Innovative Applications of Steel-Mesh Reinforced Cementitious Composites

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Abstract—The unprecedented growth in construction activities have led to speedy consumption of global natural resources like river sand, blue metal, water, and some raw materials like limestone (for producing cement). This study explores the possibility of using Steel-Mesh Reinforced Cementitious Composites (SMRCC) as an alternative to conventional concrete, aiming at sustainability. In order to understand the practical applications of SMRCC, the present authors have cast precast slab elements of size 700 mm (length) X 200 mm (width) in various thickness, 12.5 mm (1/2”), 18.75 mm (3/4”) and 25 mm (1”), arched lintel slab (25 mm thick) for a door width of 900 mm, and water tank using several layers of galvanized steel mesh. The construction methodology of some of the elements cast using SMRCC technology, along with recommendations is brought out in this paper. This study recommends that the mechanical strength (impact strength, flexural behaviour and toughness) of thin SMRCC elements may be studied by researchers in future before actual application in the construction industry.

Keywords—Cementitious Composites, Plates, Ferrocement, Sustainability

I. INTRODUCTION

Urbanization have resulted in modernization of cities, the main activity being construction of high-rise buildings. The most widely used material, concrete employs massive quantities of natural resources like blue metal, river sand, water, and cement (using limestone as raw material) giving rise to global sustainability issues. In this context, we may have to explore whether there are alternative materials to conventional concrete that can be used to minimize the consumption of resources and achieve sustainability in construction. Also, vigorous research has to be done in order to innovate new building materials which will reduce the letting out of CO₂ into the atmosphere (Pereira et al., 2013; Dobson et al., 2013).

Several authors (Dobson et al., 2013; Shaikh, 2013; Zhou et al., 2013; Cheng and Venkataraman, 2013; and Imbabi et al., 2013) have recommended that in order to protect the globe, with respect to the natural ecosystem, and ensure sustainability of natural resources, there is an absolute and urgent need to go for innovative, eco-friendly, light-weight and cost-effective materials, and especially the ones that can perform the desired functions (Akhtar et al. 2009). Steel-Mesh Reinforced Cementitious Composites (SMRCC) (traditionally known as ferrocement) appears to be an alternative low-cost material for flat and corrugated roofing system and wall construction as it uses lesser quantities of natural resources as raw materials and suitable for low-cost roofing and wall construction (ACI 549; Ibrahim, 2011). If SMRCC elements are to be prefabricated in any desired shape, it requires only little or no formwork, whereas in the case of conventional concrete or steel system, it needs complicated shuttering system (Sakthivel and Jagannathan, 2011).

SMRCC is generally cast by encapsulating the steel mesh with a properly designed cement mortar (made of cement and natural sand, with no coarse aggregate like gravel) in smaller thickness (ranging from 10-25 mm) (Yang et al. 1995; Naaman, 2000; Sakthivel and Jagannathan, 2012a,b). SMRCC is employed in the construction of domes, vaults, shells, grid surfaces and folded plates (Ibrahim, 2011a). In SMRCC, the wire/ weld mesh reinforcement is evenly distributed throughout the section with openings large enough for adequate bonding with cement matrix (Naaman, 2000; ACI 549; Hago et al., 2005; Ibrahim, 2011a; Hossain and Awal, 2011; and Lin and Quek, 2011) and the specific surface of reinforcement in SMRCC is one to two orders of magnitude higher than that of reinforced concrete.
Due to the presence of a significant amount of transverse mesh wires, there is a bond transfer between the two materials, cement matrix and reinforcing mesh, exhibiting excellent crack control, and enhancing the impact resistance and toughness (Naaman, 2000; Naaman, 2002; Lin et al., 2011; Cheah and Ramli, 2012; Shaheen et al., 2012). A greater use of SMRCC could be made in water-retaining structures and other similar elements where crack width is an important design criterion. Because of its very small crack widths under service load and its superior extensibility, SMRCC provides excellent leakage characteristics for applications in water tanks; moreover, should pressure increase, the structure stretches to allow higher leakage and acts as a safety valve, thus not allowing the structure to fail (Naaman, 2000). Considering the above merits, SMRCC has been classified as a separate material (when compared to conventional concrete) under the family of laminated composites (reinforced with metallic or non-metallic meshes) (Yardim et al., 2013) in terms of reinforcement arrangement, structural behaviour, strength and performance.

While understanding the importance of Steel-Mesh Reinforced Cementitious Composites (SMRCC), the objective of the present study is to bring out the construction methodology and practical applications of SMRCC elements like thin precast slab elements, arch-shaped lintel slab and water tank. The study on mechanical strength/behaviour of SMRCC elements is not covered here and is beyond the scope of this paper.

II. MATERIALS AND METHODS

A. Materials

For casting of precast SMRCC elements, viz., slab, arch-shaped lintel slab and water tank, Ordinary Portland cement (OPC-53 Grade) conforming to IS 12269-1987 (Reaffirmed 2008) with specific gravity of 3.37 and locally available natural river sand conforming to Zone II of IS 383: 1987 (Reaffirmed 2007) with fineness modulus of 2.91 and specific gravity of 2.64 have been used. Sand passing through 2.36 mm sieve, as recommended by ACI 549 and Lin et al. (2011) has been used in cement mortar to cast the SMRCC elements. The sand-cement ratio of 2:1 (by weight) and water-cement ratio of 0.43 (by weight) (ACI 549; Shanag and Mourad, 2012; Sakthivel and Jagannathan, 2012c) have been fixed in this study based on several trial mixes done by the present authors. Potable water was used for mixing the cement mortar and curing purposes.

The steel mesh of 0.70 mm diameter (with galvanized coating of 4-6 microns) with tensile strength of 512 N/mm² and yield strength of 406 N/mm² has been used as reinforcement in SMRCC elements.

First, the river sand has been dried properly, before sieving in 2.36 mm sieve size and using it in cement mortar, to prevent the water-cement ratio being affected. The cement and sand (by weight and as per the above proportions) is ready for mixing in a dry state (Fig. 1) and the mixing of cement mortar and water was done for 1-2 minutes till the required amount of consistency has been achieved (Fig. 2). In order to maintain the water-cement ratio, without getting affected, a plastic bowl/container was used for mixing purposes (Fig. 2). It was found that the reference specimens which were cast with cement mortar have a cube compressive strength of 33 N/mm²; split tensile strength of 4.60 N/mm², and prismatic flexural strength of 5.80 N/mm².

![Fig.1 Sand and Cement](image1.png)

![Fig.2 Cement Mortar Mix](image2.png)

III. CONSTRUCTION METHODOLOGY

The casting procedure of various types of elements are presented in this Section.

B. Casting of Precast Slabs

Prototype precast slab of size of 700 mm (length) X 200 mm (width) of varying thickness 12.5 mm (1/2"), 18.75 mm (3/4") and 25 mm (1") were cast using aluminium moulds with easily dismountable sides, and light oiling was done for easy demoulding process. It was decided to use 2 nos. of galvanized steel mesh for slab thickness of 12.5 mm, and 2-4 nos. of mesh for 18.75 mm and 25 mm thick slabs. Also, 3 mm reinforcing cover to finished top and bottom slab surfaces, and minimum mortar thickness of 3 mm in-between any two mesh layers was maintained. The first base layer of cement mortar of 3 mm was laid (Fig. 3) by using glass spacers, and over this base layer, the first layer of galvanized steel mesh (cut to required size) was placed (Fig. 4).
The cement mortar is now spread over the first layer of steel mesh (Fig. 5) and the second layer of steel mesh is now placed. Next, 3 mm glass spacers are used to maintain the top cover, and the top surface of the slab is then finished to proper levels, as shown in Fig. 6. It was noticed throughout the casting process that sufficient workability has been achieved with the cement mortar prepared with sand-cement ratio of 2:1 and water-cement ratio of 0.43. The test specimens were demoulded after 24 hours and cured using wet gunny sacks for 28 days before actual application in the field.

Initial curing was commenced after 24 hours of hardening of the cement mortar using gunny sacks. Subsequently, the arch lintel was easily demoulded by removing the two halves of shuttering as shown in Fig. 13. The demoulded arched lintel (Fig. 14) was cured for 28 days, and is now ready for use in construction as permanent shuttering with the required arch shape above door and window openings.

C. Casting of Precast Arched Lintels

SMRCC arched lintel of 900 mm (designed for a door opening size of 900 mm width), with end bearing projection of 230 mm on brick-walls (Fig. 7) was cast. Thin plywood is cut in arch shape (Fig. 8) and the galvanized steel sheets bent in semi-circular shape (with radius of 450 mm). Two such symmetrical semi-circular moulds are made and joined on either side and nailed to a wooden platform to avoid any movement while casting (Fig. 9). The cement mortar is prepared (as discussed in Section 2.0), and the base cover layer of 3 mm has been laid using glass spacers. Then the first layer of galvanized steel mesh is placed over the base mortar (Fig. 10). Next, the cement mortar is laid over the first layer of steel mesh (Fig. 11). Above this layer of cement mortar, the 2nd layer of mesh is placed, and the top layer is finished (Fig. 12) after ensuring that the top cover of 3 mm to the top reinforcing mesh (2nd layer) is maintained.
D. Casting of Precast Water Tank

Prototype precast slab of size of 700 mm X 200 mm X 25 mm (thickness) was cast using wooden moulds with easily dismountable sides (Fig. 7), and the contact surfaces of the wooden mould to the mortar were oiled/greased before casting the specimens. The prototype water tank has an outer (base) and inner diameter of 650 mm and 600 mm respectively, wall height of 325 mm, and wall thickness of 25 mm, as detailed in Plan (Fig. 15) and Section (Fig. 16). Two layers of galvanized mesh reinforcement (Fig. 17) was used for slab and wall reinforcement of the water tank. Skeleton reinforcement of 6 mm mild steel has been used with one ring at top and the other ring at bottom, and 4 vertical rods in wall to hold the mesh in place, and one mesh was placed in the outer side and the other in the inner side of the skeleton reinforcement. No formwork was used, and only unskilled labour was employed for casting the water tank. First, the 3 mm base mortar was laid using glass spacers, and then the mesh reinforcement (base and walls) was placed over the cement mortar base. Then cement mortar was applied on top of base slab reinforcement (Fig. 17) and then to the inner side walls. The cement mortar was applied on the reinforcing wire-mesh by hand-trowelling method, and wooden template in curved shape has served the most important role in forming the inner and outer curves of the tank (Fig. 18), and then outer walls are properly finished (Fig. 19), maintaining the wall thickness of 25 mm. The top levels are checked with tube level (Fig. 20), and the water tank is completely finished (Fig. 21). The water tank is allowed to dry for 24 hours and then curing is done for 28 days. Finally, the leakage test was performed for the water tank by retaining the water in the tank for several days (Fig. 22), and the water tank was found to be 100% leak-proof.

IV. Recommendations

Based on the present work involving casting of precast slab elements, arched lintel and water tank using Steel-Mesh reinforced cementitious composites (SMRCC), the following are the recommendations:

1. Since there is no need for any specialized skills for casting SMRCC precast elements, and also the formwork is simpler in nature, SMRCC can be effectively used in roofs and secondary slabs.
2. As very thin precast elements (of thickness 12.5 mm) can be cast with SMRCC, which is generally not possible with RCC (with smaller thickness), SMRCC can be used for elevation features like fins and facias, claddings and sunscreens in buildings, and sloping chajjas, percolas, which will add architectural beauty to the structure, mainly due to thin and sleek nature of the elements.

3. The SMRCC arched lintel is an innovative idea, as this element directly gives the finished arch shape without any need for plaster finishing, and the element will serve as a permanent formwork, and the brickwork can be directly constructed over the arched lintel.

4. The portable SMRCC water tanks discussed in this study will be very useful for storing water for drinking and washing purposes and also for feeding water for cattle in farms, and other agricultural purposes. Also since the water-tank constructed of SMRCC is found to be 100% leak proof, which is the main criteria for water retaining structures, SMRCC can be effectively used in swimming pools, underground and overhead water tanks.

V. CONCLUSION

Some of the applications of steel mesh reinforced cementitious composites (SMRCC) have been highlighted in this paper. SMRCC can certainly be classified as a sustainable material due to lesser consumption of natural resources (when compared to conventional concrete), thus protecting the eco-system and the environment. SMRCC is used for a number of innovative applications involving novel shapes like domes and pyramids, shell structures, corrugated, hyperbolic and sandwich roofing, and swimming pools of irregular shape. The elements made of SMRCC will be quite useful to alleviate the acute shortage and high cost of skilled labor in many developing countries. This study further recommends that the flexural behaviour and toughness be studied on precast slab elements made of SMRCC in various thickness, 12.5 mm (1/2"), 18.75 mm (3/4") and 25mm (1") to ascertain the load, deflection, stress-strain relations, etc., before actual application on the field.

REFERENCES


