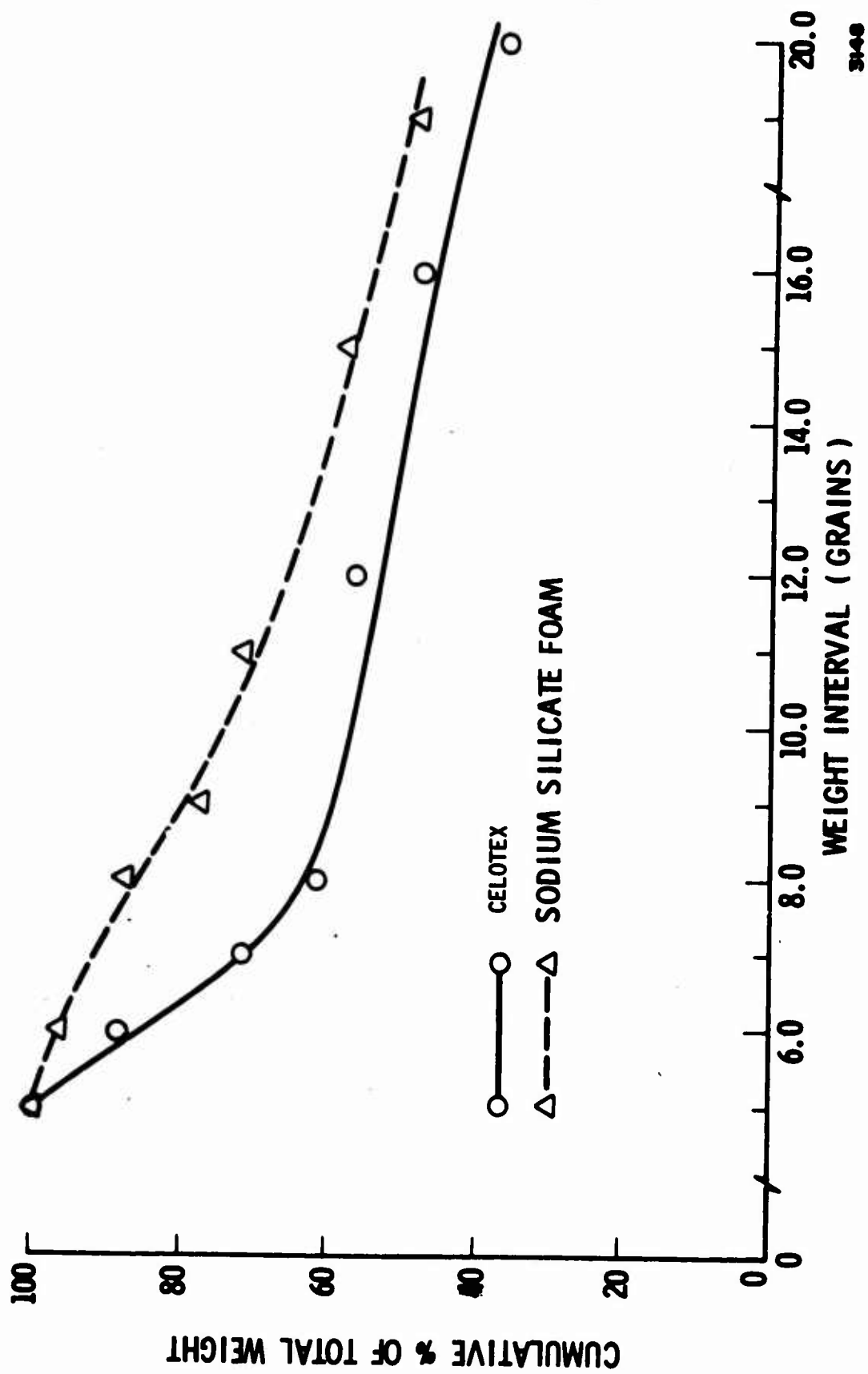


FIGURE 2. WEIGHT DISTRIBUTION OF FRAGMENTS IN CELOTEX AND SODIUM SILICATE FOAM

a particular projectile. Once a particle is found, it must be thoroughly cleaned before weighing. This is often difficult since the wood fibers are imbedded in the fractures of the metal. Any method allowing all the catcher material to be dissolved from the fragments in one operation would greatly reduce recovery time. It is also desirable to remove any material imbedded on the fragment by a simple washing procedure.

Sodium silicate is a manufactured material prepared from soda ash and sand, fused at temperatures of 1300° C to 1500° C. After fusion, it is dissolved by steam to form solutions in water of various concentrations. It is possible to make this material at various ratios of Na to Si and at various concentrations of solids in solution.

In the early 1960's, SwRI began to explore the possibilities of using this material to make foam. One result of this investigation was a foam containing 90% sodium silicate and < 1% organic materials which could be produced in-the-field or as a preformed product.

This foam is made by mechanically entraining air into the silicate solution. A surface tension depressant, usually organic, is the agent which achieves this air entrainment. After foaming is complete, a chemical is added which rigidizes the foam in a few minutes. A well-designed system can produce foam at the rate of 4 to 5 cu ft/min.

The materials used to manufacture this foam are inexpensive and readily available throughout the world. The raw materials for a typical formulation cost 2.7¢/lb, in bulk. Assuming a density of 12 to 14 pcf were needed, the cost would be 52¢ per cu ft. The apparent discrepancy in cost per pound and cost per cubic foot is due to the large loss of water from the foam after its manufacture. That is, if the foam were made at 20 pcf, it would dry to weight of 12 pcf.

The properties of sodium silicate foam are determined by the raw materials. This foam is a rigid, white, open cell foam containing 99+ % inorganic material. It has a compressive strength in a range of 20 to 35 psi. Because it is almost exclusively inorganic, it has no combustion temperature and melts at 1800° F. The foam can be poured into any mold shape, with a small amount of shrinkage, or it can be trimmed by hand with a knife. The raw materials produce no toxic effects. The finished foam can be handled without using protective gear.

To dissolve the foam requires tanks of water containing small amounts of NaOH. A typical dissolving solution consists of tap water containing 0.5 N NaOH. Such a solution causes a mild drying effect on

the skin but is not harmful in any other way. The purpose of NaOH in the solution is to raise the pH of the solution to accelerate the dissolving step. It is interesting to note that sodium silicate is considered a buffering material, and it will, therefore, maintain the high pH after dissolving. For example, the initial solution of 0.5 N NaOH in water would have a pH of 12 to 13. After an equal volume of foam is dissolved in it, the pH will still be 11 to 12 and will remain at that level after several more volumes of foam are dissolved.

Before a large test was performed, a small-scale test was devised to give a value of penetration for the foam compared to fiberboard. Small slabs of foam 12 X 12 X 1 in. were made and stacked beside fiberboard slabs 12 X 12 X 1/2 inch. A .308 caliber bullet was discharged from a conventional rifle through the 1/2-in. slabs of fiberboard. The bullet was recovered and depth of penetration was recorded. An identical caliber bullet was fired into the foam and a subsequent measure of penetration was made. Figure 3 is a display of both projectiles on the materials used. It is apparent that the damage to the bullet in the foam is much less severe than in fiberboard.

An identical test was performed using a 30-06 caliber bullet having a slightly higher velocity than the .308 caliber. The results of that test were important to the study since it was shown that foam with a high water content (35% compared to 15%) caused significantly greater damage to the projectile. It was therefore decided that the foam should have a water content of 15%, which is achieved by proper drying of the foam for 2 to 3 days. Research has shown that 15% of the initial water in the foam is chemically bound; thus, the water will not affect the performance. Any water in the foam which is not bound creates a packing effect similar to fiberboard.

Tests such as these do not establish absolute criteria for a test dealing with fragments. The fragments from an exploded shell will travel at more than twice the velocity of these bullets, and the fragments will not be aerodynamic in shape. Bullets were used in a preliminary test to predetermine the relative effects created by variations in the foam.

To make use of sodium silicate foam in a fragment retrieval system, the following procedure can be used. Foam can be produced either at a plant site or at the site of testing. If produced at a plant site, molds would be prepared to meet the specifications of the test, the foam would be prepared, it would be trimmed, packaged and shipped to the site for testing. If the foam were produced on-site, molds would be built in-place and filled

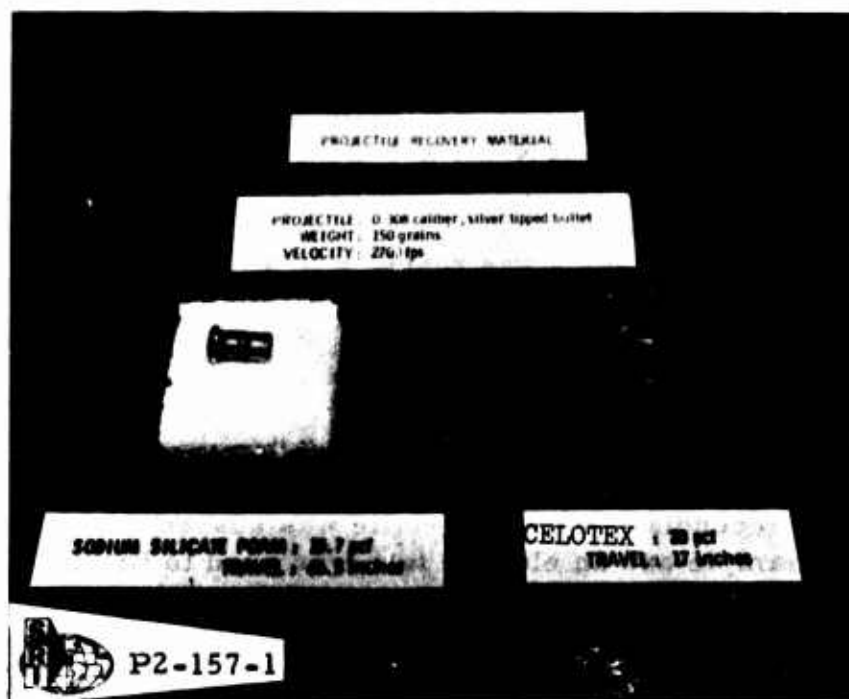


FIGURE 3. RESULTS OF DAMAGE TO .308 CALIBER BULLETS
IN SODIUM SILICATE FOAM AND IN CELOTEX

from a portable foam generator. After setting, the mold would be removed and the test would proceed.

It is apparent that for large-scale testing the most practical approach would be on-site foaming. Transporting large volumes of foam would be impractical and costly. The choice of methods would depend on the facilities available where the testing is to be done. Small tests involving only a few cubic feet of foam could best be done with preformed sections.

For the initial experimentation of foam as a retrieval medium, SwRI decided to use preformed slabs. Samples of foam were made in molds having dimensions 4 ft X 4 ft X 8 inches. The foam was made on a sand base, with plywood panels for side support.

After the foam set, it was removed to a trimming block where the surfaces were leveled and the trimmed samples set aside until the test. These samples had dimensions of 3 ft 8 in. X 3 ft 8 in. X 6.2 in. (see Figure 4).

Figure 5 shows the foam samples which were moved to the site and stacked with a sheet of Kraft paper between the layers of foam. A 20-mm high explosive incendiary (HEI) projectile was suspended 24 in. above the center of the sample and an electric fuse was used to fire the 20-mm shell. The selection of a 20-mm HEI was based on the available data for this shell, which has been evaluated extensively by X-ray photography and by retrieval from fiberboard.

After the shell was exploded, the foam samples and Kraft paper were removed (Figures 6 and 7). Each slab of foam was immersed in a tank of hot water, treated with NaOH. A metal screened box was used as a container for the foam slabs. This consisted of a 4 ft X 4 ft X 8-in. expanded metal frame, lined with a galvanized window screen. A cover screen was placed over the framework with the foam in place, and weights were added on top to hold the foam in the solution.

The box containing the foam was submerged in the solution and held for 30 min. It was then inspected, and, if any foam remained undissolved, it was submerged for another 30 min.

As each slab of foam was dissolved, a magnet was passed over the screen surface to pick up the metal fragments. Fragments from each 3 ft 8 in. X 3 ft 8 in. X 6.2-in. sample of foam were bottled and set aside. On inspection of the fragments, it was decided that a second washing in hot water would remove any traces of foam. Following this wash, the fragments were sprayed with preservative and weighed.



FIGURE 4. TRIMMING OF FOAM SAMPLES PRIOR TO TESTING



FIGURE 5. TEST SITE WITH FOAM SAMPLES IN PLACE

NOT REPRODUCIBLE

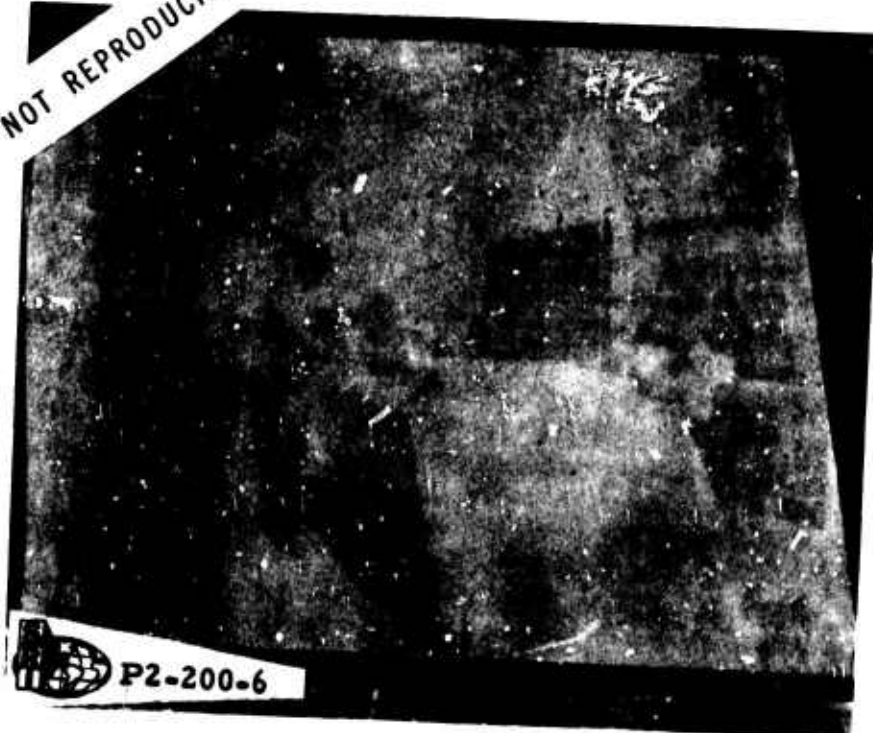


FIGURE 6. KRAFT PAPER SHOWING DISTRIBUTION OF FRAGMENTS



FIGURE 7. FOAM SAMPLE AFTER TEST WITH 6-INCH RULE IN CENTER

RESULTS

Two tests were performed on sodium silicate foam using 20-mm HEI projectiles. The 3 ft 8 in. X 3 ft 8 in. X 6.2-in. foam samples were stacked on each other. The amount of penetration was based on the number of samples that contained fragments. If the Kraft paper over any sample of foam was punctured, it was assumed that a fragment was in the sample.

The foam samples of the first test had a density of 13.0 lb/cu ft, while the foam samples of the second test had a density of 12.5 lb/cu ft.

On the first test the fragments penetrated into the second foam sample but did not reach the third sample. This indicates a penetration of less than 12.4 inches. The second test showed penetration through two samples, with one large fragment entering the third sample. This makes an approximate penetration of 14 in. for the second test.

The total weight of fragments in Test 1, sample 1, was 3.6 gm. Sample 2 of Test 1 contained 9.6 gm of fragments. This would indicate a total fragment retrieval of 13.2 gm and would be approximately 22.5% of the total fragments. For the second test, the total weight of fragments was 15.5 gm and again contained an amount equal to approximately 22.5% of the total fragments. Figures 8 and 9 show the fragments after they were recovered from the foam, washed, and treated to prevent oxidation. It can be seen that there are large fragments with rough edges, as would be expected from the type of explosive, and indicates that the foam does very little damage to the fragments.

The physical appearance of the foam after the test indicated that there was no packing of the foam in front of the fragment. This supports the idea that packing could be the cause of damage to fragments in fiber-board.

Due to the nature and location of the tests, there was a lack of hot water for dissolving the foam samples. The result was variations in dissolving rates since the temperature of the dissolving tank fluctuated with outdoor temperature changes. The dissolving times varied from 30 min to 2 hr, and it was decided that the foam could be broken into smaller pieces and dissolved more rapidly.

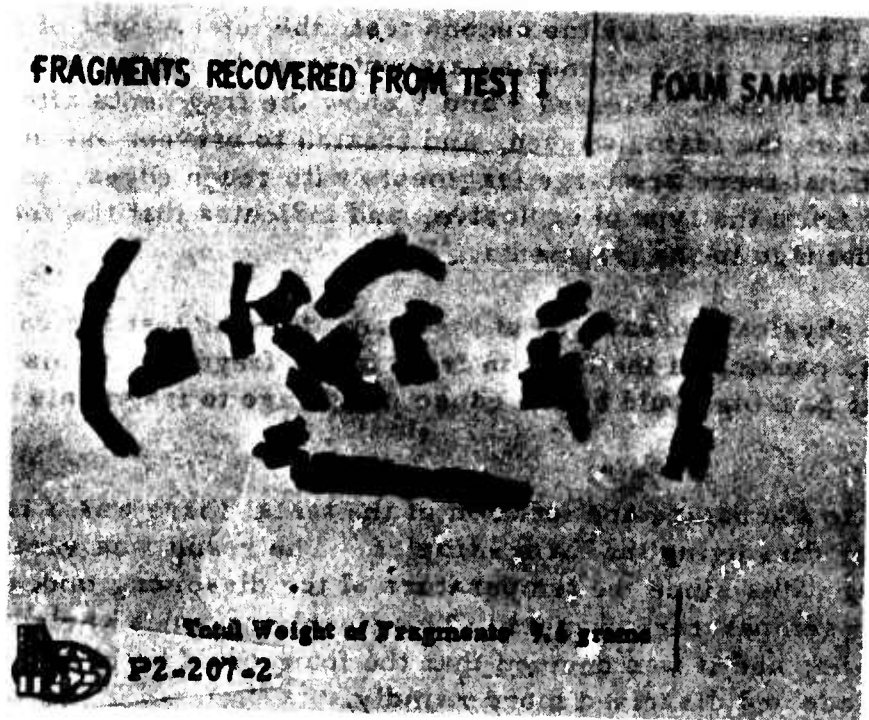


FIGURE 2. TEST 1 SPECIMENS ILLUSTRATING LONG, IRREGULAR SHAPES UNLIKE THOSE OBSERVED IN CELOTEX

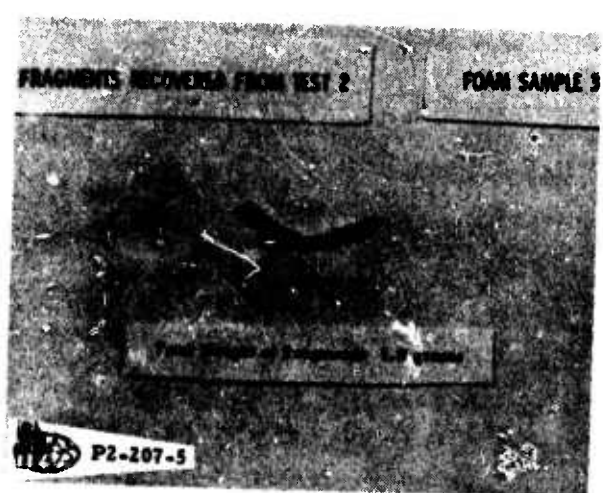
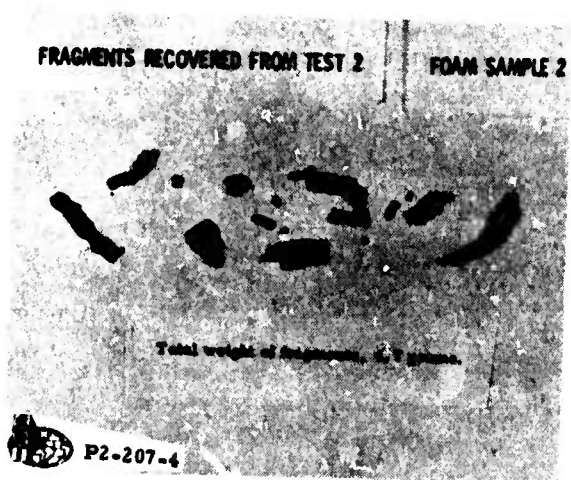
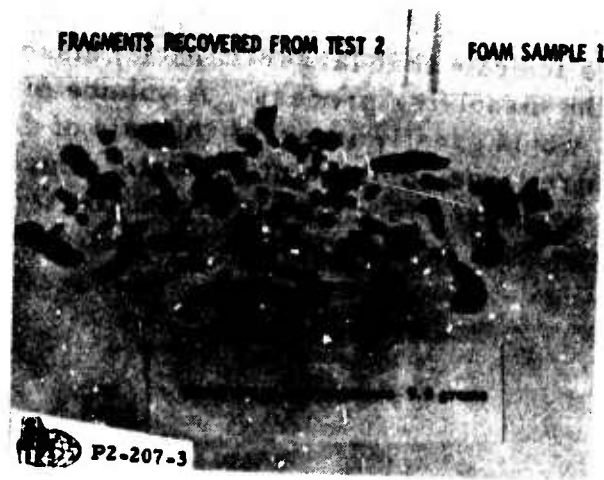


FIGURE 9. TEST 2 SPECIMENS ILLUSTRATING LONG, IRREGULAR SHAPES UNLIKE THOSE OBSERVED IN CELOTEX

These results indicate that larger-capacity dissolving tanks are needed to speed up the dissolving process. A volume of liquid to volume of foam ratio of 5 : 1 would greatly improve the rate of dissolving. Such a system would require large volumes of hot water which could be circulated through a heat exchanger to maintain a constant temperature. The most desirable temperature is 140° F, at a concentration of 0.5 N NaOH.

CONCLUSIONS

The objective of this program was to give comparative data on fragment retrieval from fiberboard and from sodium silicate foam.

Fragments recovered from fiberboard have never agreed with the X-ray photographs because of the apparent secondary breakup of the fragments. A comparison of Figure 1 with the curve of weight distribution of fragments recovered from sodium silicate foam (in Figure 2) shows that only 20% of the total weight of fragments is in the 8 grain to smaller size, and unlike the Celotex distribution there is a more uniform particle size distribution over the entire weight range.

It is also of interest that the photographs of the recovered fragments more closely resemble the fragments as shown in Figure 1 than would those observed from Celotex recovery. Also, there are sharply defined edges on the fragments which indicate that the foam caused little or no damage to the metal.

Fragment recovery from the foam was much easier than a similar recovery from fiberboard. Using the foam, there was no need for inspecting small segments since the entire sample could be dissolved at one time. The recovery of the foam required the use of a magnet to pick up the fragments from the solution and a secondary washing system to insure that all foam particles were dissolved.

When the dissolving tank was properly regulated, the retrieval time was less than 1 hr for 8 cu ft of foam. It has been calculated that if the volume of dissolving solution were ten times the volume of foam the time of solutioning would be approximately 15 min. Since the initial solution can be reused many times due to buffering this means the total volume of foam which can be dissolved is equal to the volume of dissolving liquid.

From this test, it can be concluded that, to stop all fragments from a projectile, it will take a volume of foam approximately double that required for fiberboard.

Comparative data has been determined for a 105 mm M1 arena test. This arena has a volume of 960 cu ft. The material cost for using Celotex in such a test has been evaluated at \$3024.00. An equivalent amount of foam would have a material cost of \$1301.50. The labor costs (at a rate of \$23.21/man hour) using Celotex is \$3720.00. The labor costs using foam would be \$2224.16.

The figures for labor when using foam as the retrieval material are based on an eight hour foaming period and include dissolving the foam and retrieving the fragments.

There are two approaches to produce silicate foam. It could be produced at a plant site where it would be packaged and transported to the test location. This approach is very practical when the total volume requirements are small, as in the case of 20-mm projectiles. It is not, however, practical when large arena tests are conducted. For an arena test, the best method would be to use a portable generator, mounted on a truck bed. The generator could operate under field conditions where water and compressed air are available. The raw materials could be trucked to the site, and the foam would be generated into molds conforming to the necessary dimensions of the test. This would require the fabrication of plywood panels to contain the foam until setting, and these could be dismantled and reused on consecutive tests. Such a system would minimize the labor costs and eliminate the shipping costs.

After a test firing, the foam could be cut into appropriate zones and moved to dissolving tanks placed either in the field or at a central location. A small tank which could hold the foam representing a single zone or a larger tank with an inner framework of screens for dissolving a number of zones could be built. With this system blocks of foam could be immersed for the desired length of time, thus displaying the cleaned fragments for hand or mechanical recovery.

The particular type of projectile would determine whether to use preformed sections of foam or in-place foaming as the method of preparation.

RECOMMENDATIONS

Silicate foam can be produced in a wide range of densities, from 3 to 20 pcf. This variability offers an opportunity for the use of foam in other types of projectile recovery. An example of a potential use would be the recovery of projectiles having fuses which are armed during acceleration or deceleration. By varying the density of the foam, an ideal deceleration rate could be achieved without damage to the projectile.

Any use of silicate foam in arena testing would require a modification to the present foaming system but is well within the capability of SwRI. Also, the proper adaption of this system to large scale tests such as the 105mm M1 arena test would require further study of the dissolving system. It is important that the dissolving be economical and rapid.