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Transparent, Lightweight Safety Shields for Small-Scale Operations Involving Explosives

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by

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TRANSPARENT, LIGHTWEIGHT SAFETY SHIELDS FOR SMALL-SCALE OPERATIONS INVOLVING EXPLOSIVES

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ABSTRACT

Laminated glass, polymethylmethacrylate, and polycarbonate (Lexan) safety shields were subjected to blast and fragments from 11.5 gm, steel-confined explosive charges, and to impact by .30 cal bullets. A 1/4-in.-thick sheet of glass backed by a 1/2-in.-thick sheet of Lexan proved to be an especially effective combination under the conditions of these tests and is recommended as a lightweight, transparent safety shield for small-scale operations involving explosives.

INTRODUCTION

Transparent safety shields for laboratory work are commonly made from laminated glass or an acrylic plastic, such as Plexiglas. For many applications, either is satisfactory. However, for our work with high explosives we have long had a requirement for a light, transparent shield to provide protection from the blast and high velocity metal or glass fragments that could arise from the accidental detonation of several grams of explosive in a laboratory experiment. Neither safety glass nor Plexiglas completely satisfied the requirements, although both were tried in a variety of arrangements.

Recently the polycarbonate resins became commercially available, and it appeared that they might possess the combination of toughness and flexibility required for a blast and fragment shield. The material we selected for testing is the polymer marketed by the General Electric Company under the trade name Lexan. Two-foot-square sheets of Lexan in thicknesses of 1/2, 3/4, and 1 in. were obtained from Argo Plastics Company, Los Angeles, California, and were compared in several configurations with safety glass and polymethylmethacrylate. The results, summarized below, indicate that Lexan by itself provides an effective shield in this application, but the best transparent shield we have yet tested is a composite shield consisting of a sheet of glass backed by a sheet of Lexan.

TEST PROCEDURE

For the purpose of comparing shield materials, we use the arrangement shown in Figs 1 and 2. Four samples, loosely supported in a metal frame, are symmetrically arranged around the charge and at a distance of 12 in. from it. The charge, which is supported at the center on a block of foamed plastic, consists of a 1/2-in.-dia x 2-in.-long cylinder of plastic-bonded explosive (94% HMX, 6% binder, density 1.84 gm/cc) confined in a 1/8-in.-wall mild steel case. The explosive weighs about 11.5 gm, the steel case about 61 gm. Usually, 3/4-in.-thick plywood targets are located 6 in. or so behind the shields to assess the number and penetrating power of any fragments that may penetrate the shields, or that may originate as spall from their back surfaces. A 1/4-in.-thick Dural plate is frequently included as one of the four sides to determine the fragment pattern. In all the tests reported here the shields were about 24-in. wide; their heights

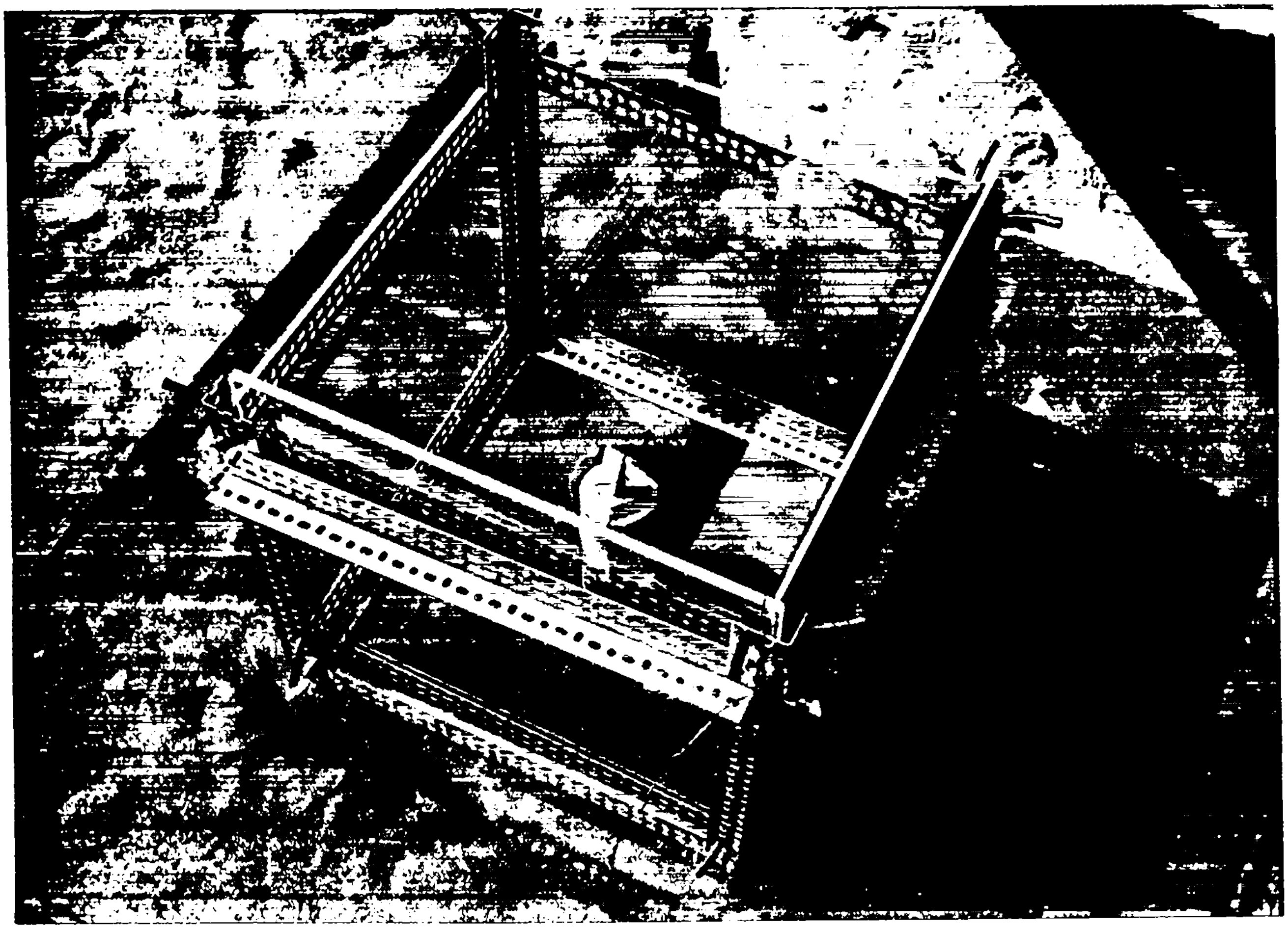

Fig 1 - Experimental arrangement used for safety shield tests.

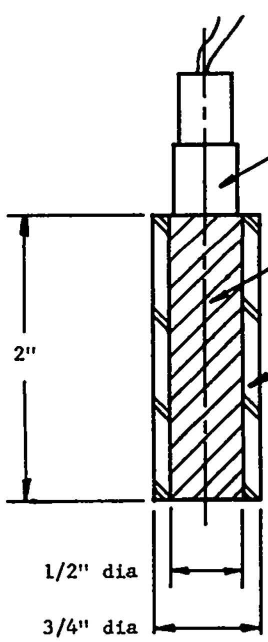

Fig 2 - Charge assembly used for safety shield tests.

varied somewhat, but were generally within the range 18-24 in. The results are usually assessed from the appearance of the shields and targets after the shot (Fig 3), but a high-speed (Fastax) camera sometimes is used to observe the dynamic response of the shields. Shields that appear to be effective at the 12-in. distance may be retested at 6 in. (one at a time) to determine if their performance at the larger distance is marginal.

This procedure provides a severe overtest for most operations carried out in the laboratory, but occasionally it is convenient to observe operations that could create conditions approaching in severity those provided by the test.

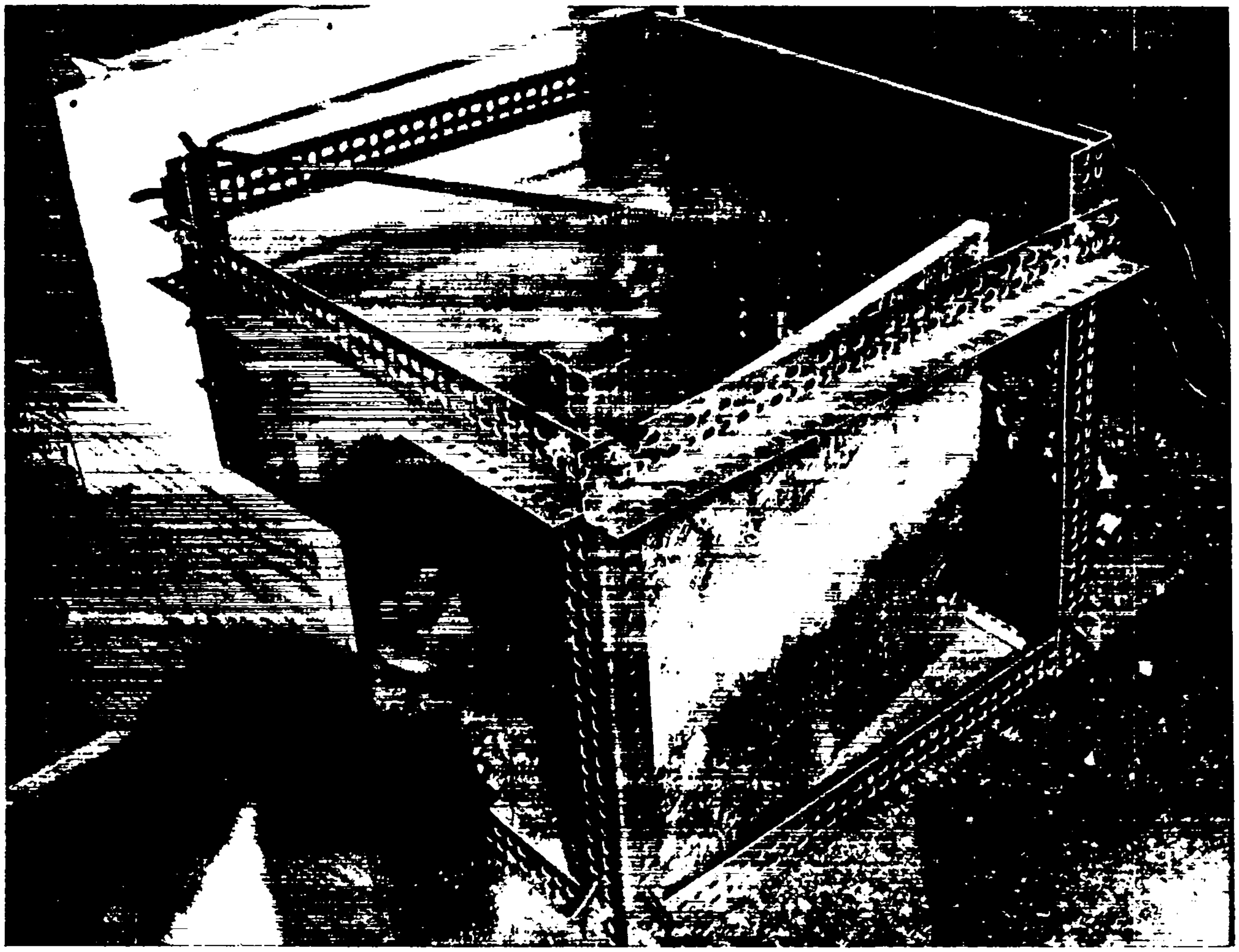

Fig 3 - General appearance of a test assembly after the shot. Clockwise from the Dural plate at the upper right are 1-in.-thick safety glass, Lexan, and polymethylmethacrylate shields. The dark spots in the Lexan are embedded fragments.

RESULTS

Results illustrating the response of some of the materials tested in this program are given in Table 1.

A 1-in. thickness of 4- or 5-ply laminated safety glass will stop the metal fragments, but the glass spalls badly. However, the velocity of the spall, estimated from the high-speed camera record, is only about 270 ft/sec, and only a few small pieces of glass remained embedded in the plywood target. Anyone standing behind such a shield, wearing safety glasses and a lab coat, probably would receive only superficial injuries except, of course, for whatever damage might be done to his hearing by the noise of the explosion.

Little, if anything, is gained by using two 1/2-in.-thick sheets of glass, separated by 1/4 in. of air, in place of a single 1-in.-thick sheet.

The 3/4-in. safety glass shield behaved similarly, except that in one of the two tests a metal fragment penetrated the shield and stuck in the plywood target. The velocity of the spall from the 3/4-in. shield (~ 300 ft/sec) was only slightly higher than that from the 1-in. shield, and damage to the target from this source would still not be rated overly severe. A substantial amount of spall is produced, however, as can be seen in Fig 4. The protection provided by this shield against the test charge is marginal.

Table 1

Shield	Distance from Chrg(in.)	Results
1/4" 2024-T351 Dural	12	Dural spall embedded in target
1/4" 2024-T351 Dural (2 tests)	6	Steel and Dural fragments in target
1/4" 2-ply safety glass	6	Shield and target penetrated.
1/2" 2-ply safety glass	12	Shield spalled and penetrated
3/4" 3-ply safety glass (2 tests)	12	Shields spalled, penetrated in 1 test, not in other
1" safety glass (a)	12, 6	Badly spalled, but not penetrated
1/2" safety glass, 1/4" air, 1/2" safety glass	6	Not penetrated, considerable low vel spall
1/2" acrylic (b)	12	Shield penetrated, spalled, and broken up
3/4" acrylic (b)	12	Shield penetrated, spalled, and broken up
1" acrylic (b)	12	Shield penetrated, spalled, and broken up
1/2" Lexan	12	Penetrated, but no breakup or spalling
3/4" Lexan	12	Penetrated, but no breakup or spalling
1" Lexan	12	Penetrated by one fragment
3/4" Lexan, 1/4" air, 1/2" Lexan	6	First layer penetrated, second layer intact
0.1" window glass, 1/2" acrylic (b)	12	Spalled, but not penetrated
0.1" window glass, 1/2" acrylic (b)	6	Fragment penetrated plywood target
1/4" plate glass, 1/2" Plexiglas (c)	6	Spalled, but not penetrated
1/4" 2-ply safety glass, 1/2" acrylic (b)	6	Spalled, but not penetrated
1/4" 2-ply safety glass, 1/2" Plexiglas (c)	6	Shield shattered, but not penetrated
0.1" window glass, 1/2" Lexan	6	Shield and target penetrated
1/8" window glass, 1/2" Lexan (3 tests)	6	Not penetrated in 2 tests, 1 fragment embedded in plywood in third test
1/4" plate glass, 1/2" Lexan	6	Not penetrated
1/4" 2-ply safety glass, 1/2" Lexan (6 tests)	6	Not penetrated
0.1" window glass, 3/4" Lexan	12	Penetrated
1/8" window glass, 3/4" Lexan	12	Penetrated
1/4" Plexiglas, 0.1" window glass, 1/4" Plexiglas (c)	6	Shield and target both penetrated
1/4" Plexiglas, 0.1" window glass, 1/2" Lexan	6	Penetrated, but target not damaged

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(a) Both 4- and 5-ply 1-in. safety glass were used.
(b) Swedlow, Inc, Los Angeles, Calif.
(c) Rohm & Haas, Philadelphia, Pa.

Fig 4 - Enlargement of one frame of the high-speed camera record, showing the cloud of spalled glass projected from the back of a 3/4-in.-thick safety glass shield.

The 1/4-in. and 1/2-in. glass shields were clearly inadequate, and, in the case of the 1/4-in. shield, the metal fragments penetrated both the shield and the 3/4-in. plywood target.

The results obtained with acrylic shields are given in the third section of the table. The metal fragments will penetrate even a 1-in.-thick sheet. The acrylic spalls much as the safety glass does, and, in addition, large pieces of plastic from the outer edges are blown out of the frame. With the thinner sheets, little if any of the plastic remains in the frame after the shot is fired.

Glass/acrylic composite shields represent an improvement so far as penetration of the shield is concerned, but the plywood targets are still damaged by fragments spalled from the shield.

The results obtained with Lexan are entirely different. The Lexan does not break or spall, and the entire shield remains in the frame. Even a 1 in. thickness of Lexan is penetrated occasionally, but in a peculiar way. The fragment generally does not travel through the plastic in a straight line, but instead changes direction one or more times as though it were moving through a viscous liquid.

Consideration of these results suggested that a glass/Lexan composite shield might have significant advantages. The thought was that the glass would retard and flatten the fragments, while the Lexan would intercept the penetrating fragments and spall. This led to the experiments reported near the bottom of the table, which indicate that as little as 1/8 in. of glass backed by 1/2 in. of Lexan will provide almost complete protection against the test charge. Shields consisting of 1/4 in. of glass backed by 1/2 in. of Lexan were not penetrated in 7 tests.

We call attention to the result obtained with the 1/8-in. glass/3/4-in. Lexan shield, which was penetrated in a single test at 12 in. This could indicate that nothing is to be gained by increasing the thickness of the Lexan. However, in sawing these sheets we noted that the thicker sheets (3/4 and 1 in.) seemed to be softer and gummier than the thinner sheets, and it is quite possible that the thicker sheets used in our work were incompletely or improperly cured.

The effectiveness of this combination was further demonstrated by some experiments in which the resistance of the shields to penetration by .30 cal, M2 ball rifle bullets was determined. The rounds were hand-loaded to obtain a range of velocities. In the following table we give the maximum velocity at which the bullet failed to penetrate the shield, the minimum velocity at which it did penetrate the shield, and the average of these two numbers.

As would be expected, these bullets, with their favorable ballistic shape, readily penetrate one inch of Lexan. The glass/Lexan combination, however, resists penetration at velocities up to about 1900 ft/sec and is as effective as the much heavier 1-in. safety glass.

Shield	Max Vel for No Pen (ft/sec)	Min Vel for Pen (ft/sec)	Average
1 in. acrylic	900	930	915
1 in. Lexan	920	990	955
1/4 in. safety glass plus 3/4 in. acrylic	1540	1600	1570
1 in. safety glass	1840	1920	1880
1/4 in. safety glass plus 3/4 in. Lexan	1840	1960	1900

DISCUSSION

These results demonstrate that, on the basis of weight and resistance to penetration and spall, the glass/Lexan composite shields are much more effective than the other materials tested in providing protection against the blast and fragments produced by the test charge. A shield composed of 1/4 in. of glass plus 1/2 in. of Lexan weighs about two-thirds as much as a shield of 1-in.-thick safety glass, provides equal protection against penetration by fragments, and is superior from the standpoint of spall. It is also worth noting that in the laboratory the glass of the composite shield will protect the plastic against damage from spills or splashes of corrosive chemicals, since it is located on the side facing the operation.

In short, the glass/Lexan composite shield represents a fortunate combination of desirable properties, and we consider it to be a substantial improvement over the transparent shields that were previously available for use in small-scale operations involving explosives.

ACKNOWLEDGMENTS

The authors are indebted to Marion Clancy for assistance with the fragmentation tests, and to L. W. Hantel, who performed the bullet penetration tests.

While this report was being prepared for publication, we were advised that the Pittsburgh Plate Glass Company and the Aerojet-General Corporation, under contract with the U.S. Army Materials Research

Agency, had studied in considerable detail composite shields similar to those described here, with special reference to their ability to resist penetration by .30 cal ball and armor-piercing ammunition. The PPG work is summarized in a confidential report entitled "Transparent Armor" submitted by the PPG Glass Research Laboratories under Contract No. DA-36-034-AMC-0309X. The Aerojet-General work is summarized in a confidential report entitled "Transparent Composite Armor Materials for Aircraft Applications" submitted under Contract No. DA-04-495-AMC-328(Z).

A Lexan/air/safety glass shield is now being marketed by the Arthur H. Thomas Company (CHEMICAL & ENGINEERING NEWS, June 5, 1967, page 15). However, the arrangement of the Lexan and glass layers in this shield is the reverse of that recommended here.