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USE OF SHOCK-ABSORBING CONCRETE (SACON) AS AN ENVIRONMENTALLY COMPATIBLE BULLET-TRAPPING MEDIUM ON SMALL-ARMS TRAINING RANGES

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ABSTRACT

Shock-absorbing concrete (SACON) is a low-density, fiber-reinforced, foamed concrete that is used as an energy absorbing material. SACON has found wide applications in the construction of live-fire training villages and the fabrication of target structures. SACON is manufactured by blending sand, portland cement, and water with an aqueous-based foam and a steel or polymer fiber. Typically the resulting concrete will have a density that is approximately one-half that of conventional concrete and an unconfined compressive strength that is one-third to one-fourth that of conventional concrete. SACON offers numerous advantages over wood, rubber tires, or earth berms in trapping bullets on small-arms firing ranges. It will not burn, does not rot, and does not have to be protected from insects. SACON does not erode away, typically maintains an alkaline condition that can slow down metal corrosion and, it is a closed-cell, foamed solid that has low leachability. The current study was undertaken to develop design data for SACON to be used as bullet traps on training ranges. Test blocks were fired on using the M16 rifle with M855 ball ammunition so that the effects of multiple impacts at a single point could be assessed. The bullet debris that accumulated in thick blocks of SACON did not produce ricochets, even when thousands of rounds were fired at a single point. Pockets or cavities containing bullet debris were developed in some block as shooting continued. The debris deflected incoming bullets upward in the blocks and eventually bullets would crack the top surface of the block. Polypropylene fiber-reinforced SACON performed in a manner comparable to steel fiber-reinforced SACON. Examination of samples of dust produced by the bullet impacts showed that bullet-to-bullet impacts can result in metal particles that can be detected in the dust.

1. INTRODUCTION

The Army is the major service involved in training troops in the use of small-arms (weapons equal to or smaller than 0.50 caliber). Sixty-seven percent of Army firing ranges are small-arms training ranges. The Army currently operates 1,400 outdoor, small-arms ranges in the continental United States and fires over 302 million rounds of small-arms ammunition each year. Military ammunition is fabricated using a full metal jacketed bullet that consists of a brass (copper and zinc) jacket over a hardened lead alloy (lead and antimony) or lead alloy and steel core. Training activities distribute approximately 3139 tons of bullets into the soil on training ranges annually. Bullets impacting in soil typically fragment and the fragments corrode. The bullet debris and corrosion products become mixed into the soil. The cost of removing metals from soil can range from \$390 to \$650/m^3 (\$300 to \$500/yd^3). In order to prevent metals from being distributed in the soil it is necessary to trap the bullets and reclaim the metal that would normally be distributed over the training range. Systems for trapping bullets before they enter the soil are being investigated as part of the U. S. Army Environmental Center program for controlling the migration of heavy metals on training ranges and reducing any potential impact on the environment at these training sites[1]. The investigation reported here relates to the use of foamed, fiber-reinforced concrete (SACON) as an environmentally compatible, bullet trap.

1.1 SHOCK-ABSORBING CONCRETE (SACON) BULLET TRAPS

SACON traps are made by adding an aqueous foam and fiber to a slurry of sand, portland cement, and water. The light-weight concrete develops a closed, cellular structure that collapses when a bullet impacts the concrete. In a properly designed target system the incoming bullet buries itself in the concrete and does not ricochet[2]. The fiber adds fracture toughness and reduces spalling. The proportions of materials used to prepare SACON with a nominal density of 1,442 kg/m^3 (90 lbs/ft^3) is given in Table 1. SACON differs from conventional concrete in that no coarse aggregate is used in the mixture and foam and fiber are added to the mixture to reduce the density and reduce cracking and spalling, respectively.

1.2 PHYSICAL PROPERTIES OF SACON

Increasing the amount of fluid-filled void space in concrete lowers its strength. Conventional concrete has a unit weight of approximately 2,560 kg/m^3 (160 lbs/ft^3), while a typical SACON block (prepared using the proportions given in Table 1) will have a nominal density of 1,440 kg/m^3 (90 lbs/ft^3). SACON has about one-half the density of concrete. The unconfined compressive strength of conventional concrete is on the order of 21 MPa (3,000 psi); while that of SACON is approximately 6 MPa (870 psi) or one-third the strength of conventional concrete (Table 2). When steel fiber is used as reinforcement the flexural strength of SACON (as measured by the modulus of rupture) is over 3.4 MPa (500 psi)[3].

TABLE 1. FORMULATION OF SHOCK-ABSORBING CONCRETE NOMINAL 90 LB/FT^3 DENSITY* (1,442 KG/M^3)

Cement, Portland Type 1	972 lb/yd^3	577 kg/m^3
Sand (ASTM C 33)	972 lb/yd^3	577 kg/m^3
Water	465.6 lb/yd^3	276 kg/m^3
Aqueous Foam	8.9 ft^3/yd^3	0.33 m^3/m^3
Stabilizer	0.27 lb/yd^3	0.16 kg/m^3
Steel Fiber	193 lb/yd^3	115 kg/m^3

* Actual density after addition of steel fiber is 97 lb/ft^3 (1,554 kg/m^3)

1.3 CHEMICAL PROPERTIES OF SACON

SACON is designed using Type I portland cement and can be expected to have the chemical characteristics associated with conventional concrete made with this same cement. In the hardening process in concrete the calcium silicate phases in the cement react with water to form calcium silicate hydrate gel and calcium hydroxide. The predominant calcium silicate phase present in Type I portland cement is tricalcium silicate (typically 50 percent of the cement by mass). During hydration the tricalcium silicate will produce 21 kg of calcium hydroxide for every 100 kg of tricalcium silicate (or 21 kg of calcium hydroxide for every

TABLE 2. PHYSICAL PROPERTIES OF 90 LB/FT^3 DENSITY* STEEL FIBER REINFORCED SHOCK-ABSORBING CONCRETE

Unconfined Compressive Strength	psi	MPa
7 day age	663	4.57
28 day age	836	5.76
60 day age	956	6.59
Flexural Strength		
28 day age	565	3.90
60 day age	525	3.62

* 90 lb/ft^3 is the nominal density, actual density is 97 lb/ft^3

200 kg of cement reacted). Hardened concrete will generally react very slowly with the carbon dioxide in the air and over the course of years the solid mass will drop in alkalinity with the center of the concrete mass being affected last[4]. Concrete made with portland cement can be expected to remain alkaline for years under normal atmospheric exposure. While the low density of SACON could increase the rate of gas diffusion, the high cement content in SACON will work toward maintaining alkalinity.

1.4 BULLET-TRAPPING PROPERTIES OF SACON

SACON has a cellular structure and projectiles impacting on SACON crush the cells as they enter the solid. The effects of fractures propagating from the impact point are minimized by the fibers cast into the foamed concrete matrix. The depth of penetration of a bullet into SACON depends on the shape, cross-section, density, pattern of deformation, and the kinetic energy of the bullet. The complicated nature of the interaction of these factors has caused most investigators to rely on empirical data obtained in live-fire testing as a basis for designing bullet-stopping structures. The most common data obtained in a live-fire test is the apparent depth of penetration, the distance from the surface of the SACON to the rear of the embedded bullet. Table 3 shows typical penetration depths observed when a variety of rounds are fired at close range (less than 6 m) into 1,442 kg/m^3 (90 lb/ft^3) SACON.

TABLE 3. DEPTH OF BULLET PENETRATION IN 90 LB/FT^3 *
STEEL FIBER-REINFORCED SACON

Weapon	Average Penetration	
	inches	mm
0.38-cal pistol	1	25
0.45-cal pistol	1.25	32
9-mm pistol	2.37	60
M-16 A2 rifle (5.56 mm 56 grain ball)	2.5	64
M-16 A2 rifle (5.56 mm 62 grain penetrator)	2.8	71

* Nominal Density - Actual Density is 97 lb/ft^3 (1,554 kg/m^3)

In designing SACON bullet-traps, the depth of penetration of a particular round is only one consideration. The objective of a trap is to successfully contain the fired bullet. The SACON must be of such low density that the bullet will not ricochet even when striking the surface at a low angle. Intact bullets are less of a problem for containment than bullet fragments. Traps that do not cause the bullets to shatter or separate the core and jacket are preferred. These additional considerations make live-fire testing a necessary starting point for any bullet trap design effort.

2. LIVE-FIRE TESTING PROGRAM

Most small-arms training in the Army is conducted with the M16A2 rifle firing the M855, 5.56-mm ball cartridge. The M855 round has a fully brass-jacketed, 4-g (62-grain) pointed-tipped bullet. The bullet contains a steel cone and a lead slug. Live-fire tests were undertaken using this cartridge with the following objectives:

a. Establish the depth of penetration for single and multiple impacts at a single point on the bullet-trapping block.

b. Determine if bullet-debris accumulating in the SACON bullet trap will result in the production of ricochets that could be a hazard to the shooter.

c. Determine the effect of fiber type on the depth of penetration.

d. Make a preliminary assessment of the composition of dust generated in bullet-to-SACON and bullet-to-bullet impacts.

2.1 TEST SPECIMENS AND TEST METHODS

Concrete samples were prepared by mixing the components in the proportions indicated in Table 1. One specimen prepared with the identical formulation and polypropylene fiber added at a rate of 7 kg/m^3 (12 lbs/yd^3) was available from an earlier test sequence. All specimens were cured in a 100 percent humidity condition at 23 °C for 28 days.

All live-fire testing was done at an outdoor range, with the shooter-to-target distance maintained at 6 m (18 ft). The rifle used was bench-mounted and equipped with a telescopic sighting device that allowed the bullets to be grouped within a 5-cm (2-in.) circle. All rounds were fired perpendicularly into the target block The test blocks were placed in a plexiglass enclosure with a bullet port in front of the impact point. The dust that was produced by the bullet impacts collected in front of the target block and could be periodically sampled. At selected intervals during the shooting, the apparent depth of penetration of the bullet hole was determined by measuring the lateral distance a 4-mm diameter wooden rod could be pushed into the bullet hole before it encountered resistance.

After the live-fire testing was completed selected test blocks were injected with urethane foam to hold the bullet debris in place and cut into halves vertically along the bullet path using a diamond saw. The blocks were photographed and the size of the cavity was determined by removing portions of the bullet debris contained in the block.

Selected dust samples were pressed into pellets and coated with carbon, and analyzed using an Electroscan 2020 scanning electron microscope equipped with a Princeton Gamma Tech Prism, digital x-ray spectrometer. The surfaces of selected pellets were mapped using a Princeton Gamma Tech microanalysis unit attached to a Hitachi S2500 scanning electron microscope to determine the distribution, composition, particle size, and shape of metal fragments present in the dust.

2.2 RESULTS

Table 4 summarizes the data obtained on penetration from successive bullets fired at the same point. All blocks less than 46 cm (22 in.) thick were shot through front-to-back with fractures occurring at the rear of the blocks. In blocks that were 56-cm thick or thicker, the bullet debris accumulated at a depth ranging from 25 to 48 cm (10 to 19 in.) and subsequent bullets were deflected upward inside the block. When blocks thicker than 56 cm (22 in.) showed failure, the fractures occurred at the top of the block, not on the rear surface.

TABLE 4. RESULTS OF LIVE FIRE TESTING

Specimen Designation	Thickness cm (in.)	Maximum Depth of Penetration cm (in.)	Number of Rounds Fired	Remarks
12B	30.5 (12)	30.5 (12)	12	Back of block failed.
12C	30.5 (12)	30.5 (12)	21	Back of block failed
12D	30.5 (12)	22.8 (9)	30	Block removed for examination
12E	30.5 (12)	29.2 (11.5)	81	Back of block failed
24A	57.2 (22.5)	25.4 (10)	370	Top of block failed
24B	57.2 (22.5)	47.8 (18.8)	570	Top of block failed
36	91.4 (36)	46.2 (18.2)	1,800	Top of block failed
22 Poly*	57.2 (22.5)	45.7 (18)	5,800	Block removed for examination

* Polypropylene fiber used in this block

No ricochets occurred at any point in the live-fire testing program. A SACON block that was prepared with polypropylene fiber was hit at one impact area with 5,800 bullets and although an extensive cavity containing bullet debris developed (Figures 1 and 2), no ricochets were produced. The mass of compacted bullet debris was evident when the block was cut apart, but the mass had been impacted by incoming rounds thousands of times during the test without forcefully deflecting a bullet out of the block.

The single polypropylene fiber-reinforced SACON block that was tested behaved in a manner similar to the steel fiber-reinforced SACON. The depths of penetration were comparable and the deflecting effect of the bullet debris was similar to the effect observed in the blocks containing steel fiber.

The preliminary analysis of the dust ejected from a block that had been hit at four separate impact points (only bullet-to-SACON impacts) showed that the dust is primarily sand and hydrated cement (Figure 3). Dust from a block that had taken 30 bullet impacts at a single point (producing a significant number of bullet-to-bullet impacts) showed detectable fragments of lead and copper (Figure 4).

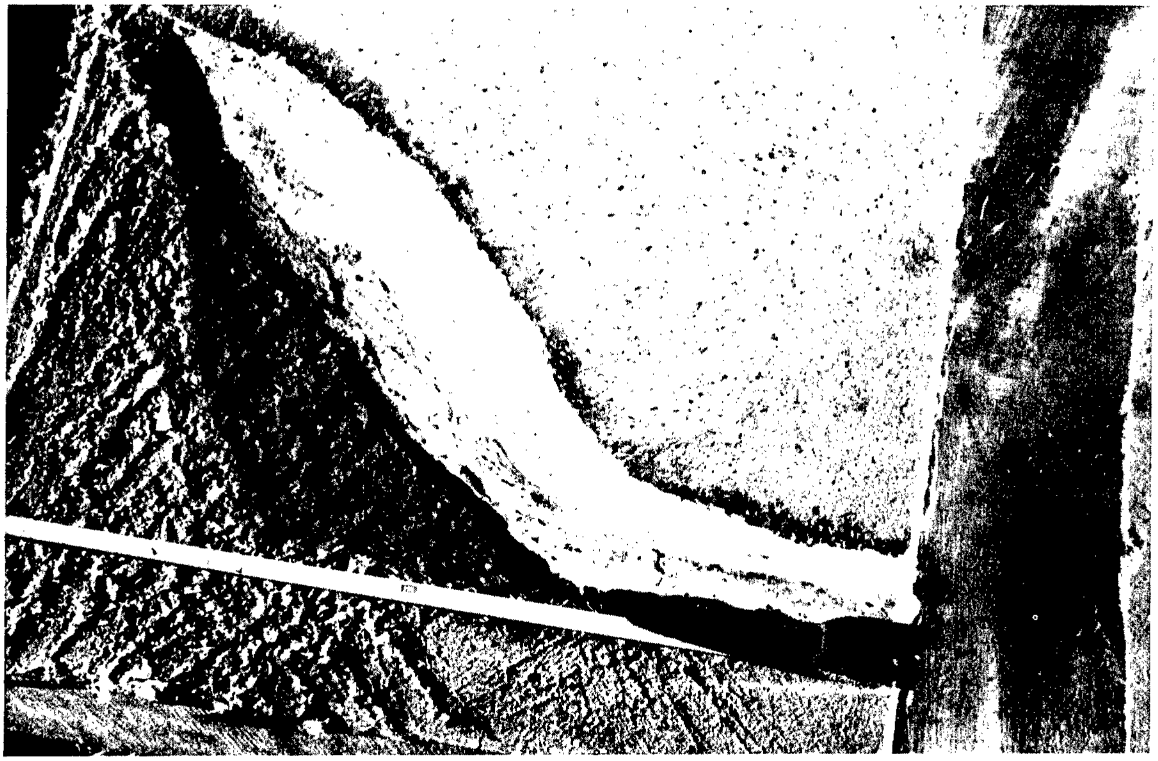

Figure 1. SACON block impacted by 5,800 bullets. The cavity was filled with white urethane foam prior to cutting the test block. The point of entry is the lower right end of the foam mass. The dark grey material to the left is bullet debris.

Figure 2. Close-up of cavity in SACON block. The cavity extended over 10 cm from the center line of the bullet path. The point of the trowel is resting on a mass of bullet debris.

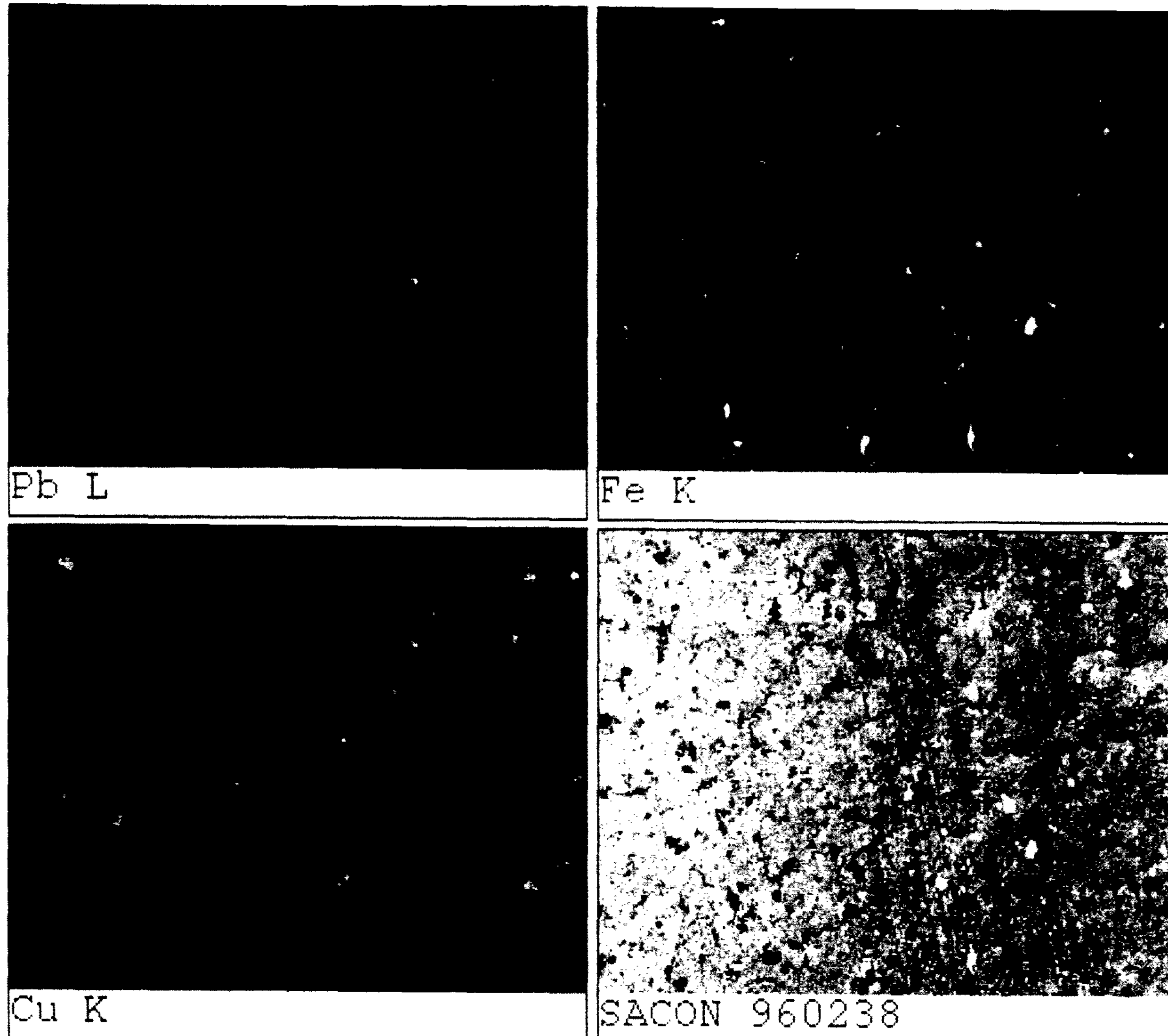

Figure 3. Electron-excited x-ray fluorescence maps showing metal distribution in the dust from a block having only bullet-to-SACON impacts. Very few particles are imaged by the characteristic radiation from lead or copper. The image on the lower right is the electron-backscatter image of the surface of the powder pellet. Bulk analysis using x-ray fluorescence showed no measurable lead (estimated at less than 0.1% by mass) and 0.3% by mass copper.

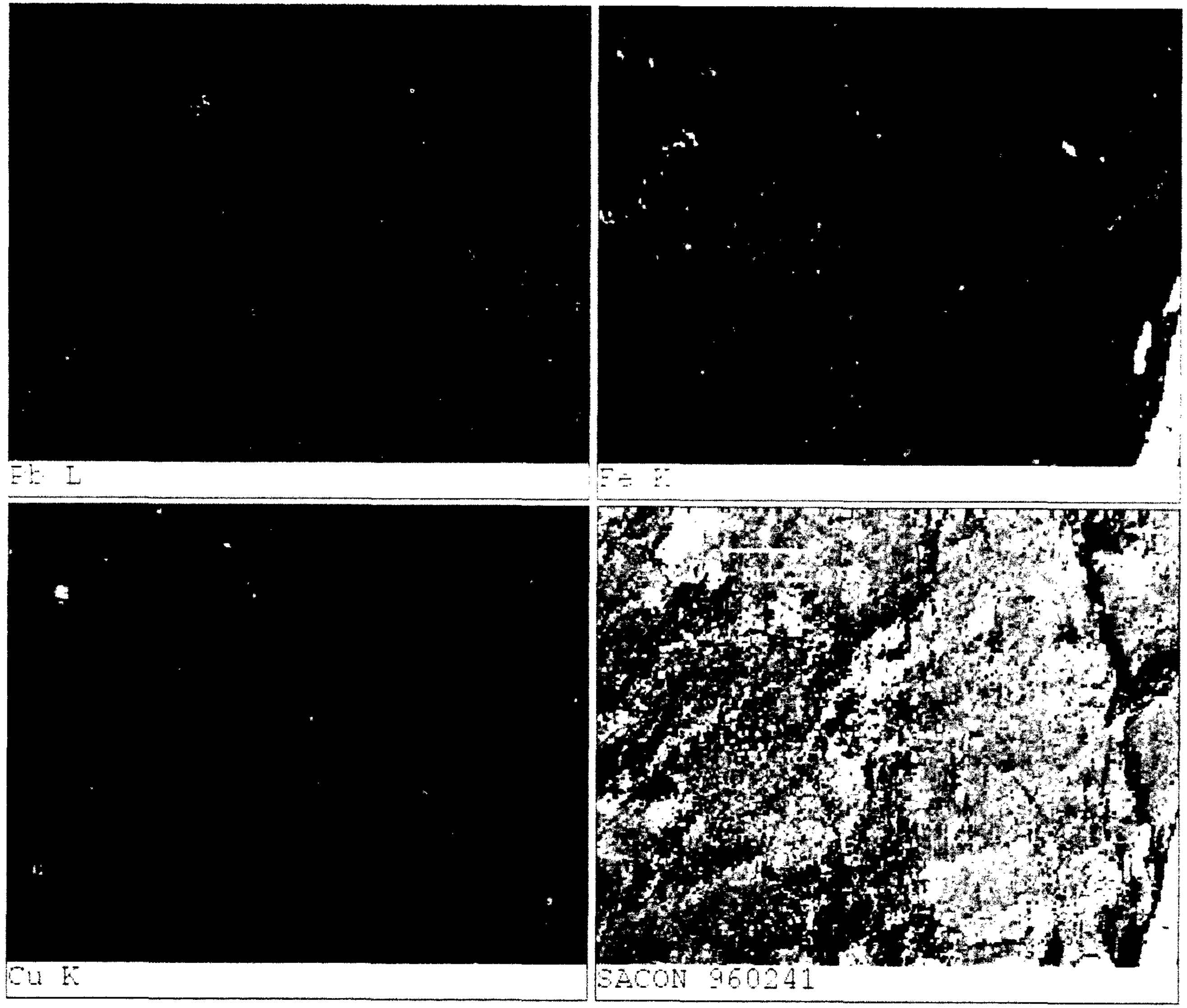

Figure 4. Electron-excited x-ray fluorescence maps showing metal distribution in the dust from a block having numerous bullet-to-bullet impacts. Block was hit at a single point with 30 bullets. A large number of particles are imaged by the characteristic radiation from lead or copper. The image on the lower right is the electron-backscatter image of the surface of the powder pellet. Bulk analysis using x-ray fluorescence showed 3.2% by mass lead and 1.1% by mass copper.

CONCLUSIONS

The investigations of SACON reported here indicate that multiple bullet impacts at a single point can produce a dense mass of bullet debris inside a thick SACON bullet-trapping block. The debris does not produce ricochets; and can deflect the subsequent bullets upward inside the block. The bullet deflection can cause blocks to eventually fail at the top surface rather than the rear surface. The polypropylene fiber-reinforced SACON showed penetration and bullet-trapping characteristics that were basically similar to those observed with steel fiber-reinforced SACON. The preliminary examination of dust from bullet-to-SACON impacts showed negligible metal debris. Dust from blocks where a significant number of bullet-to-bullet impacts occurred contained detectable fragments of copper and lead.

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REFERENCES

1. TRW, Inc. (1996) "Bullet Trap Feasibility Assessment and Implementation Plan. Technology Identification." Report Number SFIM-AEC-ET-CR-96005. U. S. Army Environmental Center, Aberdeen Proving Ground, MD. 94 pp.

2. Denson, R. H., Kane, R. J., and Watanabe, W. A. (1987) "Combat-in-Cities. Live-Fire Training Test." Letter Report to U. S. Army Training Support Center, Concrete Technology Division, Structures Laboratory, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 20 pp.

3. Denson, R. H., Hoff, G. C., Koop, D. L., Monahan, A., and Tom, J. G. (1984) "Materials Systems Investigation for MOBA/MOUT Live-Fire Training Villages." Miscellaneous Paper SL-84-12. U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 194 pp.

4. Neville, A. M. (1973) "Properties of Concrete." John Wiley and Sons. New York. 686 pp.