EQUIPMENT ARMOR INC.

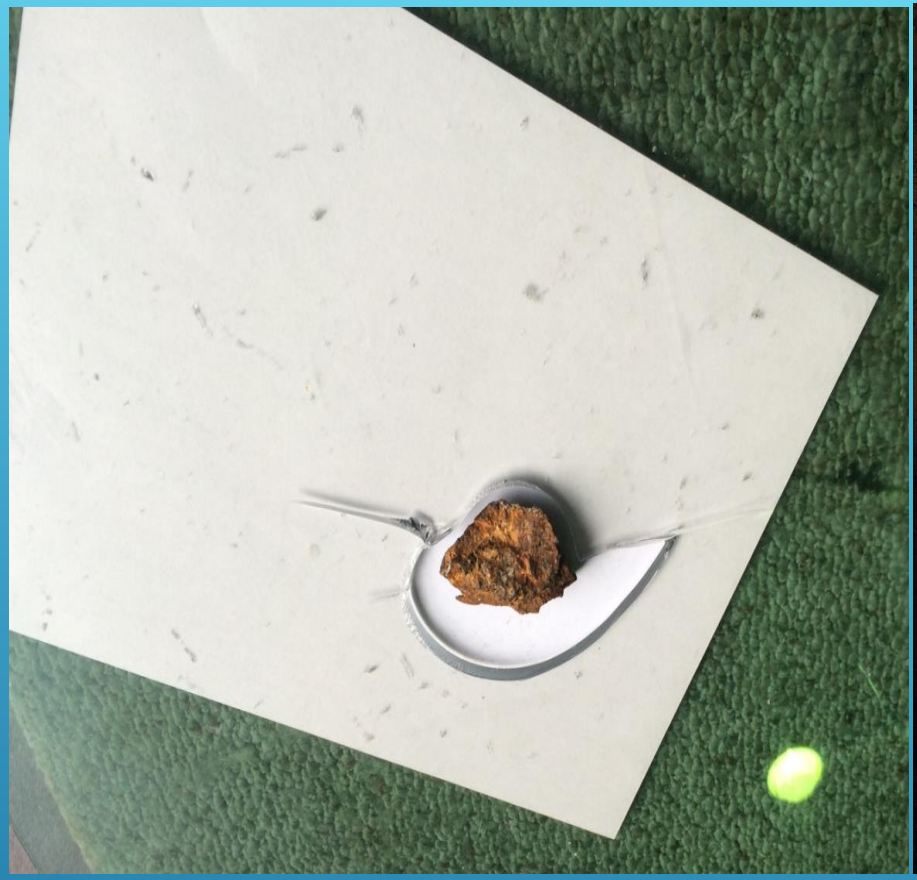
AN EXAMPLE OF **MISDIRECTION** AND **COMPLACENCY** IN THE MINING INDUSTRY

Tim Nickodemus

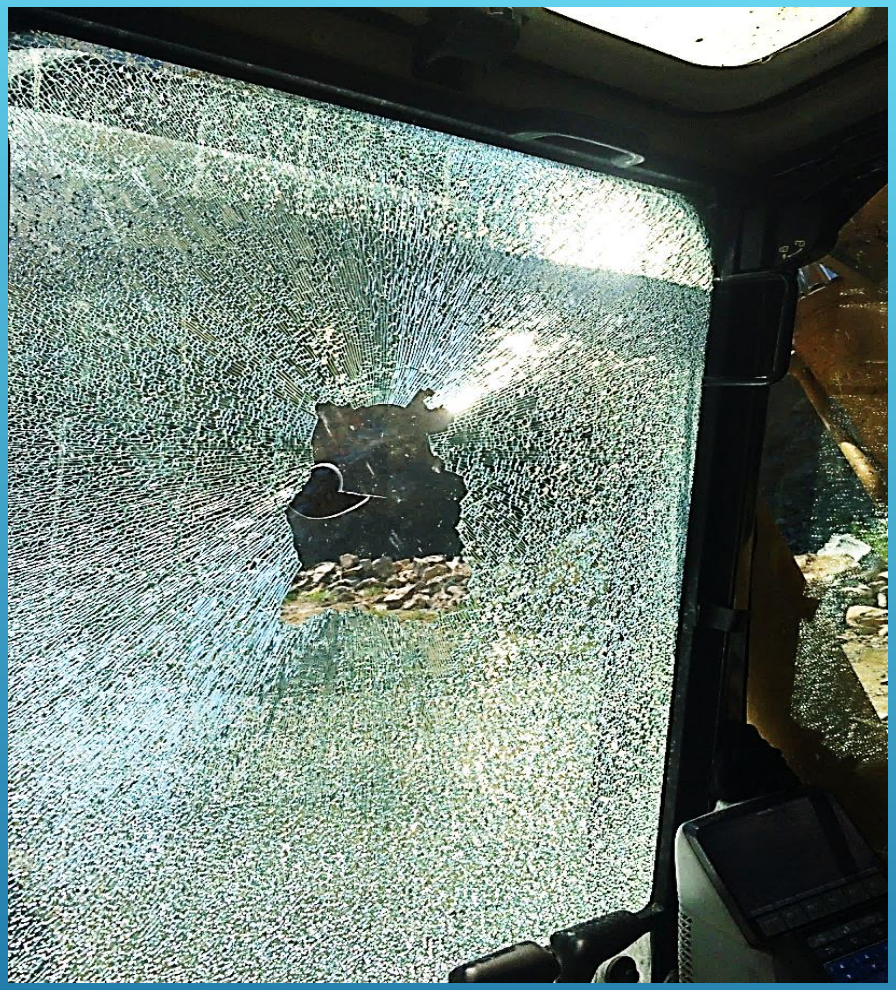
President

TERMINOLOGY

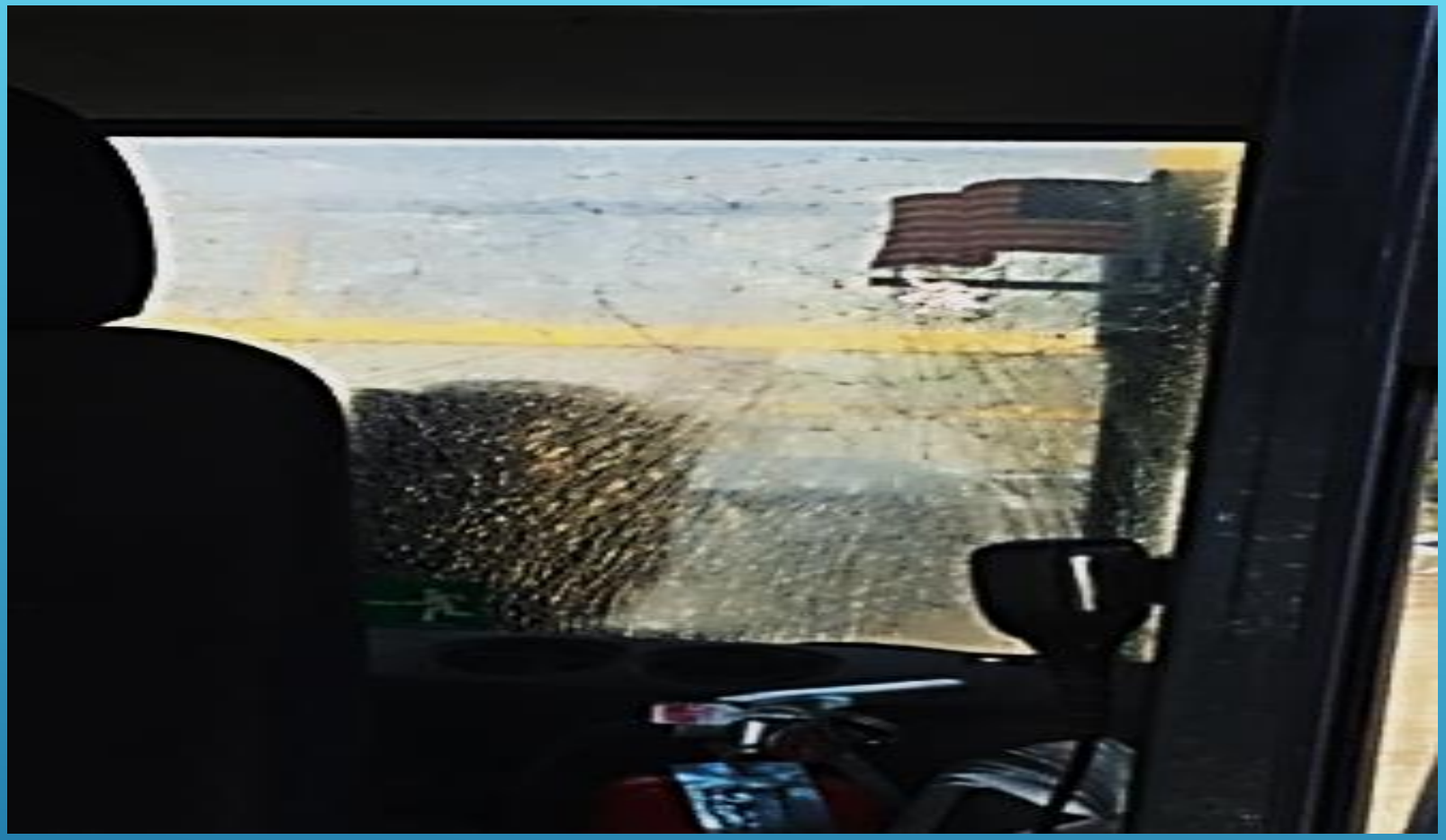
- Monolithic Sheet – A sheet of standard polycarbonate (PC).
- Laminated Sheet – Composite PC sheet consisting of multiple layers.
- Lexan, Makrolon, Palguard - Trade names for PC.
- Lexguard - Trade name of laminated PC.
- Coating – A mar resistant or abrasion resistant hard coating that extends sheet life.
- Equipment Armor Shield – Composite monolithic PC assembly.



AUGUST 2015 – A ½ LB. PIECE OF HAMMER STEEL PENETRATED A ¼ SHEET OF LEXAN MOUNTED ON AN EXCAVATOR RUNNING A 16,000 LB. HAMMER.



THE PROJECTILE PASSED THROUGH THE INSIDE OF THE WINDSHIELD IN FRONT OF OPERATOR….



AND OUT THE BACK GLASS.

THE PROJECTILE: AREA - 2''X1.5''X1.0'', WEIGHT - .5 POUND

VELOCITY CALCULATIONS

- Knowns:
  - Mass of Projectile.
  - Distance from hammer to impact point.
  - Materials penetrated.
  - Final resting place of projectile.
- Unknown:
  - Co-efficient of drag of projectile through Lexan.
  - Co-efficient of drag of projectile through glass.

7093 Fleet Glass Services

Hammer Point Ballistics Rough Estimation, Rev 0

2/23/2016

Given

Test projectile x-section	2.06	in^2
Mass of projectile	224	g
Cab height	10	feet
	3.0	m
Cab width	6	feet
Lexan to windshield dist.	0.5	feet
Projectile flight to cab	30	feet
Projectile flight beyond cab	180	feet
	54.9	m
Lexan shield thickness	0.25	in
Tempered glass thickness	0.25	in

Lexan				Front Windshield				Back Windshield				Flight to Ground			
r	1.20	g/cm3	medium density	r	2.44	g/cm3	medium density	r	2.44	g/cm3	medium density	g	9.8	m/s^2	
A	13.31	cm2	cross sect area	A	13.31	cm2	cross sect area	A	13.31	cm2	cross sect area	t	0.79	s	$y - y_0 = (v_0 sin\theta_0)t - \frac{1}{2}gt^2$
M	224.00	g	projectile mass	M	224.00	g	projectile mass	M	224.00	g	projectile mass	θ_o	0	deg	
Cd	12.00	unitless	coefficient of drag	Cd	6.00	unitless	coefficient of drag	Cd	6.00	unitless	coefficient of drag	Δx	54.9	m	
												V_o	69.6	m/s	$x - x_0 = (v_0 cos\theta_0)t$
a	0.428	1/cm	retardation coef.	a	0.435	1/cm	retardation coef.	a	0.435	1/cm	retardation coef.				
s	0.635	cm	material thickness	s	0.635	cm	material thickness	s	0.635	cm	material thickness				
E0	100		Assume 100% Ke initial	E0	58.1		Rel. Ke IN	E0	33.4		Rel. Ke IN				
E	58.1		Rel. Ke final	E	33.4		Rel. Ke final	E	19.2		Rel. Ke final				
Vi	158.5	m/s	Velocity Initial	Vi	120.8	m/s	Velocity Initial	Vi	91.7	m/s	Velocity Initial	V_i	69.6	m/s	Velocity Initial
	354.7	mph			270.3	mph			205.1	mph			155.6	mph	
Ke	2815.4	J	Ke Initial	Ke	1635.5	J	Ke Initial	Ke	941.5	J	Ke Initial	Ke	542.0	J	Ke Initial

$a = \frac{r}{2} \times \frac{A}{M} \times C_d$ $E = E_0 e^{-2as}$ per Harvey, et al in Beyer

Notes

Several approaches were investigated, considering quite a few more references than those listed on the Reference tab, including hole punch force. Lambert's approach (taken from Beyer) seemed like a reasonable starting point. The critical part of this method is in deriving the coefficient of drag for each material. Harvey, et al. in Beyer's work empirically measured the Cd for each material to be penetrated (in Beyer's work this would be flesh and bone). Ideally, the kinetic energy attenuation values of a projectile through Lexan or tempered glass could be empirically measured and better Cd values approximated.

IN SUMMARY: WHAT ARE THE FACTS

- A projectile (approximately ½ pound) separated from the hammer point and traveled through a ¼ sheet of Lexan (polycarbonate).
- The projectile continued traveling through the front windshield of the cab and out the back glass missing the operator by inches.
- The projectile was found approximately 60 yards (180 feet) from the back of the cab.
- The projectile was traveling at a speed of 240 to 400 miles per hour.
- If the operator of the machine had been struck it would have resulted in a fatality.

OUR **MISDIRECTED FOCUS:**

- Was To protect the windshield.
- Should have been protecting the operator from serious injury or death.
- Both the hammer (NPK) and tool(Allied) manufacturer gave **WARNINGS** on their products regarding shielding.

ALLIED HAMMER POINT

THE OPERATOR MUST BE FULLY PROTECTED BY A PROTECTIVE SHIELD BETWEEN THE OPERATOR AND THE HAMMER.

NPK HAMMER WARNING - DO NOT OPERATE HAMMER WITHOUT AN IMPACT RESISTANT GUARD BETWEEN HAMMER AND OPERATOR. NPK RECOMMENDS LEXAN® OR EQUIVALENT MATERIAL, OR STEEL MESH.

NPK AND ALLIED SERVICE DEPARTMENT RECOMMENDATIONS

- NPK Service Department – "No standards", but a ¼" to ½" sheet of Lexan is known to work in protecting the windshield from flying rock.
- Allied Construction Products Service Department – "No industry standards" but they recommend a bullet resistant Lexan.

1/8” Polycarbonate

¼” Polycarbonate

½” Polycarbonate

OUR **COMPLACENCY** IS PRESUMING A SHEET OF POLYCARBONATE WILL PROTECT THE OPERATOR FROM SERIOUS INJURY OR DEATH.

"SOLVE THE PROBLEM"

- GE Plastics Division (now SABIC).
- Mr. Joe Brown, Heavy Equipment Market Manager visited one of our local mines.
- "ABSOLUTELY NOT" – "Standard PC is not designed as a protective barrier from high velocity projectiles."
  - Bullet Resistant - UL 752 Rating Levels 1 through 4.
  - The uniqueness of the application.
  - ROPS vs. FOPS.

PRODUCT RECOMMENDATIONS

The GE (SABIC) PC Engineering Group recommended:

- Lexguard MPC375 (3/8") (UL752 - Level 1-9MM) for hammers up to 8000 lbs.
- Lexguard MPC500 (½") (UL752 - Level 2 - .357) for hammers over 8000 lbs.
- A coated cover sheet to extend sheet life by 2 to 3 times over standard PC sheet.
- Cost was an issue - $3K to 5K per sheet.

BALLISTIC FIELD TESTING
MORE QUESTIONS THAN ANSWERS.

Actual Field Testing of GE (SABIC's) recommendations:

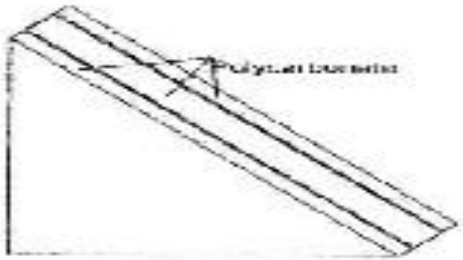
- Test #1 – Standard monolithic vs. laminated Sheet.
- Test #2 – Level 1 Testing – Composite Shield.
- Test #3 – Level 2 Testing – Composite Shield.
- Test #4 – Validate Testing Protocol.

Test #1

Plate	Date	Base Product	Base Thickness	Cover Product	Cover Thickness	Caliber	Grain	Type	Distance	Temp	Humidity	PASS/FAIL
1	11/6/2015	Monolithic	1/2"	N/A	N/A	0.357	158	JHP	15 FT.	73	76%	FAIL
2	11/6/2015	Monolithic	1/2"	N/A	N/A	0.357	158	JHP	15 FT.	73	76%	FAIL
3	11/6/2015	MPC500	1/2"	N/A	N/A	0.357	158	JHP	15 FT.	73	76%	FAIL
4	11/6/2015	MPC500	1/2"	N/A	N/A	0.357	158	JHP	15 FT.	73	76%	FAIL
5	11/6/2015	Monolithic	1/2"	N/A	N/A	9mm	124	FMJ	15 FT.	73	76%	FAIL
6	11/6/2015	Monolithic	1/2"	N/A	N/A	9mm	124	FMJ	15 FT.	73	76%	FAIL
7	11/6/2015	MPC500	1/2"	N/A	N/A	9mm	124	FMJ	15 FT.	73	76%	FAIL
8	11/6/2015	MPC500	1/2"	N/A	N/A	9mm	124	FMJ	15 FT.	73	76%	FAIL

TEST #1- MORE RESEARCH WAS NEEDED.

LEXGARD® MPC500 LAMINATE



Offering innovative solutions for bullet, blast, impact and wind resistance.

DESCRIPTION

- LEXGARD® MPC500 laminate is a three-ply polycarbonate laminate primarily developed for security protection.
- LEXGARD® MPC500 laminate provides dependable protection and exceptional abrasion resistance
- UL Ballistic protection, LEXGARD® MPC500 laminate

TYPI

- Ga
- W
- Sh Cl
- U-Factor: .82
- Percent Light Transmission (Average Gardner Value): 83 Clear

SPECIFICATIONS

Three-ply, clear, extruded polycarbonate of the following

Material shall have a flexural strength not less than 13,500 psi (ASTM D790); 83% light transmission (ASTM D1003). Material shall be a total thickness of .500" ± 5%. Material shall have an abrasion resistant surface to improve service life performance, and must conform with ICBO, BOCA, and SBCCI Model Building Codes as an Approved Light Transmitting Plastic with a C1 (CC81) flammability performance level.

LEXGARD® MPC500 laminate alone maintains no Underwriters Laboratories (UL 752) ballistic rating, but is used as a component in systems which include laminated safety glass and an appropriate air space to achieve varying ballistic ratings.

LEXGUARD – MPC 500 Laminate alone maintains no UL752 ballistic rating, but is used as a component in systems that include laminated safety glass and an appropriate air space to achieve varying ballistic ratings.

LEXGARD® MPC500 laminate, when used as a stand-alone glazing product, meets the requirements of HPW-TP-0500.00 for:

- Level A — Ballistic material(.38 Special handgun)
- Level II (Step 14) — Forced entry material

Tested using ASTM F1915-03 forced entry standard:

- Test result = Security Grade Level 2
- LEXGARD® MPC500 laminate is capable of providing varying levels of ballistic protection per UL Standard 752 when used behind glass as a component in a replaceable glass system.
- WMFL 60-minute forced entry

Tested using ASTM F1233-08 forced entry standard:

- Test result = Contraband Class II (Last step passed = Step 6)
- Test result = Body passage Class V (Last step passed = Step 22)

GLAZING INFORMATION

- Do not use setting blocks made from PVC, EPDM, or neoprene rubber materials. Santoprene® rubber should be suggested. If these other rubber products are required, a protective barrier material should be used between the rubber setting block and the LEXGARD® sheet edge.

Test #2 Composite Shield

Plate	Date	Base Product	Base Thickness	Cover Product	Cover Thickness	Caliber	Grain	Type	Distance	Temp	Humidity	PASS/FAIL
9	11/8/2015	Monolithic	1/2"	Monolithic	1/4"	9mm	124	FMJ	15 FT.	54	47	Fail
10	11/8/2015	Monolithic	1/2"	Monolithic	1/4"	9mm	124	FMJ	15 FT.	54	47	Fail
11	11/8/2015	MPC500	1/2"	Monolithic	1/4"	9mm	124	FMJ	15 FT.	54	47	Fail
12	11/8/2015	MPC500	1/2"	Monolithic	1/4"	9mm	124	FMJ	15 FT.	54	47	Fail

1. The first shot held but subsequent shots failed.
2. This test revealed that fissures were developing after the first shot.

TEST #2 – LEVEL 1 – COMPOSITE SHEET - 9MM FAILED.

Test #3

Plate	Date	Base Product	Base Thickness	Cover Product	Cover Thickness	Caliber	Grain	Type	Distance	Temp	Humidity	PASS/FAIL
13	11/8/2015	Monolithic	1/2"	Monolithic	1/4"	0.357	158	JHP	15 FT.	54	47	Pass
14	11/8/2015	Monolithic	1/2"	Monolithic	1/4"	0.357	158	JHP	15 FT.	54	47	Pass

1. ½" monolithic sheet was strong enough to use as a base for composite shields.
2. Perhaps the hollow point was too soft to use in testing and we needed to use an actual piece of a hammer tool.

TEST #3 – LEVEL 2 – COMPOSITE SHEET - .357 PASSED.

TEST #4

Plate	Date	Base Product	Base Thickness	Cover Product	Cover Thickness	Caliber	Grain	Type	Distance	Temp	Humidity	PASS/FAIL
15	11/8/2015	MPC500	1/2"	Monolithic	1/4"	0.357	158	JHP	15 FT.	54	47	Pass
16	11/8/2015	MPC500	1/2"	Monolithic	1/4"	0.357	158	JHP	15 FT.	54	47	Pass
17	11/8/2015	MPC500	1/2"	Monolithic	1/4"	0.357	158	JHP	15 FT.	54	47	Pass

TEST #4 – UL752 - LEVEL 2 TESTING PROTOCOL VERIFICATION.

BALLISTIC TESTING SUMMARY

- Test #1 – A composite shield is needed to "Manage Energy".
- Test #2 – Fissures developed after the first catastrophic incident leading to a failure.
- Test #3 – Passed but the actual projectile was critical to real world testing.

INDEPENDENT TESTING OF THE COMPOSITE SHIELD

- Testing protocol:
  - Use actual pieces of a hammer point that have been cut to size.
  - Shoot the sample projectiles at shields constructed of composite monolithic, and laminated sheets.
  - Attempt to obtain velocities between 240 mph and 400 mph.

INDEPENDENT TESTING

The Test Lab;

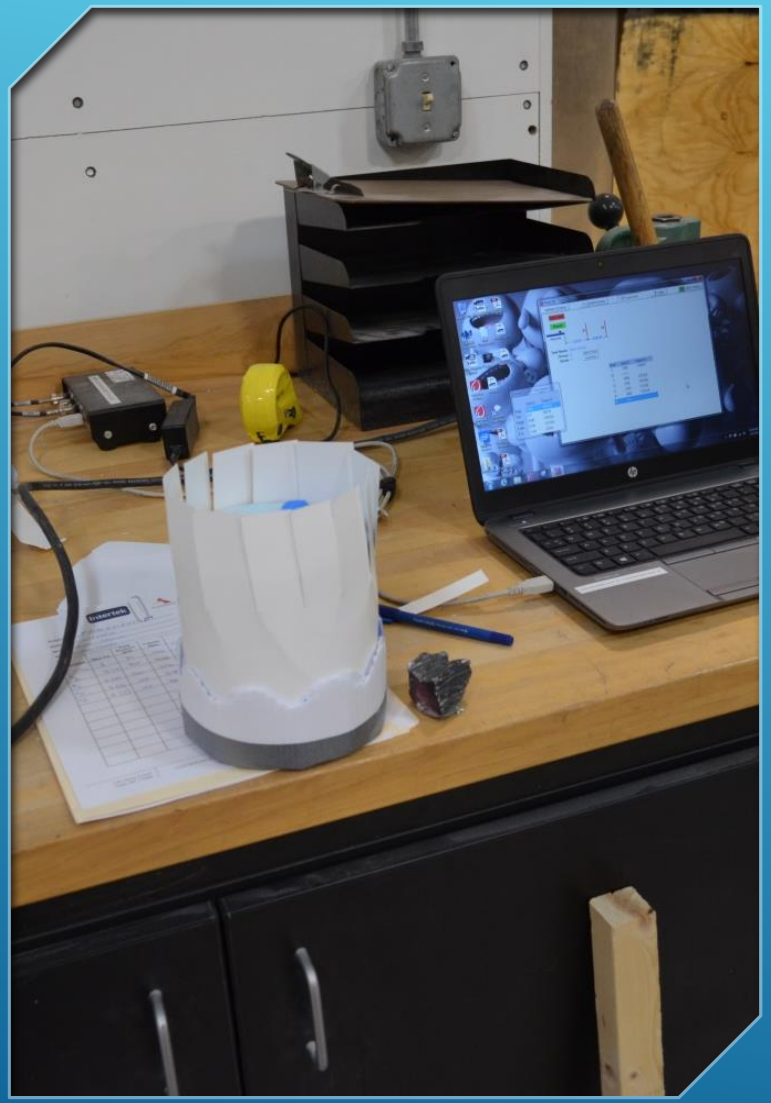
- We considered three test labs:
  - Sabic (GE) – Boston, MA.
    - Sabic could only mount projectiles on a standard sabot for shooting so they declined.
  - Intertek – Architectural Testing – Springdale, PA.
    - Cannon designed to shoot the "Dade County and Miami 2x4" for hurricane testing resulted in only 125 mph with our projectile.
  - Intertek – Ballistic Testing – York, PA.
    - They built a cannon to shoot our projectile but we only achieved a level of 300 mph in testing, before blowing the sabot that holds the projectile apart.

AIR CANNON

A 200 psi air tank with butterfly valve and 8 foot long 6” Cast Iron Barrel.

LASER SPEED METERS

Measures speed (FPS) of projectile by passing through the first meter and triggering the computer to measure time until the second meter is tripped.



SABOT

A specially designed sabot was built to accommodate the projectile. It looks very much like a shot gun shell's wadding.

INSIDE OF SABOT

Projectile was wrapped in paper which held it in place in the Sabot. The Sabot was then placed in barrel and rammed approximately 6 feet into the barrel.

THE TEST SUBJECTS

Tested Three Plates

- Plate 1 – ½" Monolithic sheet.
- Plate 2 – Monolithic Base Composite shield.
- Plate 3 – Laminated Base Composite Shield.

PLATE 1- BASE LINE TEST

Plate 1 – The first two shots at 235 and 224 MPH showed impact points but no noticeable cracking. However, at the molecular level there were fissures developing throughout the plate.

PLATE 1 – THIRD SHOT

On the third shot, 243 mph, the plate exploded. There was flying shards all over the lab. It was a very dangerous situation and a totally unexpected result.

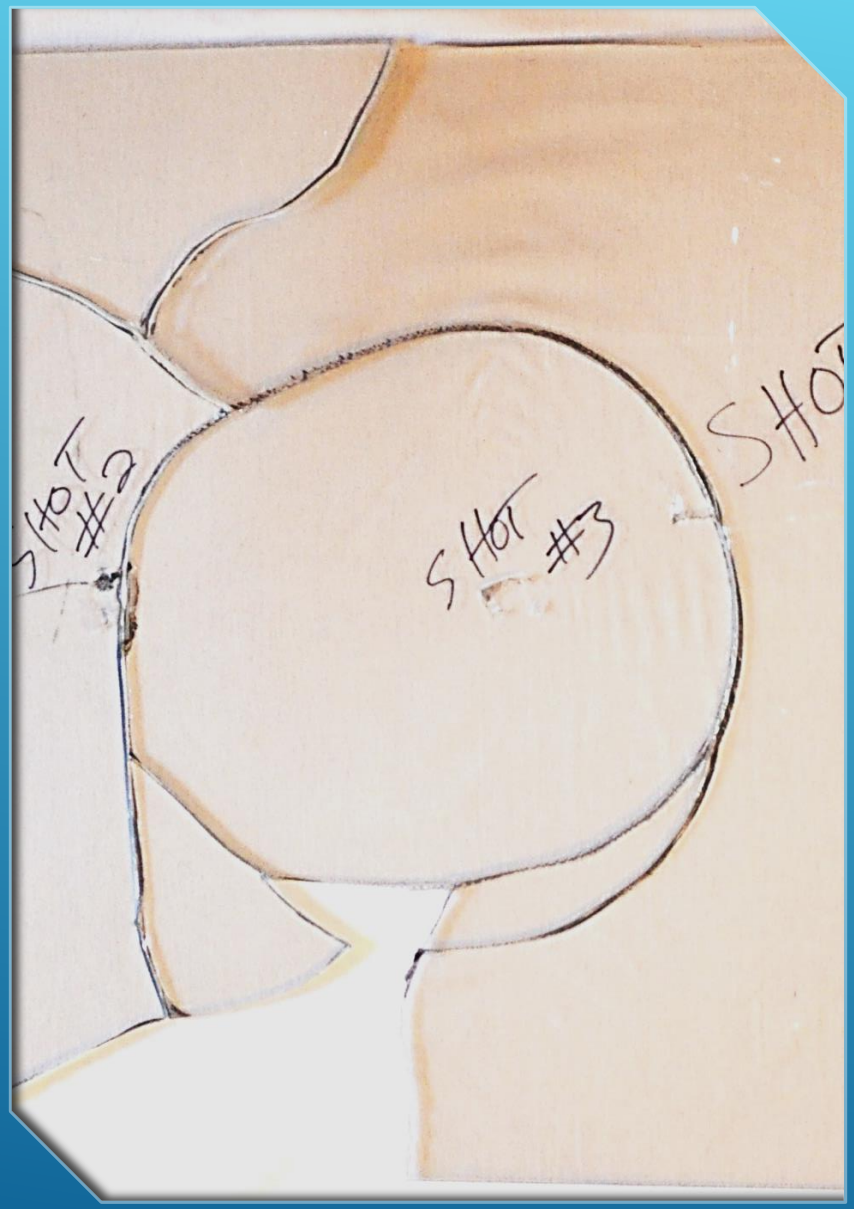


PLATE #1

The explosion of Plate #1 as a result of shot 3, documented the circular pattern prominent in fissure development throughout the testing.

PREPARING TO TEST THE SHIELD/BLAST PLATES, SECURING THE FRAME.

An actual Equipment Armor Shield Frame was used for the testing. It was attached to a wooden/metal buck system for support.

THE FRAME READY FOR TESTING.

This is a stainless steel frame made specifically for testing the shield at the lab.

PLATE #2 MONOLITHIC COMPOSITE PLATE

- Test Results:
  - Shot 1 – 406 fps, 276mph
    - Results – Pass – Cover plate penetration.
  - Shot 2 – 256 fps, 175mph
    - Results – Pass.
  - Shot 3 – 379 fps, 258mph
    - Results – Pass.
  - Shot 4 – 369 fps, 252mph
    - Results – Pass – Cover plate penetration.

PLATE #3 LAMINATED COMPOSITE PLATE

- Test Results:
  - Shot 1- 376 fps, 256 mph
    - Results – Pass.
  - Shot 2 – 250 fps, 175 mph
    - Results – Pass.
  - Shot 3 – 325 fps, 222 mph
    - Results – Cover plate breakout – physical representation of fissures.
  - Shot 4 – 356 fps, 243 mph
    - Results – Pass – Visual representation of fissures.
  - Shot 5 – 438 fps, 299 mph
    - Results – Pass – Visual representation of fissures.

PLATE 2 MONOLITHIC COMPOSITE SHIELD VS. PLATE 3 LAMINATE COMPOSITE SHIELD

- Plate 2 showed the greatest amount of base plate deflection with Shot #4 at 252 mph.
- Plate 2 did not show the amount of fissuring on the cover plate that was shown by Plate 3.
- Plate 3 did not show significant base plate deflection.
- Plate 3 showed fissuring in the cover plate at each impact plus an actual break out on Shot #3 at 222 mph.

FINAL SHIELD RECOMMENDATIONS

- 1/8", ¼", and ½"polycarbonate sheet alone is inadequate to prevent catastrophic events from occurring.
- A composite shield is capable of providing catastrophic incident protection.
- Given the difference in base plate deflection from 175 mph to 300 mph, a composite shield is capable of withstanding impact up to 400 mph.
- The life of a composite polycarbonate shield should be limited to 2 years due to embrittlement and fissuring occurring during normal operating conditions in the mining environment.

CURRENT VALIDATION – ON ALL MATERIALS PURCHASED
UL752 - BALLISTIC TESTING
LEVEL 1 9MM AND LEVEL 2 .357.