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LDRD Summary Report
Part I: Initiation Studies of Thin Film Explosives used for Scabbling Concrete
Part II: Investigation of Spray Techniques for use in Explosive Scabbling of Concrete

Robert A. Benham, Robert W. Bickes, Jr., Mark C. Grubelich, David E. Wakerbarth, Jerry L. Brock

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Part II: Investigation of Spray Techniques for use in Explosive Scabbling of Concrete

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Abstract

We describe a new method for the scabbling of concrete surfaces using a thin layer of explosive material sprayed onto the surfaces. We also developed a new explosive mixture that could be applied with commercial spray painting equipment. The first part of our report describes experiments that studied methods for the initiation of the sprayed explosive. We successfully initiated layers 0.014" thick using a commercial EBW detonator, a flying plate detonator, and by pellet impact. The second part of our report describes a survey of spray methods and tests with two commercial spray systems that we believe could be used for developing a robotic spray system.

Acknowledgments

We thank The Ensign-Bickford Company for providing PETN for use in this study and Jim Salas, 1552, for finding the PETN procurement information. Thanks also to Bob Patton, 1552, for providing the particle size analysis for the various powders, and Lynn Loveland, 9732, for providing the calibrated cartridges and gun for driving the projectiles used in the initiation study. We also thank Bill Tarbell,1554, and Steve Harris, 1553, for reviewing the text; Gladys Powell, 1553, for preparing this document for release; and Ben Duggins, 1553, for preparing the figures.

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DISCLAIMER

Contents

Tables

Figures

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Introduction

Safe and cost effective Decontamination and Decommissioning (D&D) of Department of Energy (DOE) surplus facilities requires new and innovative technologies. The fact that the DOE complex has over 5,000 facilities that will enter the demolition process over the next 60 years clearly reflects the need for new technologies for the removal of those structures. Further, cost projections are huge for addressing decommissioning needs in commercial nuclear power plants, DOE facilities and international nuclear facilities. For the DOE alone, $200 billion is the estimated cost to accomplish its D&D tasks.

The removal of contaminated surface layers from a wall, ceiling or floor (scabbling) of a decommissioned nuclear power plant structure may allow further demolition by standard means. Thus, large cost savings in the reduced handling of mixed hazardous waste may be realized. The process of using thin layers of explosives for scabbling of concrete is applicable to the D&D of DOE surplus facilities. It is a safe and cost effective method for facilities where conventional methods cannot be used. This technique may be especially attractive when replacing mechanical methods which use working fluids that become contaminated, exacerbating disposal problems. Where personnel exposure to radiation is not a concern, plastic sheet explosive may be manually attached to the wall and detonated to scabble the concrete. Where personnel exposure is a concern, then we suggest a robotic system may be used that is capable of remotely spray painting an explosive layer on the wall to give the correct amount of scabbling.

This study attempted to answer the following questions:

1. Can a new explosive mixture be found that can be used for scabbling?
2. What is the minimum thickness of this new explosive mixture that will sustain a detonation front?
3. What kind of initiating systems will reliably initiate the explosive layer?
4. What commercial spray systems are available that will handle the explosive mixture of question 1?
5. Can a successful demonstration be achieved with inert solids to assess the capability of the spray systems found in question 4?

We describe in Part I of this report the development of an explosive mix and experiments that determined the initiation sensitivity of the mix. Initiation methods include conventional detonators as well as impacting the explosive surface with a steel sphere driven by a gun. We conclude with a description of our experiments on concrete surfaces. In Part II we describe a spray technology for depositing thin layers of explosive onto vertical or horizontal surfaces.

The results of our study proved the feasibility of using spray-deposited explosive for concrete scabbling. Follow-on work is required to optimize the spray process, the explosive performance properties, and the initiation scheme specifically for concrete scabbling. Fitting this system to a robot for total remote applications will provide for a safe method for scabbling in contaminated environments.

Part I: Initiation Studies of Thin Film Explosive Used for Scabbling Concrete

Development of Explosive Mix

Spraying of explosive slurries has been conducted at Sandia for about two decades. Most of the explosive painting involved a conventional spray gun system and a slurry of silver acetylide–silver nitrate (SASN) explosive suspended in acetone. Thin, controlled layers were deposited over large (three square meters) areas and explosive layers ranged from 0.005 to 0.120" thick. Some additional experiments[1] were conducted using PETN explosive dissolved in the acetone of the SASN slurry to enhance the explosive energy delivery. PETN explosive dissolved in acetone was also sprayed on surfaces for higher energy explosive output experiments. Technically, any of these methods could be used for concrete scabbling.

A mixture of PETN/diene rubber/toluene has been used for producing flexible sheets of explosive for impulsive loading of surfaces.[2] The material was mixed into a stiff slurry and then cast/screeted into a mold. This technique worked quite well and the "cast/screet into a mold" method was used for the explosive layer initiation for the present study. The same ratio of binder to solids was used for the trials of the spray gun systems purchased for evaluation in this study.

Acetone and toluene are environmentally unacceptable for a spray fluid diluent, and silver acetylide–silver nitrate is much too sensitive for use in a scabbling application; therefore, a new explosive mix was required for this work. A search for a solvent/binder combination was conducted. The solvent must dissolve the binder but not dissolve PETN in order to preserve the particle structure of the explosive material. The binder must be dissolved by the chosen solvent and acetone. The explosive, PETN, and the binder both being soluble in acetone allows cleanup of a spray gun after an operation by dissolving the explosive slurry constituents within the gun.

The binder-solvent system developed for this study was shellac with an ethanol or isopropanol diluent. Several different ratios were tried of binder to explosive mix in the final product. The ratio that was used for most of this work was 7.4% binder by weight. The initiation study was completed with the explosive/ binder mix being cast and screeted into molds of the correct thickness. Insignificant shrinkage occurred during these charge fabrication activities. The same ratio of binder to solids for the spray mix was used for the spray trials. Fine MgO or Al_2O_3 powders were used as an inert substitute for the explosive powder in the spraying tests.

The explosive PETN was chosen for this application because it is relatively safe (classed as a secondary explosive) to use, because its properties are well understood, and because of its availability. Two potential suppliers of PETN were identified The first was Reynolds Industries Inc. (two PETN types were available designated as Standard or High Surface powder). Reynolds uses the material for detonator applications, and we had samples of this material on hand. The second source was the Ensign Bickford Company who uses the PETN in the fabrication of their Prima Sheet™ material (EB Superfine, sample #12 Au 96G1-1R, PETN); they produce thousands of pounds per year. Ensign Bickford company sent a sample of the material to Sandia for use in this study. The Ensign Bickford Superfine PETN material was the principle explosive used in our tests and will be the explosive used in any scabbling application arising from this study.

Analysis of small samples of the PETN materials and of some MgO powder (used as an inert simulant for the spray trials in Part II) was completed to document the pedigree of the specific material being used in the study. The results of the measurements are shown in Figure 1 (see Appendix A). The Reynolds Standard PETN was a better match to the EB Superfine material than was the Reynolds High Surface area material. For the majority of the experiments in this study the EB Superfine material was used. A few experiments using the Reynolds Standard PETN were conducted to measure the difference between the EB and Reynolds explosives.

The PETN explosive can be procured from Ensign Bickford Company; a minimum order is $2500.00 at $9.00 per pound. The material is stored and shipped in water and ethanol and designated as "Super Fine PETN Powder, 5-8 micron".

Initiation Study

Wedge Tests

We designed and built assemblies into which we could prepare wedge shaped samples that varied in thickness from 0.050" to 0.015" (nominal dimensions). The sample length was 4" and the width was 1/2". The explosive sample was positioned on a 4"x 6"x 0.062" thick witness plate of aluminum (6061-T6). The explosive material was initiated using a Reynolds RP-2 exploding bridgewire detonator positioned over the thickest end of the wedge. Figure 2 shows the test sample with the detonator in place. The purpose of these tests was to determine the minimum thickness of this new explosive material mix that would detonate.

A fast framing camera viewed the sample through a window in the explosive chamber. Analysis of the frames allowed us to determine the burn (detonation) rate in the sample. Figure 3 shows a series of frames from the camera. The frames are separated by three micro-seconds. The reaction can be seen moving from the right to the left. The velocity of the detonation was obtained from the fast framing camera data for each test (see Table 1).

Our first test (laboratory shot number 1301) used the Reynolds Standard PETN powder with 5.13% binder. The average density of the material screeted into the assembly was ~0.70 g/cm^3. The thickness of the samples ranged from 0.049" to 0.014". The entire sample detonated. The detonation velocities ranged from 3297 m/s at the thick end to 2846 m/s at the thin end of the PETN wedge. These detonation velocities are in the expected range[4] for PETN for this mass density.

Our second test (laboratory shot number 1303) used the Ensign-Bickford superfine powder with 7.4% binder. The powder had been dried for 24 hours to remove moisture. The average measured density of the material screeted into the assembly was 0.76 g/cm^3. The thickness of this sample ranges from 0.047" to 0.017". Again the entire sample detonated with velocities ranging from 4088 m/s to 4344 m/s from the thick to thin end of the material, respectively. The results are summarized in Table I. *These tests indicated that the explosive material will sustain a detonation front in material 0.014" thick.* Detonation in thinner layers may be possible but this information was not sought in this study. Figure 4 shows the test sample parts after the experiment.

Table I. Wedge Test to Determine Minimum Detonation Thickness

Test No.	Shot No.	Explosive Mix Powder Binder (%)	Average Explosive Density (g/cm^3)	Maximum Explosive Thickness (inch)	Detonation Velocity at Maximum Thickness (m/s)	Minimum Explosive Thickness (inch)	Detonation Velocity at Minimum Thickness (m/s)
1	1301	Reynolds STD 5.13%	~0.70 (1)	0.049	3297	0.014	2846
3	1303	EB Superfine 7.4%	~0.76	0.047	4521	0.017	3684

Notes:
1. This value is only an estimate of the explosive density. Density measurements improved through the project.

Strip Tests

Strip tests were conducted to determine the initiation response of various explosive layers. These tests consisted of molded strips of explosive 0.25" wide by 3.00" long and 0.040" or 0.060" thick that were detonated at one end. Initiation methods included a bare exploding bridgewire, a bare Semi-Conductor Bridge (SCB)[3] and RP-2 detonators all in contact with the explosive layer. Also used were steel flyer plates (0.010" thick) driven by RP-2 detonators, at several standoff distances, and steel spheres (0.250" diameter) driven to impact by a gun (several feet standoff). Figures 5 through 7 show the setup and results for these experiments. The table below shows the results of these experiments. Explosive performance parameters are shown for the various initiation methods.

Table II. Initiation Test Results

Test parameters	Bare RP-2 Bridge-wire	SCB	RP-2 contact	RP-2 contact	RP-2 contact	RP-2, Flyer 0.15" Gap	RP-2, Flyer 0.50" Gap	RP-2, Flyer 1.00" Gap	Ball Initiator (600 FPS)	Ball Initiator (1500 FPS)
Test No.	1311	1312	1302	1308	1309	1310	1342	1343	1250	1347, 1348 1349
Shot No.	6	7	2	5	8	4	9	10	14	11, 12, 13
Explosive Mix. Type/ Binder	EB Dried/ 7.4%	EB Dried/ 7.4%	EB 35% H_2O/ 7.6%	EB Dried/ 7.4%	Rey-olds STD / 7.4%	EB Dried/ 7.4%	EB Dried/ 7.4 %	EB Dried/ 7.4%	EB Dried/ 7.4%	EB Dried/ 7.4%
Explosive density from weights. (g/cm^3)	0.67	0.67	~0.60	~0.70	0.627	~0.67	0.581	0.67	~0.700	~0.700
Explosive density from Detonation Velocity. [4] (g/cm^3)	No Deton-ation	No Deton-ation	0.622	0.583	0.606	0.651	0.587	0.582	NA	NA
Measured Detonation Velocity (m/s)	NA	NA	4124	3977	4065	4231	3994	3974	Not Measured	Not Measured
Energy (joules)	4.5 (1)	4.5 (1)	96.0 (2)	96.0 (2)	96.0 (2)	42.1 (3)	65.8 (3)	65.8 (3)	20.2 (3)	124.7 (3)
Momentum (g·cm/s)	NA	NA	NA	NA	NA	4800	6000	6000	21,963	54,545
CJ[5] Pressure (kBar)	NA	NA	28.6	29.9	28.0	32.3	25.0	28.6	~29	~29

Notes:
1. Energy stored in firing set.
2. Energy in output pellet of detonator= heat of detonation times mass.
3. Kinetic energy in impacter.

Tests 6 and 7 involved the lowest amount of energy to the explosive. The bare bridgewires of the SCB and RP-2 were placed in direct contact with the cast explosive surface. Neither of these configurations produced an initiation.

Tests 2, 5 and 8 had an RP-2 detonator placed in direct contact with the cast explosive. All produced prompt detonation. Tests 4, 9 and 10 all had a 0.010" thick steel flyer plate attached to the end of the RP-2 detonator. The flyer was spaced away from the cast explosive surface by 0.15", 0.50" and 1.00". All produced prompt detonation.

Tests 11 and 12 involved the casting of the explosive layer on an aluminum plate (0.062" thick) that was backed up with a 1.0 inch thick aluminum plate. Figure 8 shows the setup. A 0.250 inch diameter steel ball was driven into the targets at velocities of 1500 and 600 feet per second; the impact caused the explosive initiation. Figure 9 shows the results of the ball impact on the aluminum targets.

Tests 13 and 14 involved the casting of the explosive layer directly on the end of a concrete cylinder and impacting the steel sphere on the explosive to initiate the explosive layer. Figure 10 shows the setup for the ball impact tests and the resulting cracking in the concrete. The extent of cracking in the concrete was reduced by the small pattern of the explosive layer which was limited by the amount of EB superfine explosive powder that was available. We suggest future experimentation should address and optimize the concrete failure layer. Figure 11 shows the high speed camera pictures from one of the tests. The velocity of impact of the ball was obtained from these photos and the detonation wave is visible on one frame.

Strip Tests Conclusions

The electrical initiation methods (bare RP-2 bridgewire and bare SCB) did not initiate the explosive strip. The stored electrical energy delivered by the firing set to the bridges for these two techniques was 4.5 J. In contrast, all of the other systems, which delivered more than 20.22 J of mechanical energy, caused initiation. The CJ pressure[5] in the explosive for this mix of explosive (density ~0.70 g/cm^3) was about 30 kBar. Follow-on work would focus on a more dense explosive layer (~1.0 g/cm^3) which will give a considerably higher CJ pressure (~82 kBar). At least two of these techniques, the ball impact or the explosively driven flyer plate, are ideally suited for the scabbling application.

Part II. Investigation of Spray Techniques for Use in Explosive Scabbling of Concrete

Spray System Survey and Procurement

Our purpose in this part of the study was to investigate the current state-of-the-art commercial spray systems and then select one or two systems for procurement and evaluation. The evaluation was to involve trial sprays using Al_2O_3 (240 mesh) and MgO powder (see particle size information in Figure 1) as an inert simulant for the explosive powder.

The spray guns surveyed included the following classes of systems:

1. **Electrostatic systems.** These systems produce a cloud of electrically charged paint particles which are attracted to an oppositely charged sample to be painted. The electrical attraction causes the paint particles to all be attracted to the desired location. This system is of interest because all of the sprayed material is accounted for and minimal fog dust (material that dries before it hits the surface and therefore

creates dust) is generated. The electrical charging of the particles in conjunction with the explosives, however, caused enough concern to terminate our interest in this system.

2. **Conventional systems.** These systems are similar to the systems used at Sandia's explosive spray facility for the last two decades. This system can deposit the new explosive material of this study but has two drawbacks. The first is that this system generates a large amount of fog (dust) which creates a potential cleanup problem. The second is that volume flow rates with this system may be marginal for the scabbling applications.

3. **Airless systems.** These systems are designed to reduce the fog from spraying operations where very large volumes of materials are to be sprayed. This system does not directly use compressed air to atomize the paint or other coating material. Hydraulic pressure is used to atomize the fluid by pumping it at high pressure (500 to 4500 psi) through a small orifice in the spray nozzle. The release of the pressure in the fluid once it is out of the gun causes the fluid to break up into small droplets, thus atomizing the spray. This system is claimed to nearly eliminate the fog but it doesn't work very well on systems requiring the smaller volumes associated with scabbling.

4. **High Volume Low Pressure (HVLP), air assisted systems** were designed to be used in states that have strict air quality standards and require minimal fog and vaporization of the paint solvent during paint application. The fluid is ejected from the nozzle in a stream that is atomized by low (< 10 psi) pressure air. The paint sticking efficiency is high for this type of system meaning less loss and cleanup. This system appears best for concrete scabbling applications.

The HVLP, air assisted systems were chosen for further investigation. Manufacturers were contacted, literature obtained and several meetings were attended to learn about the spray systems. Two systems were chosen to be purchased for evaluation as part of this study. The systems chosen were the Binks, HVLP, Air Assisted system with a five gallon capacity and the Graco, HVLP, air assisted system also with a five gallon capacity. The capacity of each of these systems can easily be expanded as required. The fluid pumping systems and the details of the spray gun operation are different in these two systems. The fluid handling in the spray gun of the Binks system appears to be better for prevention of packing of solid material in the nozzle and the dual diaphragm pumping system may be easier to clean after a spray operation. The Graco pumping system has a larger capacity for producing fluid flow out of the nozzle and may be better for applications that require large quantities of explosive material to be sprayed.

The systems purchased for evaluation were:

1. Binks[6] HVLP Hand Held Spray Gun (MACH 1SL), automatic spray gun (MACH 1A), diaphram pump system (Model #135-105) and fluid agitator.

2. Grayco[7] HVLP Hand Held Spray Gun (Model M-1265), automatic spray gun (High Efficiency LP Model 1600), pump system (2:1 Ratio Standard Pump, 5 Gallon Duo Paint Sprayer) and fluid agitator (Model 222-695).

Preliminary Spray Trials

Two inert material spray trials were conducted. The purpose was to demonstrate that an inert slurry mix could be sprayed with these spray systems. The slurry used Al_2O_3 (240 mesh) or MgO powder (see particle size information in Figure 1) as the solid simulant for the explosive powder and Alcohol/Shellac as the binder mix (see Part I). The first trial spray used the Graco system with a 0.055" diameter nozzle. Al_2O_3 was used in the slurry with 7.6%, by weight of binder. The material was sprayed onto a cardboard target to test for spray quality (check for running, sticking and rate of accumulation on the surface). The spray was designed to simulate the spraying of a 0.060" thick layer of explosive on a 8' x 8' vertical wall in less than two hours. Figure 12 shows the Graco spray system and the results and Table 3 shows a summary of the spray parameters and results. From earlier work we knew that the Al_2O_3 material would not represent the PETN powder very well, but its properties were close enough to those of the PETN to allow estimation of setup parameters for the test with the MgO slurry. The MgO was a much better (closer match to PETN in particle size and morphology) simulant to the PETN powder but it is quite expensive. Therefore, we only wanted to do one spray test with the MgO slurry.

The second spray used the MgO slurry and the Binks spray gun. The Graco pump system was used because the longer lead time in obtaining the Binks system didn't allow enough time to assemble its pump and still complete the project as scheduled. A smaller nozzle diameter was selected (0.040") and lower fluid flow rates were used based on the findings from the Al_2O_3 slurry spray. The fluid sprayed out of the nozzle was only 41% of the amount from the first test. This trial simulated spraying the same 8' x 8' wall with explosive 0.060" thick in less than five hours. Figure 13 shows the Binks spray gun and results. Future development should be aimed at optimizing the spray deposition, shortening the application time, and optimizing the explosive mix to achieve a higher sprayed mass density of the explosive layer for more efficient scabbling of concrete.

The mass density of the explosive in Part I of this study was ~0.70 g/cm^3 giving a CJ pressure of about 30 kBar for the explosive. The mass density for the second spray using MgO was 0.78 g/cm.^{3} If the PETN could be sprayed to the same density as the simulant, the CJ pressure would be ~45 kBar - a significant improvement in pressure.

Table III. Spray System Parameters for Trial Sprays and Results

Spray Gun	Spray Gun Nozzle Dia. (in.)	Atom-izing Air Pressure (psi)	Fluid Pump-ing System	Pump Pressure (psi)	Fluid flow out of Nozzle (g/s)	Explosive mixture Solids/ Fluids	Mass Density of Sprayed Material (g/cm^3)
Graco	0.055	10.0	Graco	55	5.8	0.29-0.44	N.A.
Binks	0.040	5.0	Graco	55	3.8	0.19-0.18	0.78

Summary

This study was successful in all aspects of the project. There were five main questions being addressed and each was answered with a positive solution. The results were:

1. A new explosive mixture was developed that could be spray painted with commercial spray equipment. Trial spray tests with an inert explosive simulant verified that spray depositions consistent with scabbling requirements were possible. This mixture was used in the explosive initiation study. The mass density of the explosive for the initiation studies (~0.70 g/cm^3) and the spray process (0.78 g/cm^3) were approximately the same.

2. Explosive wedge tests demonstrated that the new explosive mixture could be reliably initiated and that the explosive would sustain a detonation front to the thinnest layers tested (0.014" thick).

3. Explosive strip tests showed that mechanical (shock and impact) stimulus would consistently initiate the thin explosive layer. Contact detonators, detonators with a 0.010" thick flyer plate (with air gaps from 0.15 to 1.00") and pellet impact (0.250" diameter steel ball at 1500 and 600 fps) all caused prompt explosive initiation. Direct electrical stimulus (bare EBW bridgewire and bare SCB) did not initiate the explosive layer.

4. Commercial spray painting systems were surveyed and two systems were purchased and evaluated.

5. Trial sprays were conducted, using parts from both of the spray systems, with inert powders (Al_2O_3 or MgO) and binder mix to simulate the explosive mixture. Thin layers of material were successfully spray deposited on a vertical surface with both systems. The implication of these trials is that the explosive mix developed in this study can be sprayed on vertical surfaces for use in concrete scabbling.

The information gained in these studies demonstrated that the concept of using spray deposited explosive for scabbling of concrete is sound. The Demolition and Decommissioning of nuclear power plants will be made safer and more efficient using this concept. Future development should be aimed at optimizing the spray deposition, shortening the explosive application time, and optimizing the explosive mix to achieve a higher sprayed mass density of the explosive layer and, therefore, more efficient scabbling of concrete. The demonstration of concrete scabbling with a simple initiator could be done as the next phase in the evolution of this mechanical process.

Conclusions

Using an explosive simulant, experiments were carried out that proved the feasibility of spray painting a layer of explosive on a wall and then detonating the layer to cause a shock wave to be introduced into the wall which causes scabbling of the front wall surface. The next step would be to optimize the spray process to deliver explosive at a higher density, to speed up the application time and to simplify the cleanup process after a spray operation.

Data concerned with the quantity and quality of the sprayed explosive versus amount of concrete to be scabbled needs to be either generated or collected from the available literature.

An automation of the explosive scabbling process through robotics should be studied.

The authors of this report believe that this technology is mature enough to move to the next step of development with a goal of accomplishing a scabbling demonstration on a concrete target.

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Figures

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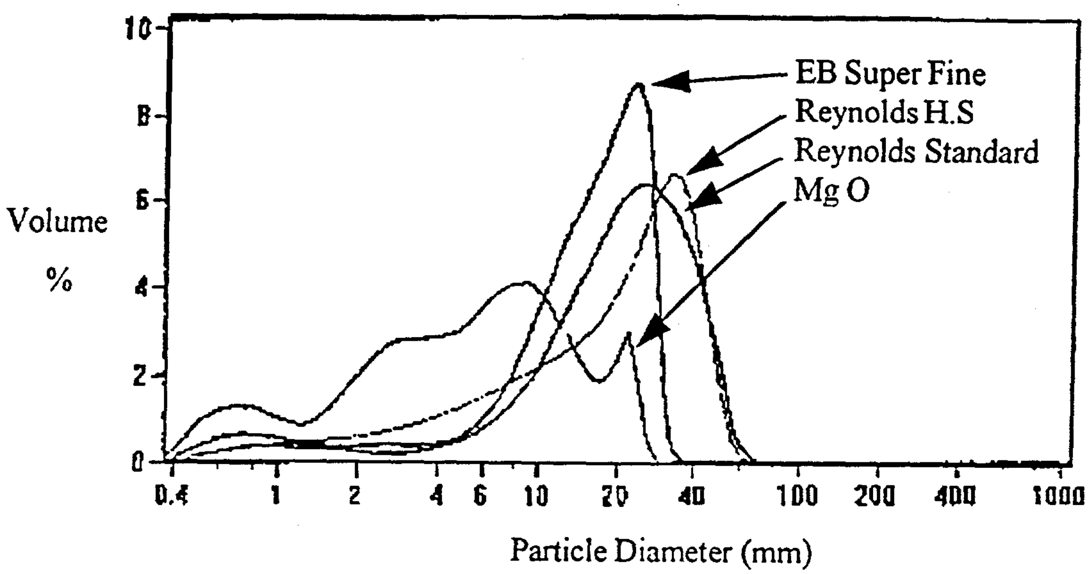

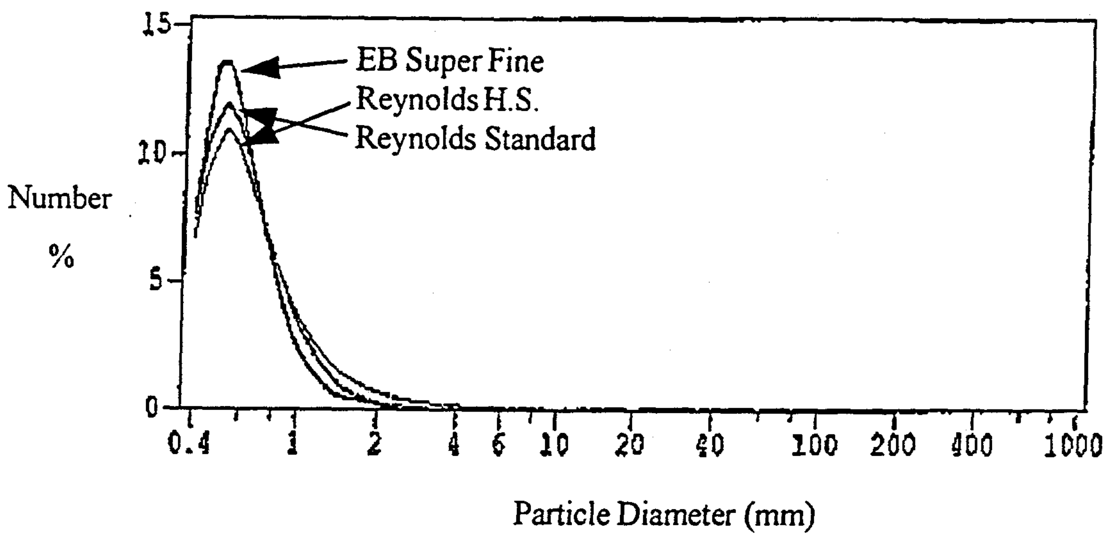

Figure 1. Explosive and MgO Particle Size Analysis

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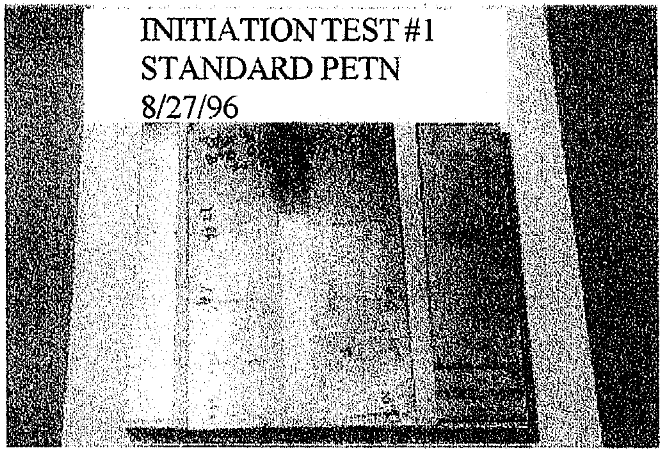
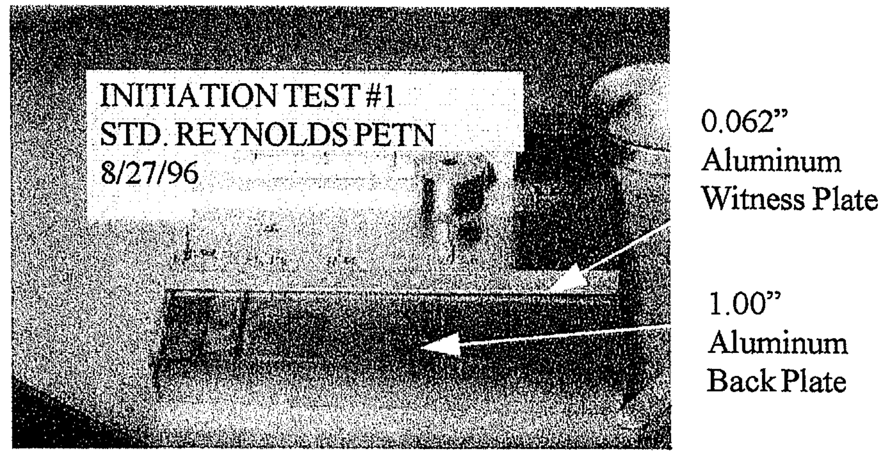
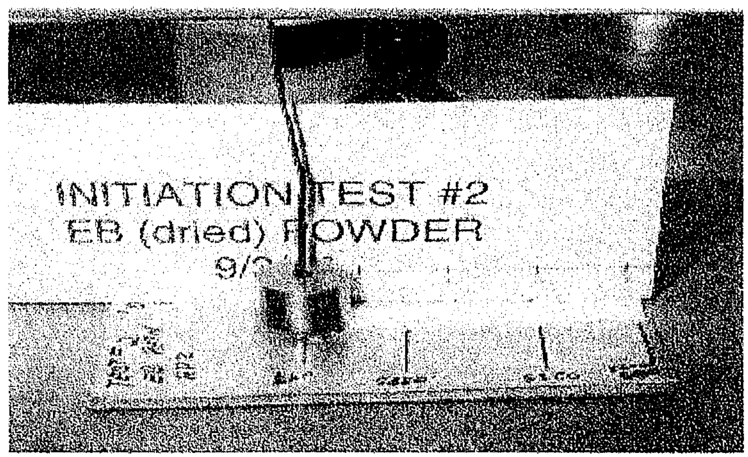


a) Wedge Mold



b.) Wedge Mold with Explosion Cast in Place



c.) Wedge Sample with Detonator Attached

Figure 2. Photograph of the Wedge Tests

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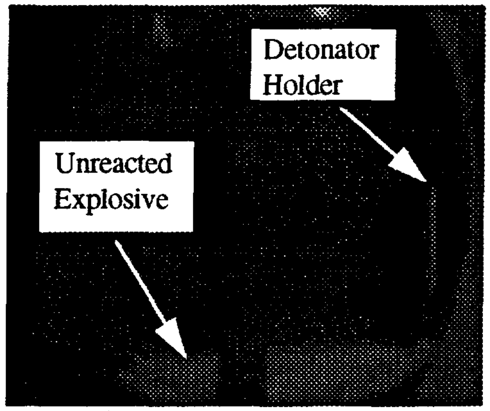

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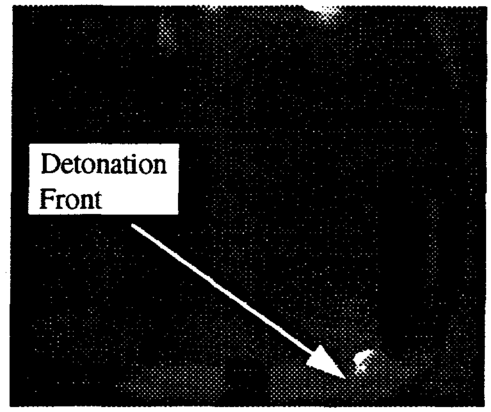

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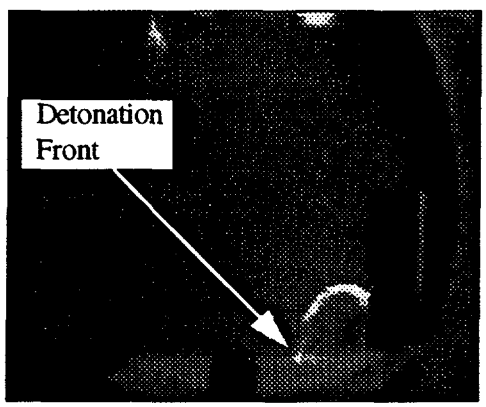

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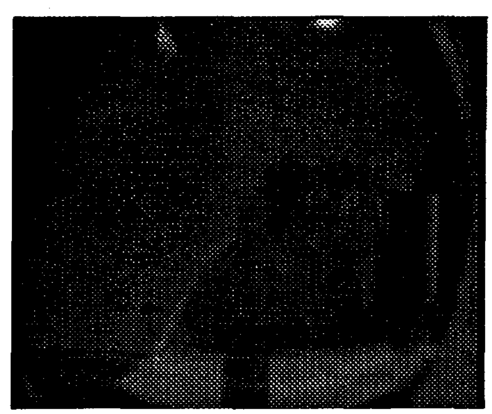
T=19 ms

T=22 ms



T=25 ms

Figure 3. High Speed Photographs of Explosive Reaction (Test #9)

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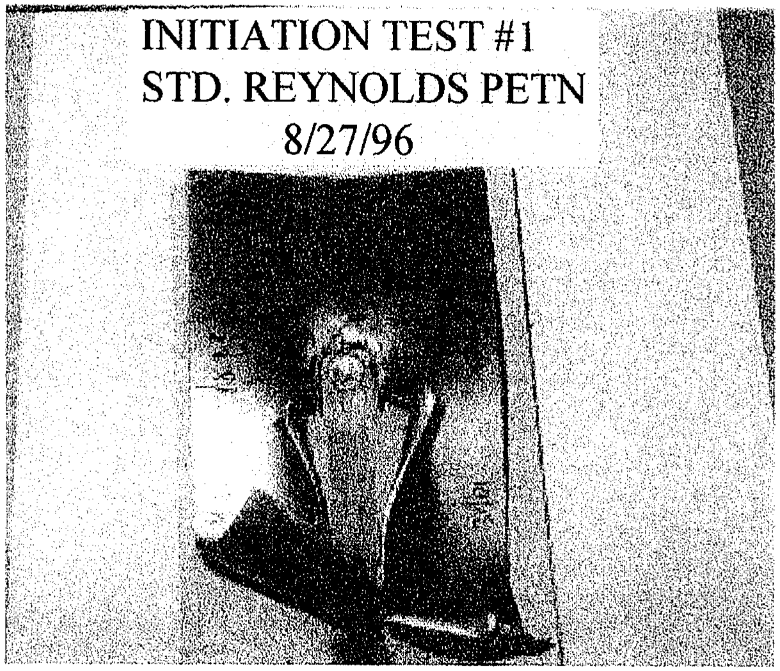
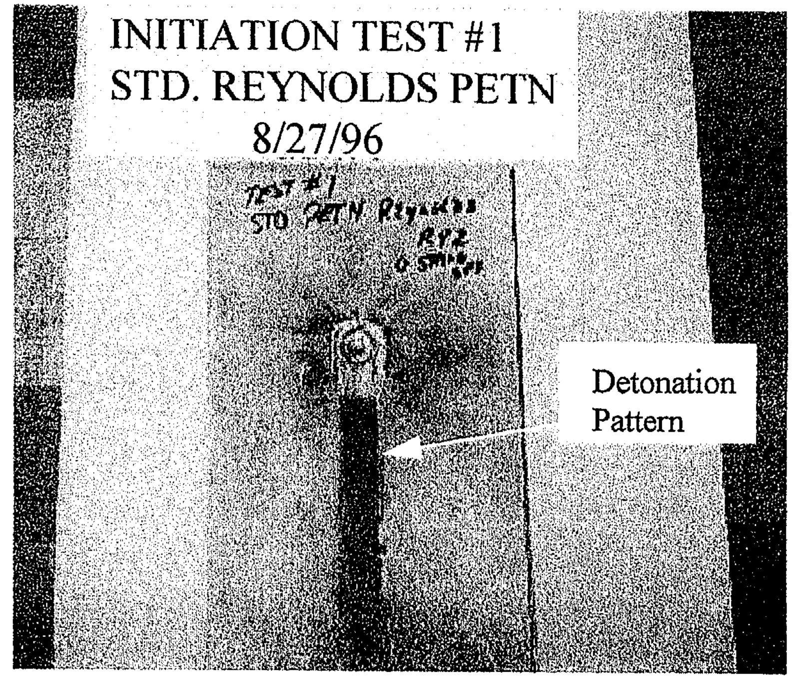


a.) Wedge Sample Mold Plus Witness Plate



b.) Aluminum Witness Plate

Figure 4. Post Test Photos of Wedge Sample, Test 1.

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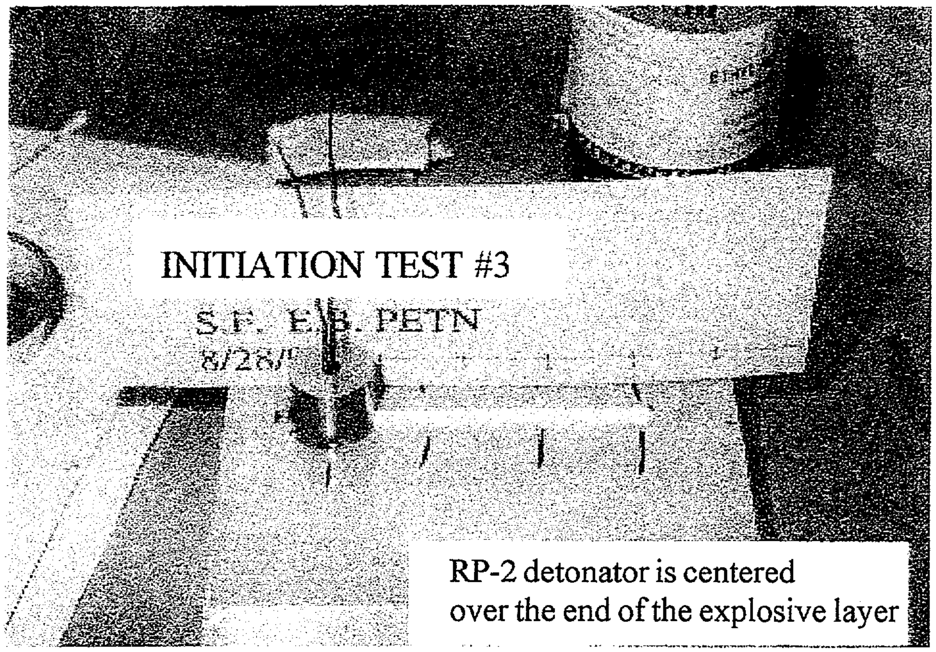
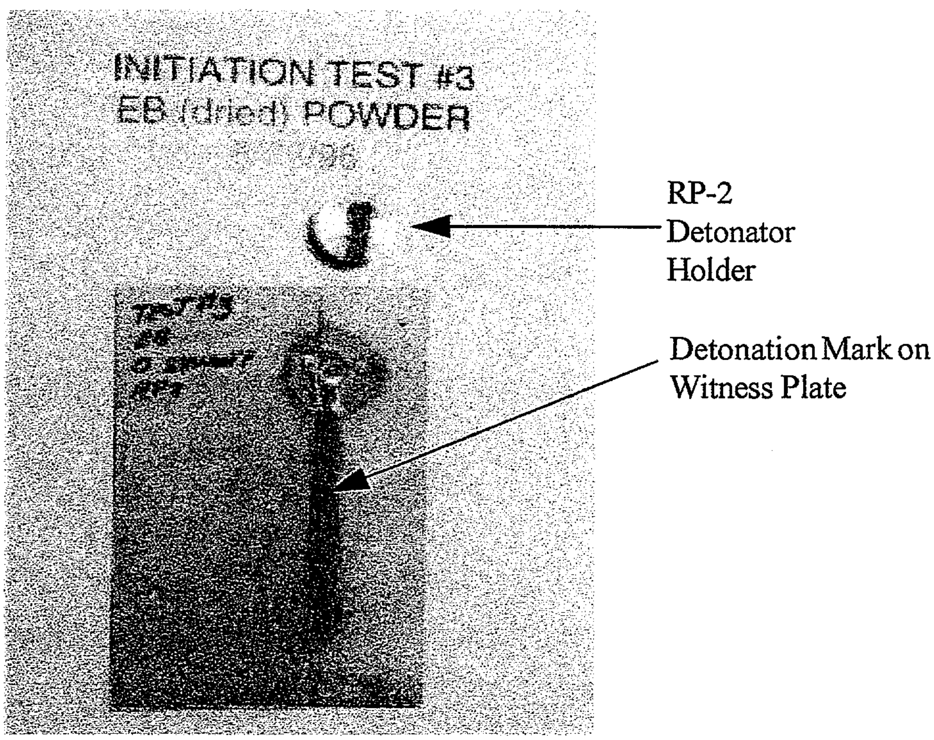


a.) Strip Test Setup



b.) Aluminum Witness Plate

Figure 5. Explosive Strip Test Setup, Sample and Result

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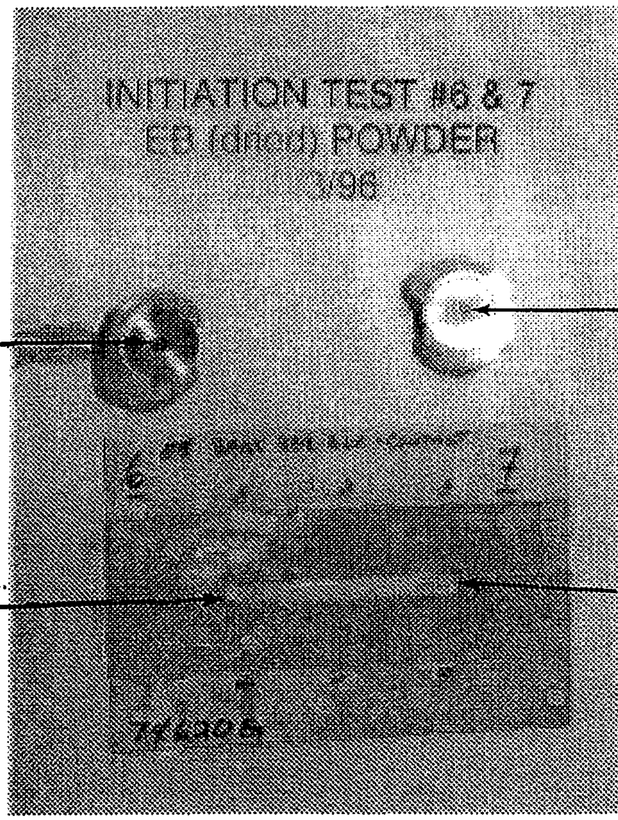

Figure 6. Results from Bare EBW and SCB

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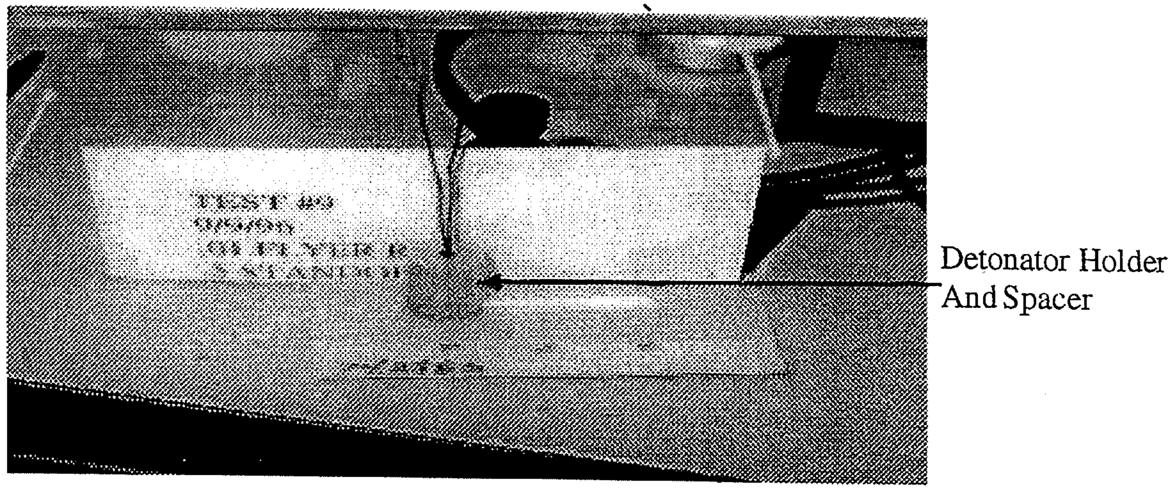
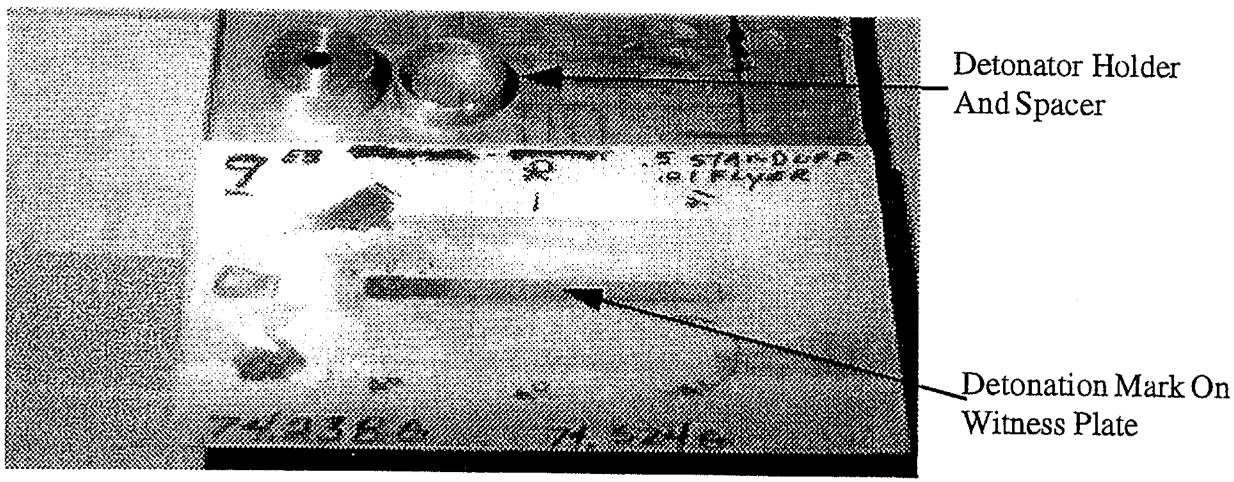


a.) RP-2 with 0.010" Thick Steel Flyer Plate, Sample Setup



b.) Test Results

Figure 7. Setup and Results for Flyer Plate Impact Tests.

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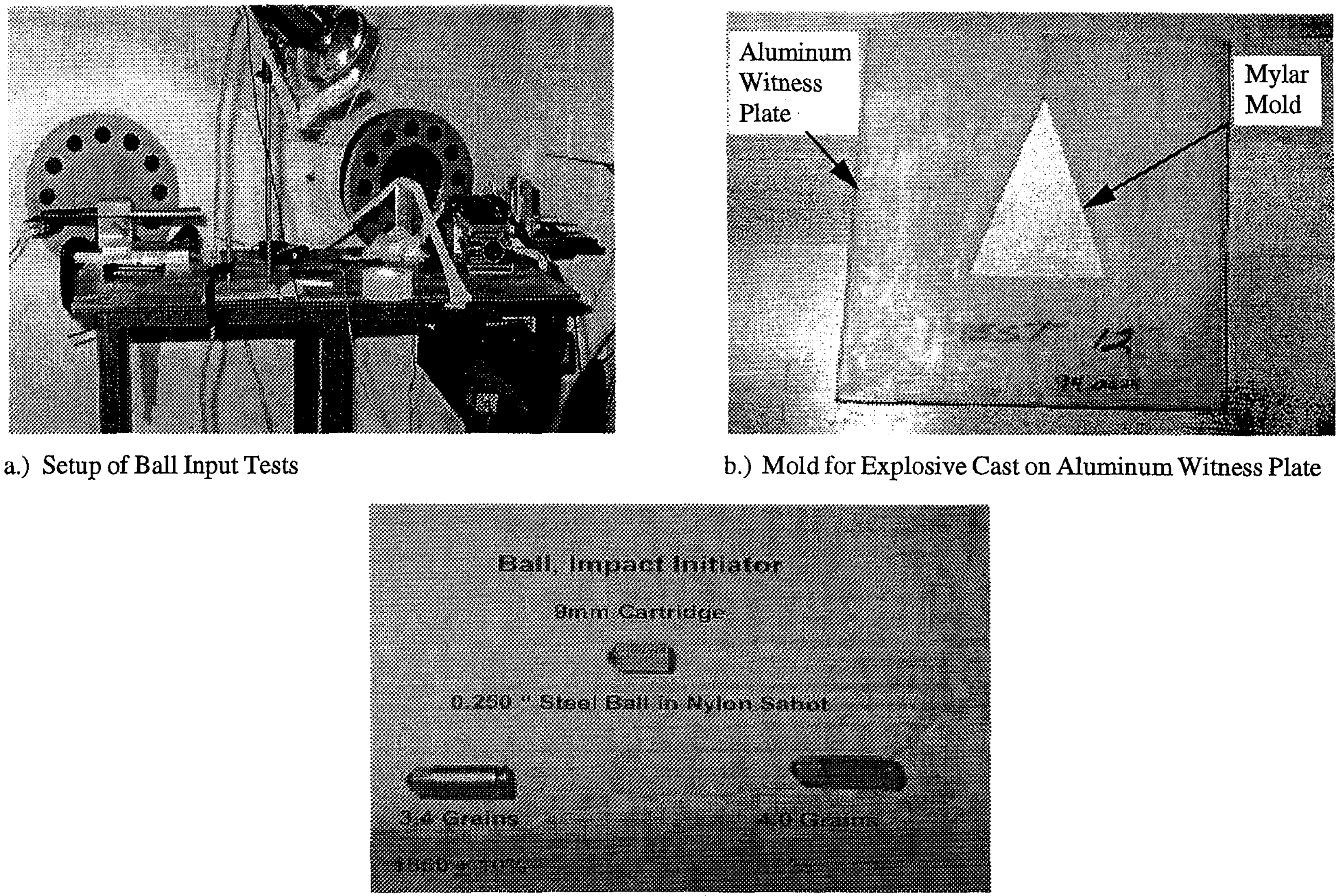

a.) Setup of Ball Input Tests

b.) Mold for Explosive Cast on Aluminum Witness Plate

c.) Cartridge/Sabot/Ball/Impactor

Figure 8. Setup for the Ball Impact Tests on Aluminum Backing.

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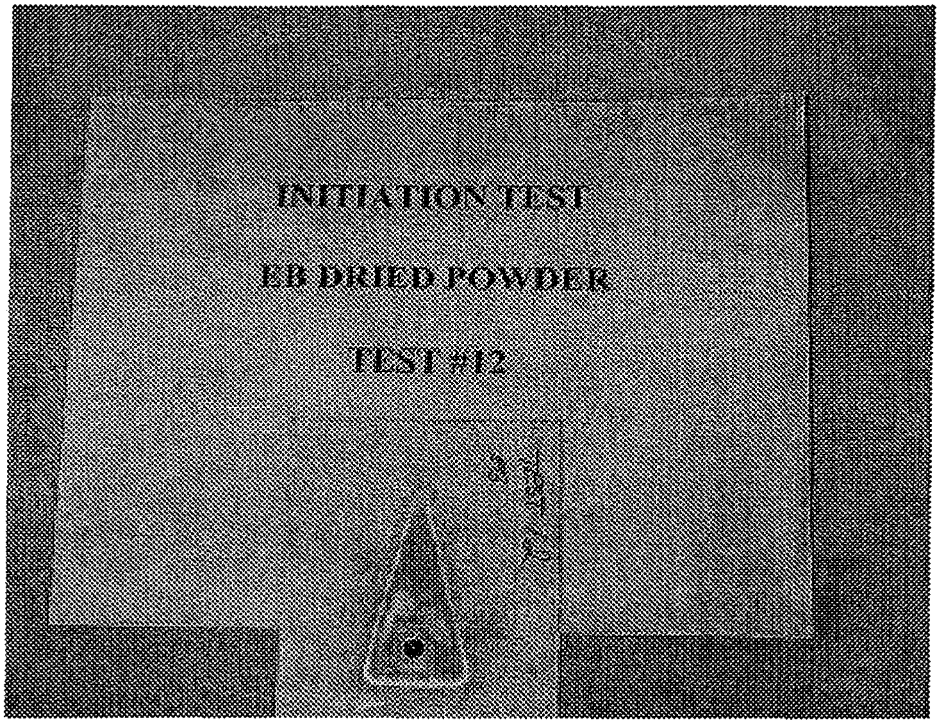
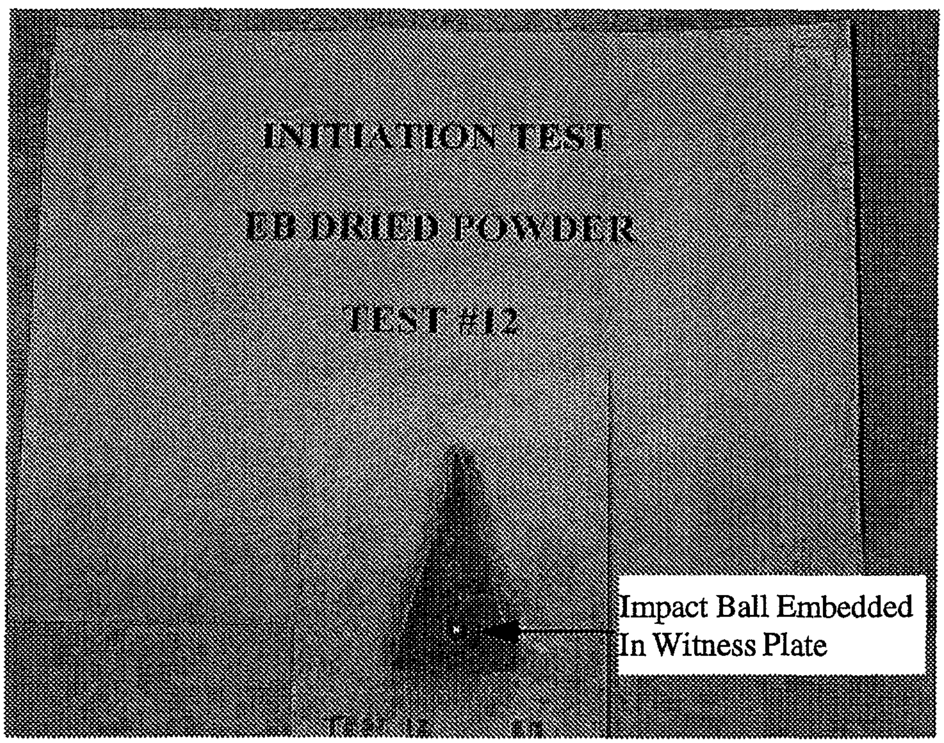


a.) Back Side of Witness Plate,
Ball Velocity (1500 fps.)



b.) Front Side of Aluminum Witness Plate,
Ball Velocity (1500 fps.)

Figure 9. Results from the Ball Impact

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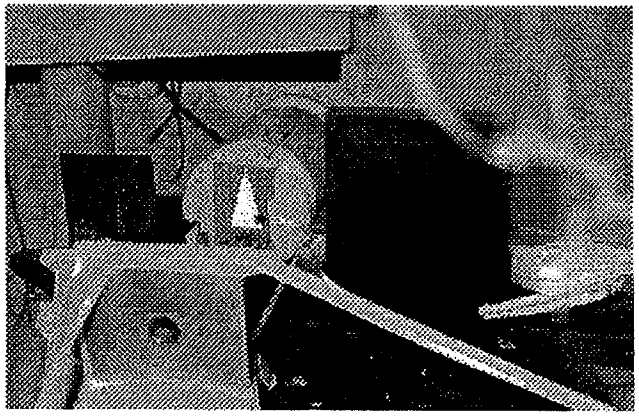
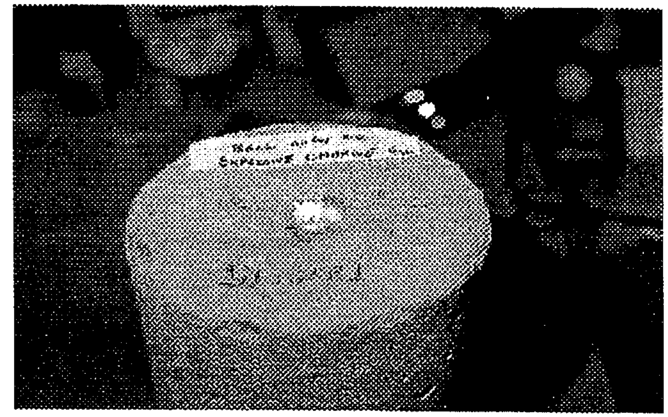
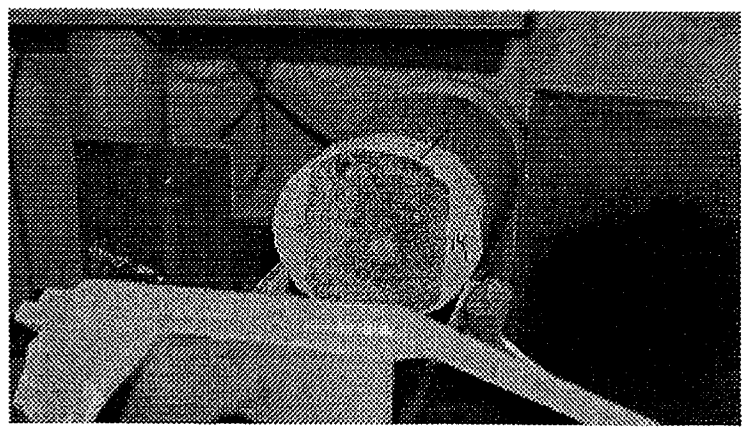


a.) Setup for Ball Input on 0.060" Explosive Layer on Concrete Targets



b.) For Reference, Ball Only Impact on Concrete (1800 fps).



c.) Results from Ball Impact Tests on to Concrete

Figure 10. Setup and Results from Ball Impact Tests on Concrete Target.

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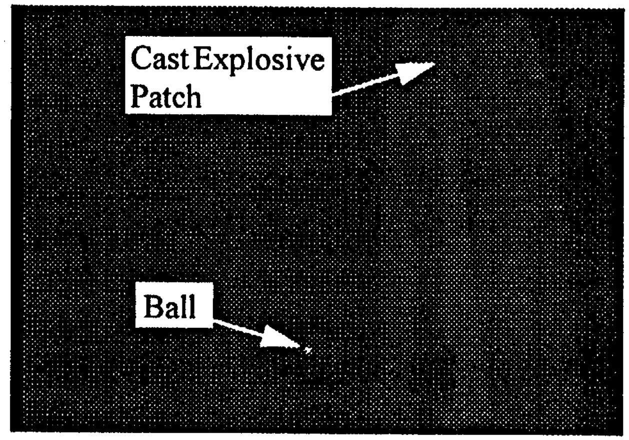
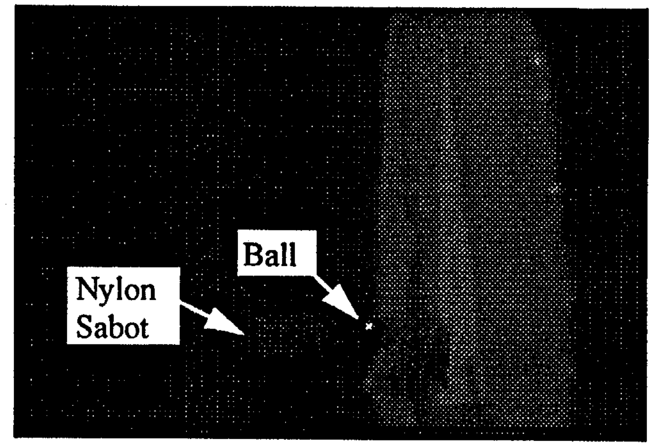
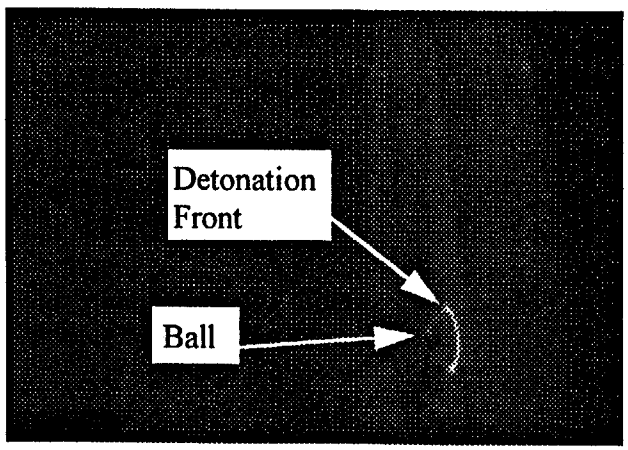


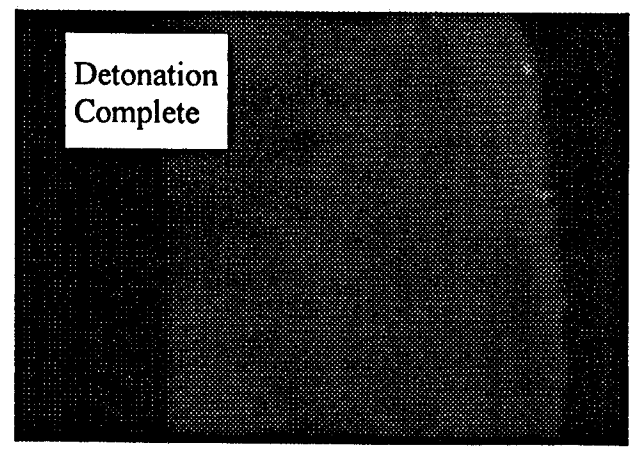
a.) Time=275 ms After Trigger



b.) T=300 ms Ball Velocity (1500 fps).



c.) T=350 ms



d.) T=375 ms

Figure 11. High Speed Photographs of Ball Impact on 0.060" Thick Explosive on Concrete

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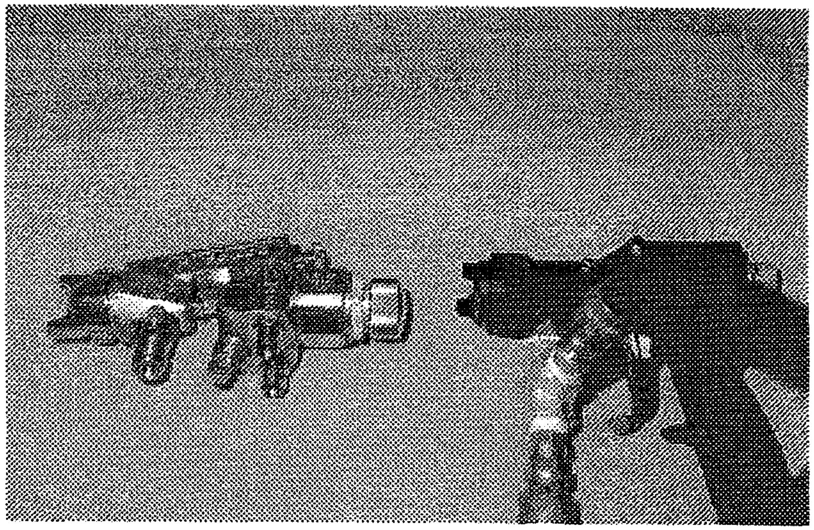
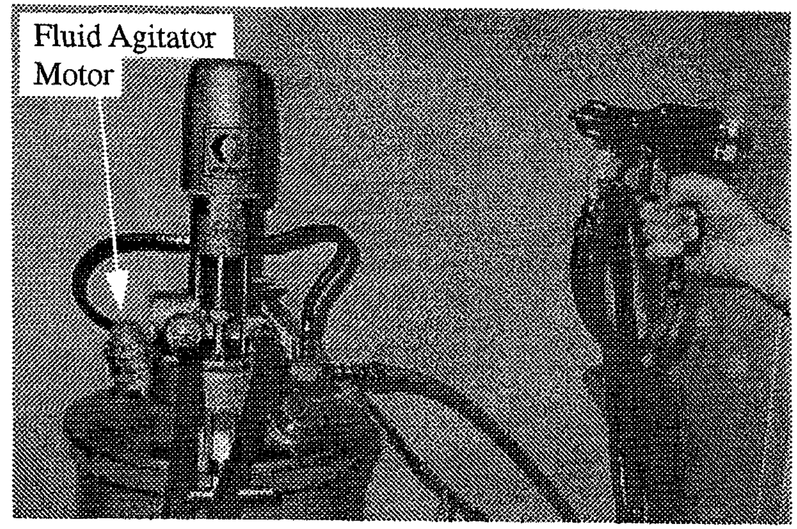
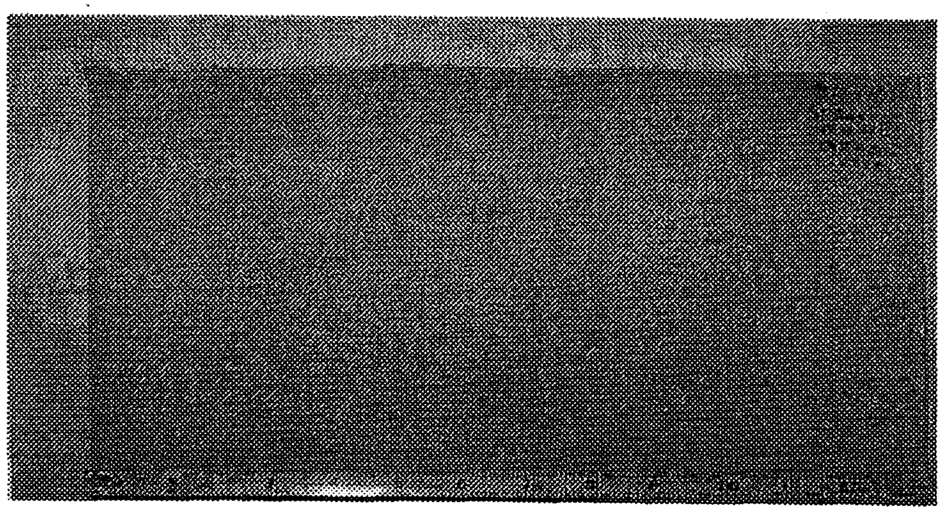


a.) Automatic and Hand Held Spray Guns, GRACO Inc.



b.) Spray System, Pump/Fluid Agitator/Spray Gun.



c.) Sprayed Sample, AL_2O_3 Explosive Simulant, 0.055" Diameter Nozzle

Figure 12. GRACO Spray System and Results.

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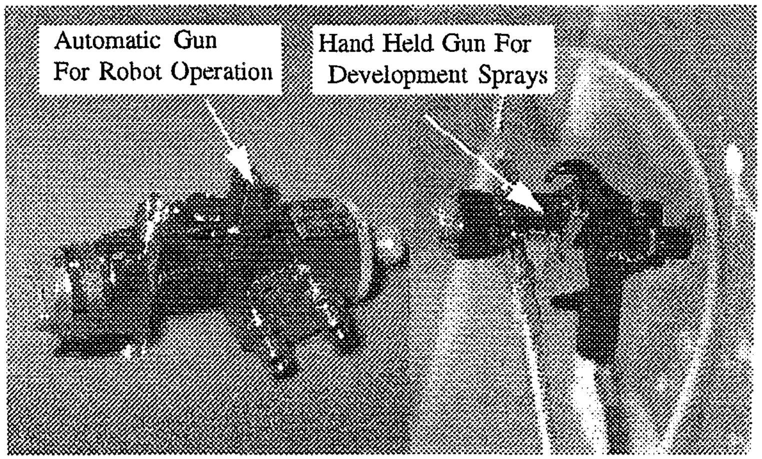
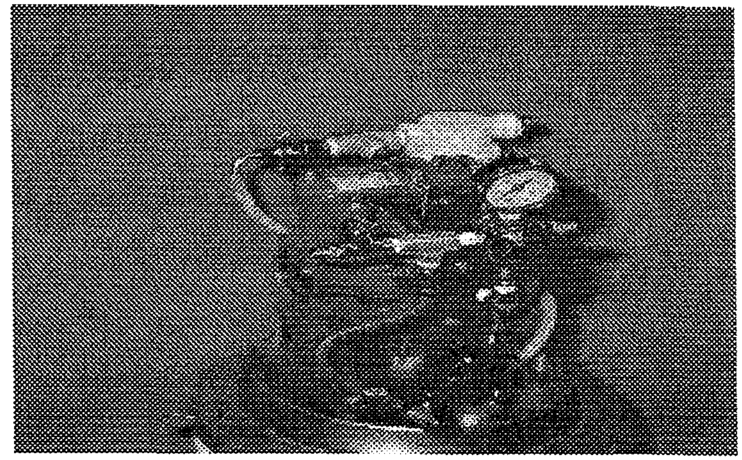
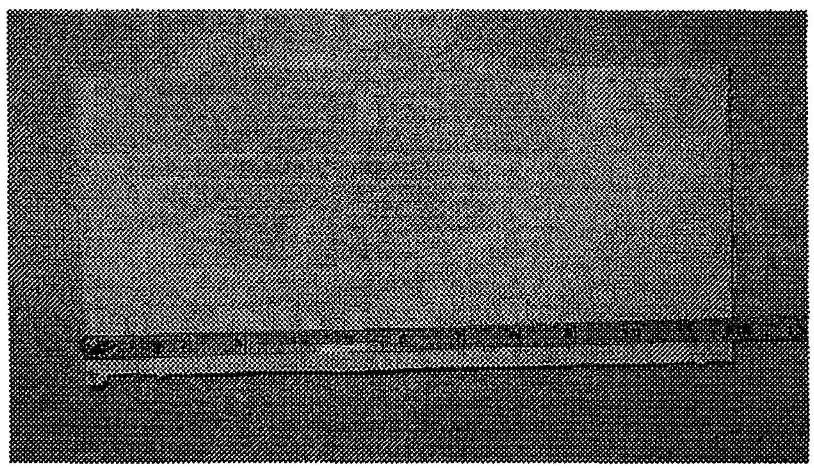


a.) Automatic and Hand Held Spray Guns, Binks Inc.



b.) Spray System, Pump/Fluid Agitator/Spray Gun.



c.) Sprayed Sample, MgO Explosive Simulant, 0.040" Diameter Nozzle

Figure 13. Binks Spray System and Results.

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References

1. R. A. Benham, *Combined Response Impulse Testing Using Light Initiated High Explosives*, SAND87-1297. Sandia National Laboratories, Albuquerque, NM, November 1987.

2. J. W. Moore, W. Gill, R. A. Benham, Experimental Technique for Generating External Surface Impulse Loading to Evaluate Rocket Motor Propellant Damage, *Proceedings of the 1990 JANNAF Propulsion Systems Meeting*, Laurel, MD, April 1990.

3. R. W. Bickes, Jr., Explosive Systems Utilizing Semiconductor Bridge, SCB, Technology, in *Propellants, Explosives, Pyrotechnics*, vol. 21, pp. 146-149, 1996.

4. H. C. Hornig, E. L. Lee, M. Finger and K. E. Kurrle, Equation of State of Detonation Products, in *Proceedings 5th Symposium (Int.) on Detonation,* Office of Naval Research, Washington, DC, ACR-184 (1970), pp. 503-512.

5. W. C. Davis, Detonation Phenomena, in *Behavior and Utilization of Explosives in Engineering Design,* 12th Annual Symposium- ASME/UNM, Albuquerque, NM, (1972), pp. 5-14.

6. Binks Instructions - Part Sheets for the Spray Systems, #2467R-2 and 2665R.

7. GRACO Instructions - Part Lists for the Spray Systems, #306-565/Rev. C, 306-713/Rev. F, 308-044/Rev. D and 380-293/Rev. E.

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