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Workshop Report

US–Thai International Workshop: Advances in the Science and Engineering of Thin Reinforced Cement Composites (TRCC)

This US–Thai International Workshop was held 6–8 February 2006 in Bangkok, Thailand, in conjunction with the Eighth International Symposium on Ferrocement and Thin Reinforced Cement Composites. The Workshop was co-sponsored by the US National Science Foundation (through Grant No. 0541604) and several generous hosts from the Thai industrial sector. Any opinions, findings, conclusions or recommendations expressed in this report are those of the Workshop participants and do not necessarily reflect the views of the US National Science Foundation.

The main contribution of this Symposium/Workshop is in reporting recent developments and assessing research needs. The Symposium/Workshop concluded with a summary panel session, which was open to all participants, that identified the following primary areas for research on Thin Reinforced Cement Composites (TRCC): textile reinforced concrete; matrix composition and tailoring for improving composite performance; resistance to extreme loads (e.g. due to blast, fire); layered, functionally graded composites; and life cycle design of TRCC structural components and systems.

1. Textile reinforced concrete (TRC)

The use of fabrics generally improves load transfer between the matrix and reinforcement, due to mechanical anchorage provided by the structure of the fabric and the geometry of the yarn elements composing the fabric. The multifilament yarns used in glass fiber textiles, for example, exhibit completely different bond and fracture behaviors compared to those of monofilament reinforcement. Experiments have shown that the interrelation between fabric geometry and composite performance is significantly more complicated than that of fabric systems within polymer binders. The cement-based matrices should be fine grained to meet special requirements with respect to the production processes, mechanical properties of the composite, and durability of the textile reinforcement. Special processing techniques, such as pultrusion, have advantages over ordinary casting, particularly for improving the bond properties of multifilament yarns.

Hybrid fabrics composed of several different yarn types allow for the engineering of desirable yarn, textile, and composite properties specific to cement and concrete applications. Three-dimensional fabrics have many potential advantages, including the precise positioning of reinforcement layers and prevention of delamination in the through-thickness direction. The performance of textile reinforced concretes under multiaxial loading and loading that is non-aligned with the principal fabric directions is another important research area. For very thin cement-based products, there are additional constraints and opportunities that need to be investigated.

The first generation of TRC applications and recent research indicate a great potential for enhancing the performance of both structural and non-structural concrete elements through the use of textile reinforcement. Research is needed for understanding, developing and/or improving:

- production technology for TRC, since improvements in processing and production are key for achieving quality and economy;
- interactions between the matrix and textile reinforcement. In particular, there is a need to understand and quantify the effects of outer and inner bond of multi-filament yarns. Efforts are needed to improve matrix penetration into the yarn or, alternatively, improve the inner bond with organic binders;
- toughness of the matrix. There is a need to understand how improvements in matrix toughness affect matrix/reinforcement interactions. Short-fiber reinforcement can be used to improve matrix toughness. Processing becomes an even more important issue in such hybrid (short-fiber/textile grid) systems;
- application areas of TRC beyond flat plates including, for example, the use of 3D fabrics for producing heavy-load bearing structural components. The use of TRC for thin, lightweight shells is another application area of interest;

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- TRC as part of integrated formwork, with the potentials to improve fire resistance, provide high quality finishes, and produce other products for housing construction;
- standard test procedures and design procedures for TRC (and similar composites) that are useful to practitioners;
- 3D fabrics that are resistant to deformation during placing of the matrix; and
- durability of various types of TRC. The use of organic versus inorganic cementitious binders is one topic of interest.

2. Matrix composition and tailoring for composite performance

The common use of high cement contents in high performance mix designs is not satisfactory with respect to various measures of environmental sustainability, such as energy usage, solid waste production, and CO_2 release to the atmosphere. High cement content can also be a source of various durability problems. The use of supplemental materials, including industrial wastes, as a partial replacement for Portland cement alleviates some of the environmental concerns and durability problems. For example, our dependence on Portland cement can be significantly reduced through the high volume usage of fly ash, which reduces water demand, improves workability, reduces cracking due to thermal and drying shrinkage, reduces the potential for reinforcement corrosion, sulfate attack, and alkali-silica expansion. However, the bulk of the related research has been for conventional test specimen geometries and structural members with conventional reinforcement. The application of these technologies to thin cement-based products and, for example, textile reinforced concrete requires additional considerations with respect to design and production of the product.

Research is needed for improving TRCC matrix composition. More specifically, research needs include:

- durability mechanics and design for durability. Crack width and permeability are key, related factors affecting durability. There is a need to understand how distributed cracking is affected by composite (matrix and reinforcement) design and how such cracking influences permeability and associated degradation processes. Performance based design that rewards durability is seen as a means for fostering innovation;
- control of cracking, recognizing that matrix shrinkage is a major source of cracking;
- optimization of workability based on rheology, particle packing ideas, and sufficient paste volumes to accommodate fibers;
- design for constructability, including nailing and sawing of TRCC;
- scientific understandings of how improved finishing and curing affects TRCC performance; and
- use of recycled and/or waste materials in the matrix mix design. There is extensive data on the use of such materials for structural concrete, yet some of the conditions and needs of TRCC are different.

3. Resistance to extreme loads

The failures of unreinforced (and/or poorly designed) structural systems have accounted for numerous fatalities during recent earthquakes in some regions of the world. Reinforced cement composite overlays can be designed to provide confinement and redundancy to structural elements and systems, greatly improving their ductility and resistance to reversed cyclic loading, such as would occur during an earthquake. High-strength wires (e.g. wires of prestressing steel grade) are one attractive option for maintaining confinement of structural members under severe loading. Improving the safety and performance of housing structures affected by landslides, floods, and tsunamis is also of immediate importance. Research has shown that some forms of TRCC are effective in resisting blast and impact loads. In addition to further research in these general areas, additional research is needed on:

- low cost solutions for blast resistance of structures in developing countries;
- post-disaster recovery, including the use of TRCC for providing shelter, as well as capabilities for water distribution and heating. There is a need for making such knowledge available to national and international agencies; and
- optimization of layer properties and interlayer lattices for blast resistance. Due to the various difficulties in conducting blast resistance experiments, numerical simulation methods are needed to understand and generalize experimental findings.

4. Layered, functionally graded composites

Examples of layered composites include ferrocement, sandwich beams, and wall components within US residential construction. Typically, most systems are designed with 2 or 3 layers for strength, stiffness, insulation and/or durability. Additional research is needed to develop:

- systems with a larger number of layers to address deficiencies in resisting blast and other forms of extreme loading. For example, additional thin sheets can be bonded to TRCC to improve various properties (e.g. a thin polypropylene layer can greatly improve resistance to blast loading);
- very thin laminates (micrometer to mm) for improving strength, stiffness, fire (high temperature) resistance, and penetration resistance;
- active laminates that react to environmental stimuli;

- laminates for retrofitting or restoring historical buildings, with interests in minimizing added weight and maintaining original characteristics;
- functionally graded composites inspired by biological materials and systems;
- crack-free composites, even if such a goal is not attainable through affordable methods; and
- shear-resistant layered composites. Some elements with lightweight cores have exhibited potential problems under shear loading.

5. Life cycle design of TRCC components and systems

Infrastructure systems degrade over time due to human use and environmental stresses. One goal is to extend the service life of TRCC components and systems, while reducing environmental costs. Towards this goal, research is needed on:

- durability mechanics of thin-reinforced cement composites, recognizing the importance of processing and treatment of the system while in the fresh state;
- technical service life estimation and associated model-based simulation. Service life estimation can help foster the development and application of new technologies, since such technologies (e.g. non-corrosive reinforcement, use of fibers to reduce crack widths) would then have a direct quantifiable effect on service life and, therefore, the design process;
- Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) of TRCC systems. The results of LCC and LCA can also be used to justify investments in research and technology development;
- repair and retrofit of civil infrastructure components; and
- socio-economic and environmental effects of housing development using TRCC. This information can be used to promote sustainable building practices.

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