Identification and Significance of the Problem or Opportunity

In a post 9/11 world, there is an urgent need for blast resistant structures. Building owners and developers, led by the U.S. government, are taking a closer look at incorporating measures to alleviate the effects of a terrorist attack on their buildings. One significant factor entering today's construction and building operation economy is the cost of blast mitigation. In view of this, this proposal outlines a program to prepare and evaluate concrete tiles or panels that can be fastened to existing facades to achieve the desired crack resistance and blast resistance.

Elastomers in concrete confer blast resistance, impact resistance or fracture toughness by absorbing the kinetic energy of the blast through deformation. It is known that elastomeric polymer coatings increase the blast and ballistic performance of concrete and steel plating by absorbing high energy.

One of the most important building materials, concrete is an artificial material similar to stone that is used for many different structural purposes. It is made by mixing several different aggregates such as sand and pebbles with water and cement and then allowing the mixture to harden by hydration. Hydration causes crystals to form that interlock and bind together.

Although the physical properties and relatively low cost make concrete the most widely used material, conventional Portland Cement Concrete (PCC) has a number of limitations, such as low flexural strength, low failure strain, susceptibility to frost damage and low resistance to chemicals. These drawbacks are well recognized by civil engineers and can usually be allowed in most applications. In certain situations, these problems can be solved by using materials which contain an organic polymer in conjunction with Portland cement. These relatively new materials offer the advantages of higher strength, improved durability and greater resistance to damage from freeze thaw cycles.

In brief, the proposed technical approach to durability and crack resistance is based on controlling the strength-to-stress and water-to-cement ratios of the concrete. A low water-to-cement ratio is obtained by replacing some of the mixing water with a high boiling point and water-soluble monomer, which subsequently graft copolymerizes onto an elastomeric polymer, polystyrene-co-butadiene (SBR). Polymerization occurs in the capillary and gel pore spaces, as well as other locations where monomer and elastomer are present, to yield the desired extensibility of the cured concrete. After graft copolymerization of the acrylate onto the rubber and hardening of the concrete, the resulting composite material consists essentially of two interpenetrating networks. One is a network of hydrated PCC and the other is an essentially continuous network of a graft copolymer that fills most of the voids in the concrete.

An important structural consideration following the Oklahoma City bombing is the exterior facade. One of the less visible causes of human injuries is blast pressure, which can rupture the ear drum, collapse the lung, or even crush the skull as a result of the blast's wave getting into the workspace. These injuries, which begin at pressures near 15 pounds per square inch (psi), can be reduced if the level of blast pressures entering the space is curtailed.

As a point of reference, the blast pressures felt on the facade in the Oklahoma City Bombing were on the order of 4,000 psi. In Iraq and other environments where car bombs and improvised explosive devices (IEDs) are prevalent, the objective is to protect against sub-sonic fragmentation (~ 700-1200 fps and 100 mg to 1.2 grams) and to reduce overpressure by ~50 psi, considering that the threshold pressures of lethality are ~100-200 psi. In order to achieve this objective, the proposed project seeks a material that can deform and absorb the kinetic forces from the blast.

Recent reviews (1-3) of the literature on rubberized concrete indicate that large benefits can result from the use of ground rubber from scrap tires in PCC mixtures. This is especially true in circumstances where properties like lower density, increased toughness and ductility, superior freeze-thaw cycling stability, and more efficient heat and sound insulation are desired (1). It is therefore logical to assume that rubber will increase the blast resistance of concrete since it is capable of absorbing the kinetic energy of the blast through deformation. Yes, rubber decreases the compressive strength, but we are concerned here with a non-structural application.

This proposal outlines a research and development program to develop an innovative crack resistant concrete comprising of a graft copolymer-modified PCC material. The system consists of monomer, initiator, emulsion copolymer latex, Portland cement, aggregates and mixing water. Laboratory testing of the materials will be performed by an independent laboratory and the results will be used to attract commercial partners.

This proposal seeks to develop a crack-resistant and less permeable concrete exterior panel that will be bonded to the more elastomeric (rubberized) concrete panel with an elastomeric adhesive. This sandwich structure could then be attached to the side of the building structure to confer blast resistance. It is suggested that had the Murray building been configured with these panels, the energy from the explosive blast would have been absorbed by the rubber. Figure 1 depicts a proposed structural representation of the proposed panels. All dimensions are tentative.

Crack Resistant Concrete Outer Layer	5 mm
Rubber Adhesive	0.5 mm
Rubberized Concrete with 20% Ground Tire Rubber	5 mm
Rubber Adhesive	0.5 mm

Figure 1 – Proposed Schematic of Blast and Crack Resistant Polymer Modified Concrete Panel

Phase I Technical Objectives

The primary objective of Phase I is to demonstrate the feasibility of using concrete panels on building facades and other critical infrastructures to achieve blast resistance. The blast resistant rubberized concrete tiles will be positioned between a crack resistant concrete layer and the existing structure; an aqueous, rubber-based adhesive will be used to attach the composite to the building structure. The immediate objective is to prepare the crack resistant concrete, followed by the fabrication of the rubberized concrete middle layer. For the latter, ground tire rubber particles will be added to a traditional concrete mix and the properties of the hardened cementitious composites will be determined. The ultimate aim is a concrete composite panel, which is capable of absorbing the kinetic energy from an explosive blast by deformation. In pursuit of these goals, we will answer the following questions in comprehensive fashion during Phase I of the program:

1. What is the minimum concentration of rubber and thickness of the rubberized panel necessary to produce the desired blast or impact resistance in hardened concrete?
2. What is the probability that a rubberized concrete block will remain intact after being dropped from a height of 20 feet?
3. What is the minimum thickness of the crack-resistant concrete tile?
4. What is the optimum concentration of cement in both types of tiles?
5. Is it feasible to achieve high strength in the outer layer and high toughness in the middle layer?
6. What is the projected cost of manufacturing concrete tiles based on the proposed technology?
7. What is the probability that the concrete tiles attached to concrete walls can withstand explosions up to 20 times greater than bare concrete?
8. What is the probability that the concrete tiles attached to plated steel or a composite structure can confer blast resistance?
9. What are the short-term criteria needed for demonstrating crack resistance?
10. What is the minimum concentration of water soluble monomer needed to yield very low or no drying shrinkage?
11. What is the minimum concentration of SBR needed to give the desired extensibility?
12. What is the optimum ratio of monomer to SBR?
13. What is the optimum water-to-cement ratio to give low permeability and suitable workability?
14. What are the drying shrinkage, restrained shrinkage, and implied strain values of the optimized formulation of the crack resistant concrete?

Specific technical objectives of Phase I are to:

1. Develop concrete design plans
2. Preparation of crack resistant concrete
3. Preparation of rubberized concrete
4. Optimize the process
5. Evaluate the fabricated concrete panels
6. Prepare the final report

Phase I Work Plan

Phase I Work Plan Outline

1) <u>Scope</u>

This work is a comprehensive program to demonstrate the feasibility of using GTR particles as concrete additives in the design and preparation of blast resistant rubberized concrete. The initial effort is to develop the crack-resistant outer layer and then to add recycled rubber to a traditional concrete mix. The next step is to evaluate the properties of the hardened cementitious composites. .The primary goal is a concrete panel or tile which is capable of absorbing the kinetic energy from an explosive blast by deformation of the rubber. As time and resources permit, other applications for low-density concrete will be pursued in efforts to demonstrate feasibility.

2) Task Outline

The work during Phase I is organized along five main tasks as delineated above in the Technical Objectives. These tasks are: concrete design; preparation of crack-resistant concrete panels; preparation of rubberized concrete panels; optimization; evaluation of prototypes; and reporting.

3) Milestone Schedule

The relevant milestones are answers to the 14 questions posed in the Technical Objective section of the proposal. It is not possible to give precise dates at the present time because of the iterative nature of the applied research plan. However, here is a tentative schedule for reaching significant milestones during Phase I.

Question #	**Milestone**	**Months following SOW**
1	Identification of the minimum concentration of rubber and thickness of the rubberized panel necessary to produce the desired blast or impact resistance in hardened concrete	4
2	Estimation of the probability that a rubberized concrete block will remain intact after being dropped from a height of 20 feet	2
3	Identification of the minimum thickness of the crack-resistant concrete tile	6
4	Determination of the optimum concentration of cement in both types of tiles	6
5	Reasonable estimate of the feasibility of achieving high strength in the outer layer and high toughness in the middle layer	6
6	Estimate of the projected cost of manufacturing concrete tiles based on the proposed technology	6
7	Reasonable estimate of the feasibility or probability that the concrete tiles attached to concrete walls can withstand explosions up to 20 times greater than bare concrete	6
8	Reasonable estimate of the probability that the concrete tiles attached to plated steel or a composite structure can confer blast resistance	6
9	Selection of the short-term criteria needed for demonstrating crack resistance	5
10	Identification of the minimum concentration of water soluble monomer needed to yield very low or no drying shrinkage in the crack resistant concrete tile	4

11	Identification of the minimum concentration of styrene-butadiene latex needed to give the desired extensibility	6
12	Selection of the optimum ratio of monomer to SBR	3
13	Identification of the optimum water-to-cement ratio to give low permeability and suitable workability	5
14	Identification of the drying shrinkage, restrained shrinkage, and implied strain values of the optimized formulation of the crack resistant concrete	6

4) Deliverables
    a. Kickoff meeting within 30 days of contract start.
    b. Monthly progress reports.
    c. Technical review within 6 months.
    d. Final report
    e. Prototypes

TASK 1 CONCRETE DESIGN

Concrete design is an important aspect in the preparation of concrete for specific applications. This is usually applicable with traditional concrete. After our initial screening program and the selection of optimal concentrations of rubber, experimental concrete mixes will be prepared according to ACI Standard 211.1 in the laboratory of the proposer and later at Bowser-Morner. The latter will assist in the design of concrete mixes prior to start of work.

TASK 2 PREPARATION OF CRACK RESISTANT CONCRETE EXTERIOR PANEL

The objective of this task is to develop crack resistant concrete based on graft copolymer modified concrete. During this task, we seek to demonstrate that the proposed material is crack resistant based on its low water-to-cement ratio and the incorporation of an elastomeric interpenetrating graft copolymer network designed to confer the required degree of extensibility.

2.1 Development of graft copolymer-modified concrete materials

These are essentially polymer-Portland cement concrete materials in which a monomer and a latex are added to the cement mix to obtain the advantages of polymer-modified Portland cement concrete (PPCC) and latex-modified concrete (LMC). The primary objective is to graft the acrylic onto the rubber, rather than using a mixture of acrylic homopolymer and styrene-butadiene rubber in the cementitious material. Before proceeding further, it is perhaps instructive to review the use of admixtures in concrete in order to emphasize the innovation and clarify the proposed route to achieving the required degree of extensibility.

Chemical admixtures are the ingredients in concrete other than Portland cement, water and aggregate. They are added immediately before or during mixing. In general, there are five main classes: air-entraining, water-reducing, retarding, accelerating, and super plasticizers. Other varieties of admixtures have specialized functions such as corrosion inhibition, shrinkage reduction, alkali-silica reactivity reduction, workability enhancement, bonding, damp proofing and coloring.

Water-soluble monomers are sometimes used as additives to impart special properties to concretes and mortars. These monomers also serve as water reducing agents. The combination of a high boiling, water-soluble monomer with a styrene-butadiene copolymer latex is the basis of the interpenetrating graft copolymer network that is the subject of the proposed project. The objective is to graft copolymerize the acrylic monomer onto the elastomeric copolymer as the concrete hardens. Copolymerization occurs because of the presence of a water-soluble initiator and heat from the exotherm. It is known that the bonding characteristics of latex modified concrete are excellent and permeability is low. Graft copolymerization expands the polymer network to produce a more extensible concrete with a low water-to-cement ratio.

The proposed technical approach to durability and crack resistance is based on controlling the strength-to-stress and water-to-cement ratios of the concrete materials. A low water-to-cement ratio is obtained by replacing some of the mixing water with a water soluble monomer, which subsequently graft copolymerizes onto a styrene butadiene rubber to yield the desired extensibility of the cured concrete material. It is important to note that the homopolymer of the water soluble monomer is a super plasticizer.

The rationale underlying this approach is that graft copolymerization occurs in the two different types of pore spaces in the cement paste. The first type is the capillary pore, which is the remnant of the originally mixing-water filled space between the cement particles. The second type of pore space is the gel pore, which is trapped in the hydrated cement paste structure, C-S-H, where C = CaO, S = SiO_2 and H = H_2O. The capillary pores are generally 3.2 to 3,000 nanometers in diameter, whereas the gel pores are less than 3.2 nanometers in diameter. Water trapped in the capillary pores will contain monomer, rubber and initiator. In addition, the other part of the water trapped in gel pores will also contain monomer, rubber and initiator. This is significant because polymerization in these spaces will yield long strands of elastomeric fibers which will contribute to the desired extensibility of the material.

The most important parameter that affects both the strength and durability of concrete is the water-to-cement (w/c) ratio; its importance is highlighted in numerous publications, including ACI 201 "Guide to Durable Concrete." It is typically considered the strongest indicator of concrete quality. For different types of structures and exposures, maximum w/c is specified and mixture proportioning mostly starts with the w/c. As cement and aggregates are mixed with water, the products of hydration start filling the originally mixing-water filled space. The amount of space originally occupied by mixing water is related to the w/c of the concrete. The smaller the fractional volume of the mixing water, the lesser the amount of hydration product required to fill it and the stronger the concrete. As the w/c is decreased, the porosity of the paste is decreased and the concrete becomes more impermeable to moisture entering the concrete. The ingress of moisture in the concrete is one cause of many concrete deterioration problems, including damage caused by freezing and thawing, and alkali-silica reactions. Of course, the situation is worse when the moisture entering the concrete is contaminated with aggressive chemicals such as chlorides and sulfates which promote corrosion of reinforcing steel and sulfate attack.

2.1.1 Formulation of graft copolymer modified concrete

Hydrated cement paste shrinks as it loses moisture from its extremely small pores. With this loss of moisture, the surface tension of the remaining water tends to pull the pores together, resulting in a loss of volume over time. Shrinkage reducing admixtures such as Eclipse® are designed to decrease the effects of drying shrinkage by reducing the surface tension in these pores. Eclipse® at a dosage of 2% by weight of cement has been shown to reduce shrinkage, as measured per ASTM C 157, by as much as 80% at 28 days, and up to 50% at one year or beyond.

We refer to this conventional approach to crack resistance only to show the concentration level of this admixture and the amount of reduction in shrinkage. This will be important in comparing our initial results with these in order to determine cost effectiveness of the proposed system.

We will rely heavily on the expertise of Bowser-Morner in preparing the lab batches according to ASTM C 192 and designing the experiments to isolate the pertinent variables. We will, of course, send them samples of the following:

hydroxyethyl acrylate
diethylene glycol monoacrylate
polyethylene glycol monoacrylate
Dow Chemical's SBR Latex Modifier A and
an azo inititiator selected from the group in Table 1 after preliminary work in our laboratory.

Table 1 Water-soluble azo initiators.

Initiator	**$t_{1/2}$ °C**	**Chemical Name**
VA-041	41	2,2'-Azobis[2-(5-methyl-2-imidazolin-2-yl)propane]dihydrochloride
VA-044	44	2,2'-Azobis[2-(2-imidazolin-2-yl)propane]dihydrochloride
VA-046B	46	2,2'-Azobis[2-(2-imidazolin-2-yl)propane] disulfate dihydrate
VA-057	57	2,2'-Azo[N-(2-carboxyethyl)-2-methyl propionamidine] tetra hydrate
VA-061	61	2,2'-Azobis[2-(2-imidazolin-2-yl)propane]

These initiators upon decomposition as a result of the exothermic heat of hydration reactions produce free radicals, which are capable of initiating graft copolymerization of the acrylic monomer onto the olefinic groups of the rubber. They are commercially available from Wako Chemicals USA, Inc.

Prior to sending samples of the admixtures to Bowser-Morner, we will discuss the test conditions and methodology for isolating relevant variables. Lab batches will be prepared following ASTM C 192. It is anticipated that the water-to-cement ratio will range from 0.3 and 0.4.

The reader is referred to the section on Related Work for additional information on the proposed approach versus a state-of-the-art system marketed by a potential Phase III partner. And when one considers formulating a low w/c concrete mixture, it is necessary to first look at the workability and ease of application of the system.

2.1.1.1 Workability

We fully recognize that workability is important at the job site. The properties of fresh concrete that determine the workability, or ease of mixing and placement into forms, also depend strongly on, but are not so simply related to, the cement paste rheological properties (4, 5).

The fresh paste even in the dormant period is normally thixotropic, or shear thinning, indicating that the structure is being continuously broken down and reformed during mixing. It is an approximately Bingham plastic body having a finite yield value and plastic viscosity from 5000 to 500 mPa.s (= cP) as the w/c increases from 0.4 to 0.7 (6). The viscosity and yield values can be greatly reduced by the addition of certain organic water-reducing admixtures especially formulated for this purpose. In the present project, we will rely on the monomer and latex to accomplish this. Workability of concrete is measured by the slump of the concrete determined after removal of a standard slump cone (305 mm high). Workable concretes typically have slumps of 75 mm or more.

2.2 Evaluation of Crack Resistant Exterior Concrete Panel

The objective of this subtask task is to conduct the tests necessary to demonstrate feasibility of the concept and to produce sufficient data to convince potential commercial partners that the material is more durable than PCC.

Durability is defined as the ability of concrete to resist weathering action, chemical attack, abrasion and other conditions of service. Because of its chemical and physical nature, concrete can certainly be designed and used to construct durable, long-lasting pavements and structures. Durability can be achieved with the use of dimensionally stable materials or materials which exhibit less stress from thermal contraction, autogenous shrinkage and drying shrinkage. Concrete cracks when the tensile stress exceeds the tensile strength and the combination of factors affecting crack resistance is referred as the tensile strain capacity or extensibility. It is understood that cracking of concrete can be managed by controlling its extensibility.

To our knowledge, there is presently no generally accepted test method or methods to determine the long-term performance of concrete. The most important material properties are likely to be those related to the various types of deformation: shrinkage, creep, modulus of elasticity, and coefficient of thermal expansion.

The strength-to-stress ratio is a measure of the probability of cracking under given conditions. A value significantly higher than 1 indicates low likelihood of cracking, and a value significantly less than 1 indicate a high probability of cracking.

2.2.1 Drying Shrinkage

We will evaluate the drying shrinkage of several formulations in our laboratory initially following ASTM C157 and select the best candidates for further testing at Bowser-Morner to repeat the test in their laboratory to confirm our results of this important test.

2.2.2 Cracking Resistance

This test will be performed by Bowser-Morner following the AASHTO method, "Standard Practice for Estimating the Cracking Tendency of Concrete."

2.2.3 Splitting Tensile Strength (ASTM C 496)

This relatively inexpensive test will be performed by Bowser-Morner after 28 days on each lab batch prepared by that AASHTO/ISO 17025 Accredited laboratory.

2.2.4 Compressive Strength

Cylinders (ASTM C 39)

Modulus of elasticity (ASTM C 469)

These tests will be conducted by Bowser-Morner on each batch.

2.2.5 Specific Gravity, Absorption, voids (ASTM C 642)

After curing of the graft copolymer modified concretes, we will measure their specific gravities in our laboratory. With respect to moisture absorption, eight concrete cubes, 3" x 3"x 3", will be cured and dried following the test procedure. The cubes will be submerged in water for 48 hours, followed by 24 hours submersion in boiling water to simulate years of intense sun and rain. Six of the eight will be re-submerged in water. Two will be broken for visual observation. Measurements on the percentage increase in weight will be recorded as follows:

Submersion Time	% Weight Increase
After 48 hours soak	
Then 24 hours boil	
Next 7 days submersion	
14 days submersion	
21 days submersion	
56 days submersion	

TASK 3 PREPARATION OF RUBBERIZED CONCRETE PANEL

3.1 Rubber

GTR Microgrind™. Fine mesh crumb rubber will be used as the source of rubber during Phase I. It is available from GTR, Inc., a potential Phase III partner.

3.2 Cement

Portland Cement (ASTM No. 1), available from Clayton Concrete, will be mixed first with the GTR. Next, aggregates (crushed stone and concrete sand purchased from Clayton Concrete) will be added to the concrete mix, which is allowed to harden.

3.3 Pretreatment

Various studies show increased adhesion between rubber and Portland cement can be achieved if the surface of the rubber is rough or etched. This is consistent with the practice of etching the surface of other polymeric materials to get stronger bonding. This means that the rougher the rubber particles used in concrete mixtures the better the bonding they develop with surrounding matrix and, therefore, the higher the compressive strength achieved. In order to obtain enhanced adhesion, it may be necessary to pretreat the rubber. Pretreatment varies from merely washing particles with water to acid etching, and various coupling agents.

3.4 Preparation of Panels

ABS and silicone molds of various sizes will be used for work in the proposer's laboratory. Three silicone (2 inches x 2 inches x 2 inches) molds will be used for preliminary screening studies. Additional molds will be prepared by the P.I. after the initial screening is complete. Concrete mixes will be prepared as outlined in Tables 2 and 3 below. The concentration of rubber as volume percent of total aggregate will vary as shown in the Tables. Workability of the mix is a crucial parameter which will be used to select suitable ratios for testing in the next task. An appropriate water to cement ratio will be established early during this task, but an arbitrary w/c ratio given is assumed as starting point.

3.5 Procedure to be used in the proposer's laboratory for preparing specimens

The first step in the procedure is to clean and prepare the molds; each mold can hold three 2 inch cubes of concrete for a total of 9 samples. The molds are scraped of any excess concrete with a trowel and then brushed with motor oil with a small paintbrush to make the removal of the concrete cubes easier. Once the molds are prepared, the process of mixing concrete can start.

The second step is to mix all the dry ingredients, including the coarse aggregate, fine aggregate, cement, and rubber. Each dry ingredient is weighed and thoroughly mixed with a large spatula to ensure the homogeneity of the mixture. Water is added from a 250 ml graduated cylinder to the mixture, which is then blended completely.

After the ingredients are mixed, the molds are filled with the concrete mixture using a small spatula and placed on a vibrating table to complete the packing in the third step. Pressing follows with a trowel and more concrete added to fill in any molds when necessary.

The concrete is now securely packed into the molds and left to harden for at least 12 hours. The cubes are removed from the molds and labeled accordingly and placed on a shelf for 24 hours. This is followed by immersion in a water bath for 27 days to reach their maximum hardness. After aging, they are removed and examined one day later.

Table 2 shows the ingredients for the control concrete mixture to be prepared in the proposer's laboratory.

Table 2. Ingredients portions for w/c = 47% and 0% rubber.

Ingredient	Water	Cement	Coarse	Fine	Rubber
Volume (m^3/m^3 of mix)	0.207	1.40	0.312	0.31	0
Weight (g/1.15 x 3 cubes)	93	198	381	312	0
Weight (g/1.15 x 9 cubes)	279	594	1,143	1,11	0

The first objective is to collect information in iterative fashion for identifying and selecting suitable ratios for preparing larger specimens necessary for testing in the proposer's laboratory. Accordingly, starting exploratory formulations, given in Table 3, will be prepared. It is also necessary to determine the maximum level of aggregate that will yield a satisfactory slump.

Table 3. Starting concrete additive portions to be used in initial series

#	**Cement**	**Water**	**Coarse**	**Fine**	**Rubber**
	Volume %	Volume %	Volume %	Volume %	Volume %
1	20	20	20	20	20
2	20	20	0	20	40
3	20	20	15	25	20
4	20	20	20	0	40
5	20	20	0	20	40
6	20	20	0	0	60
7	20	20	10	0	50
8	20	20	0	10	50
9	20	20	10	30	20

The proportions shown in Table 3 will be fine-tuned and suitable formulations will be prepared following consultation with Bowser-Morner. Good adhesion to the matrix is a key objective.

After fine-tuning the formulation, we will prepare larger samples using a Hobart mixer with a flat beater and a stone concrete mixer using the procedure described in ASTM Designation: C 192/C 192M-02 entitled Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

3.6 Preparation of Prototypes

The prototypes will be used to approach manufacturers of concrete products and suppliers of crumb rubber. Needless to say, they will be available for inspection by potential Phase III partners, along with independent test results from Bowser-Morner. It is important to note that the specifications for each product will guide the selection of the specific concrete application. In addition, the advantages of the proposed technology will be emphasized during presentations to potential Phase III partners.

3.7 Evaluation of Prototypes

The plan will include a look at a series of performance variables as a function of the water-to-cement ratio and rubber-to-cement ratio. The variables are workability, permeability, modulus of elasticity, creep in compression (ASTM C 512), rapid freeze-thaw stability (ASTM C 666, Procedure A), chemical resistance, and other parameters suggested by concrete contractors and Bowser Morner.

TASK 4 OPTIMIZATION

During this task, we will determine the optimal formulations and, following successful duplication of the results, we will prepare larger samples for evaluation in the next task. This task will also entail repeating the preparation of optimal systems to confirm that the results can be replicated.

It is essential to indicate in detail what will be done in this important task which encompasses the work performed in prior tasks. If important milestones are reached early in the program, such as acceptable impact resistance and other mechanical properties, optimization will proceed and test samples will be prepared in order to demonstrate performance to local concrete contractors as early as possible. More important, the commercial partner needs valid reasons for experimenting with the proposed technology. This task seeks to develop and catalog these reasons by accumulating a database, which is crucial for marketing the cementitious composites. Accordingly, the P.I. intends to lease Design Expert version 7 from Stat-Ease prior to start of work. In the meantime, he has selected a temporary Matrix Design, which is shown in Table 4.

Table 4 Proposed Matrix Design of Rubberized Layer

Formulation #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Run Order									
GTR, wt/wt % of cement									
Cement, w/w % of concrete mix									
Course Aggregate, w/w %									
Fine Aggregate, w/w %									
Water, w/w %									
Water/Cement Ratio									
Slump, mm									

Developing the Experimental Designs

In the proposed work, the aim is to screen the overall main interaction effects among 8 independent variables (Table 4) in an economical manner. Under these circumstances (i.e. when >5 factors are considered), the Plackett-Burman design is highly recommended. Higher-order linear full factorial and quadratic Box-Behnken designs would require 66 and 52 experimental runs, respectively, which are clearly uneconomical.

The performance (dependence) variables include: 4.1 Specific Gravity (ASTM C 642); 4.2 Compressive Strength - Cylinders (ASTM C-39); 4.3 Modulus of Elasticity (ASTM C469); 4.4 Flexural Strength - Center Load (ASTM C293); 4.5 Flexural Toughness (ASTM 1018); 4.6 Splitting Tensile Strength (ASTM C496); 4.7 Water Sorption; 4.8 Acid Resistances (ASTM D 3042); and 4.9 Impact Resistance.

Other physical and mechanical properties include the following, which will be determined as time and resources permit: Thermal Expansion; Tensile Strength; Fracture Toughness; and Freeze-Thaw Resistance.

TASK 5 EVALUATION

The objective of this task is to evaluate:

5.1 The crack resistant panels;
5.2 The rubberized panels;
5.3 The composite (sandwich) structures

This task will be carried out simultaneously with the previous task in iterative fashion to determine the effect of composition on specific and relevant properties. Initial tests on small samples will be performed in the proposer's laboratory and selected larger samples will be sent to Bowser-Morner for verification of the results. The sandwich structure will be fabricated with a pressure sensitive rubber latex adhesive to fasten the crack resistant panel to the rubberized panel. In addition, this adhesive will be used to bond this composite to the exterior of the building structure.

Among the physical properties that will be determined on selected samples of hardened concrete specimens during this task are the following: 5.1 Specific Gravity (ASTM C 642); 5.2 Compressive Strength - Cylinders (ASTM C-39); 5.3 Modulus of Elasticity (ASTM C469); Flexural Strength - Center Load (ASTM C293); 5.5 Flexural Toughness (ASTM 1018); 5.6 Splitting Tensile Strength (ASTM C496); 5.7 Water Sorption; and 5.8 Acid Resistances (ASTM D 3042).

It is important to note that acceptance criteria for this novel concrete are not available as of this writing, but there are many ASTM International Standards that can be used to evaluate the experimental concretes. Some of these are given in Table 5.

Table 5. Additional Applicable ASTM Specifications

ASTM Designation	**Title**
C 31	Standard Practice for Method of Making Concrete Test Specimens in the Field
C 39	Test method for Compressive Strength of Cylindrical Concrete Specimens
C 192	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 470-02a	Standard Specification for Molds for Forming Concrete Test Cylinders Vertically
C 666-97	Test Method for Resistance of Concrete to Rapid Freezing and Thawing

TASK 6 REPORTING

In addition to weekly informal contacts with the Contracting Officer's Technical Representative or designee, monthly technical progress reports will be submitted with a complete final report at the end of the project, as required.

Related Work

Polymeric materials are currently used to protect troops, vehicles and buildings from IEDs and suicide bombs. Based on their viscoelastic properties, various types of polymeric elastomers such as polyurethanes confer blast resistance to concrete structures by absorbing the kinetic energy of the blast by deforming. For instance, tests at New Mexico Tech's (EMRTC) demonstrated that a commercially available polyurethane coating previously used to coat the interior of trucks is blast resistant.

EMRTC explosive experts tested two identical concrete structures, one unprotected and one painted with Line-X. Each room contained an office setting complete with crash-test dummy, desk and computer equipment. Following catastrophic TNT and C4 blasts, the dummy's body in the unprotected room was riddled with building fragments, while the "dummy in the Line-X protected room was unscathed " according to Allan Perryman, EMRTC's Research Engineer and Test Specialist.

Concrete walls painted with Line-X withstand explosions up to 20 times greater than what normal, uncoated walls can withstand. Applied by spray in thick films (ca. 0.125 inch), the coating absorbs the energy of blasts and projectiles in dramatic fashion. This is important because in order to make traditional concrete blast resistant it must be very thick and reinforced with rebar. In addition, the cement content must be higher so that the rebar can be inserted to provide adequate reinforcement, according to the Army Corps of Engineers.

Relationship with Future Research or Research and Development

If the proposed approach is successful and is carried into Phases II and III, profitable markets for polymer modified cementitious composites will be available. These markets are based on crack-resistant concrete panels comprising a layered structure with the protective exterior layer being a crack resistant concrete, with the rubberized, energy-absorbing concrete bonded to the existing structure.

Phase I will assess the feasibility of developing (1) a crack-resistant concrete and (2) a rubberized concrete, both of which will be extensively tested to determine their physical and mechanical properties. Large prototypes of both (panels) will be prepared, evaluated and used in presentations to Clayton Concrete and other local concrete contractors.

It is anticipated that Phase I will successfully demonstrate the methodology for preparing graft copolymer modified concrete materials that are more durable than existing materials. Achieving critical goals early in the program will provide a strong foundation for the identification of long term material performance criteria for application at diverse locations in Phase II.

During Phase II, the process will be refined and more comprehensive efforts will be made to further demonstrate the utility of the proposed technology to the same local concrete contractors and potential Phase III partners. Further, more testing will be performed at both Bowser-Morner and New Jersey Institute of Technology in Newark, NJ. Emphasis will be placed on meeting the requirements of potential commercial partners, who are interested in licensing the technology. And with the aid of consultants, we will arrange for blast resistant tests on several structures at the Energetic Materials Research and Testing Center (EMRTC) under the supervision of our test site consultant. Details on the size of the coupons will be developed early in the Phase II after consulting with Mr. Martinez of the consulting firm of K&C, officials of the EMRTC, and DHS Research Facilities, such as the Transportation Security Laboratory, of course.

REFERENCES

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Commercialization Strategy

The proposer has a Master Services Agreement with Innocentive, Inc. that will enable it to select a Phase III partner from a large number of potential companies, who may be interested in the proposed technology. Prior to start of work, and with ongoing work in its laboratory, RWG Corporation will have sufficient data for placement in the Innocentive Market Place to seek partners for various aspects of the technology. It is understood that commercialization will not proceed without a Phase III partner.

If the proposed approach is successful and is carried into Phases II and III, profitable markets for crack resistant and blast resistant concrete panels will be available. Non-structural applications include: (a) blast-resistant concrete panels or facades; (b) acoustical light weight panels; (c) sound barriers; (d) false facades; (e) stone backing; (f) blast-resistant blocks; (g) machinable (nailing) concrete; (h) jersey barriers; (i) shock absorbers in highway construction; (k) road dividers; (l)ornamental structures; (m) parking bumpers; and (j) loading docks.

After preliminary testing in the proposer's laboratory, selected samples will be sent to Bowser-Morner, an AASHTO/ISO 17025 accredited concrete testing laboratory, for determinations of stress-strain diagrams, compressive strength and modulus of elasticity, splitting tensile strength, flexural strength and modulus. The primary objective is to develop blast resistant concrete panels and to use the properties of the experimental bricks to design prototypes for other applications.

All rubber used in Phase I will be obtained from GTR, who is a potential Phase III partner. The P.I. is optimistic that a relationship will result and that GTR will be extremely interested in additional applications for the rubber. The driving force behind the proposed technology is blast and crack resistant concrete.

After feasibility of the concept has been successfully demonstrated, a primary patent application will be filed. Following this, manufacturers of non-structural concrete products will be shown prototypes and data from Bowser-Morner. Video graphic evidence of successful blast resistance tests at EMRTC will be useful in attracting public attention.

The proven characteristics of crumb rubber in concrete should be just as valid for the proposed panels. Accordingly, one can expect a lightweight panel that is beneficial in noise control and is well insulated. This insulation will also confer static reduction in walls. Freeze-thaw cycling resistance is assumed to be excellent. Reduced shrinkage, and therefore cracking, is anticipated. The lower density of the proposed concrete suggests precast sidewalk panels and Jersey Barriers.

The major challenge in the program is to collect the data to validate the proposition that the advantages outweigh the increased cost, attributed to the raw material cost of the rubber and that of monomer, initiator and SBR. However, cost will decrease as the number of applications increases. And if the blast resistance of the layered structures is proven during Phase II, the P.I. will consider the combination of rubber and cement to prepare panels for providing blast protection to the war fighters. This appears to be a logical spin-off of the proposed technology in view of the large number of casualties resulting from contact with IEDs. The advantage here is lower cost and density in a material that can absorb the kinetic energy from the blast by deformation, thus decreasing the number of casualties.

We make the assumption that DHS S&T will monitor the development of this work and may after successful testing, place the layered composite on a qualified products list. If this occurs, potential customers would include federal agencies, state, local and civilian authorities. The crack resistant concrete may also be used in concrete repair of marine structures where corrosion and cracking is a serious problem. And there are many applications for the rubberized concrete as mentioned above.