Pol. J. Environ. Stud. Vol. 32, No. 6 (2023), 4971-4980
DOI: *10.15244/pjoes/168427* ONLINE PUBLICATION DATE: 2023-09-11

Original Research

Study on the Behavioral Properties of Ferrocement Trough Shaped Panels by Partial Replacement of Cement Using Clay-Silica and Fine Aggregates Using M-Sand

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Received: 27 March 2023
Accepted: 16 June 2023

Abstract

Ferrocement, a versatile building material, is becoming increasingly popular in structural and architectural applications. It is suitable for high degrees of prefabrication due to its durability, weather resistance, and relatively low cost. Additionally, there is the possibility to achieve considerable improvements in various properties of these thin structures by using some alternates. A study has been made on the behavior of ferrocement trough shaped panels (FCTSP) under static load using clay silica for partial replacement of cement and manufacturing sand for partial replacement of river sand. First, the strength characteristics of mortar cubes were determined by varying the percentage of cement with silica sand (0%, 5%, 10%, 15%, 20% and 25%). Incorporating the optimum percentage of clay silica replacement, a study on the flexural behavior of trough shaped panels reinforced with skeletal steel and wire mesh layers by replacing fine aggregates with manufacturing sand and varying the percentage of replacement was found. According to the findings, panels made with a combination of 10% clay silica sand (CSS) replaced for cement mix and 50% manufacturing sand (MS) replaced for the fine aggregate used in FCTSP showed better results in mechanical properties and microstructural bond behavior.

Keywords: clay silica, manufactured sand, ferrocement, trough shaped panels, microstructure

Introduction

Ferrocement is a composite material made of Ferro (Iron) and cement (cement mortar). Using Ferrocement it is possible to fabricate a variety of structural elements which will be thin, lightweight and durable with high degree of impermeability. Ferrocement has received attention as a potential building material, especially for roofing of housing construction and has been used for several applications [1]. Trough Shaped ferrocement roofing elements are investigated by many researchers as these elements posses higher strength than plates without folds of same thickness [1].

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It is possible to build ferrocement element even from locally available materials. Cement mortar is the main ingredient in ferrocement. Natural sand is widely used in production of cement concrete and cement mortar. Due to shortage in availability of good quality natural sand and ill effects of extraction of natural sand from river beds on environment, various research institutes are working towards identification and characterization of alternative materials that can replace natural sand [2]. This can be done without affecting its strength and durability properties. Manufactured sand is one such alternatives whose behavior when used in cement composites gives good results [2]. M-sand is artificially manufactured fine aggregate obtained from a source material, purposely designed for use in concrete and mortar [2]. On the other hand rapid growth in construction industry and infrastructure development leads to emission of huge amount of carbon dioxide (CO_2) due to increased production and consumption of concrete [3]. About 0.9 cubic meter CO_2 is produced during the process of production of 1 cubic meter cement. In this regard it is un evitable to reduce the consumption of cement to conserve and reduce the burden of environment [3]. Use of supplementary cementitious materials (SCMs) provides great effort towards reducing the consumption of cement. Clay Silica Sand is such a cement replacement material [3-9]. Research results shows that silica sand can effectively be used as partial replacement of cement in concrete and mortar without compromising the strength [3]. Clay silica sand is the most abundant mineral found in the crust of the earth. It forms an important constituent of practically all rock-forming minerals [8]. It is found in a variety of forms, such as quartz crystals, massive forming hills, quartz sand (silica sand), sandstone, quartzite, tripoli, diatomite, flint, opal, chalcedonic forms like agate, onyx etc [8]. Silica sand contains a high proportion of silica (up to 99% SiO_2) in the form of quartz and are used for applications other than as construction aggregates. Silica sand is a heat resistance material thus it prevents the formation of cracks in structural elements [8]. Silica is hard, chemically inert and has a high melting point, attributable to the strength of the bonds between the atoms. Silica sand is not flammable, combustible or explosive. It is not known to be toxic [8]. Ferrocement is a thin composite made with a cement based mortar matrix reinforced with closely spaced layers of relatively small diameter wire mesh [10]. Over the years, applications involving ferrocement have increased due to its properties such as strength, toughness, water tightness, lightness, ductility and environmental stability. Ferrocement may be cast in various shapes and forms even without the use of form work and are aesthetically very appealing [10]. The success of ferrocement has been attributed to the ready availability of its component materials, the low level technology needed for its construction and relatively low cost of final products [10-11]. Due to their thinness, ferrocement elements can be used as roofing/flooring elements to cover large spans. The workability of cement mortar reduces while we use Manufactured sand in cement mortar as replacement of River sand [12]. The compressive strength of cement mortar increase 5% while we use manufactured sand as replacement of river sand and also the flexural strength of concrete increase about 9% while we use manufactured sand in concrete as replacement of river sand [12]. Use of manufactured sand as a fine aggregate in concrete and mortar draws serious attention of researchers and investigators [13]. Due to the high fineness modulus values, in mix proportion, the fine aggregate content is increased which reduces the voids between the coarse particles. Because of this the strength and durability characteristics of cement mortar are improved [13]. The manufactured sand contains very less amount of clay content which is the reason for improvement of strength and durability characteristics [13]. The silica sand occupies more volume than cement of same weight. So the total volume of the silica sand mortar increases for a particular weight as compared to conventional mortar. When the percentage of the silica is increased, the workability of the mix becomes very poor as compared to the conventional mortar. Silica can be added to cement mortar by 8% to 10% as the strength was increasing than conventional mortar [14-17]. Due to large deflections compared to the small thickness of the panels, it was more appropriate to consider large deflection theory in the analysis [19-22]. Slabs with channel sections supported larger ultimate loads and behaved better under service loads than their flat slabs counterparts [23-27]. Till now only few research is available in trough shaped panels made with replacement of materials for the cement mortar used. The present study is carried out by replacing percentage by weight of cement with clay silica sand and fine aggregates by manufacturing sand for casting Trough shaped roof panel sections supporting larger ultimate loads and service loads. Tests were performed by varying the percentage replacement of clay silica sand and manufacturing san with constant layers of fine wire mesh. Furthermore, there is no existing research work on this topic to our knowledge.

Materials and Methods

Cement often called hydraulic cement is a building material used in Construction, typically made by heating a mixture of limestone and clay until it almost fuses and finally grinded to a fine powder. Natural cement, is occasionally blended with Portland cement. Cement with a high aluminates content is used for fireproofing, because it is quick –setting and resistant to high temperatures; cement with a high sulphate content is used in complex castings, because it expands upon hardening and filling small spaces. Ordinary Portland cement of 53 grade conforming to Indian standard was used (Table 1). The cement used was tested and found to have a specific gravity of 3.13. Crushed stone received from quarry is known to be Robo sand or Manufacturing sand. The dust particles obtained from the quarry are fine grained below 4.75 mm IS sieve or mechanically crushed and used as M-sand (Table 3). Good quality natural river sand is readily available in many areas and may be easily obtained and processed. As with the gravels that they often accompany, the sand deposits may not have been laid uniformly, meaning a potential change in quality. Generally fines are classified based on size, i.e.; below 4.75 mm is regarded as fine aggregate (Table 3). Silica sand is made up of two basic elements: silica and oxygen. It is also known as quartz sand, white sand, or industrial sand. Silica is one of the earth's third most normal rock framing material [13]. Silicon dioxide is the main component of silica sand (SiO_2). Clay silica sand contains around 97.5-99.8% of silica (SiO_2) in its chemical composition (Table 2) that directly involves in the pozzolanic reaction when used in the cement mix [13]. Clay silica sand crushed was sieved using 90 micron sieve until it matches the fineness of cement as it replaces cement (Table 3). Based on the references, mould for trough shaped panel were made ready using mild Steel plates with standard size which would adore to standard need of using the panels in various places mainly in roofs. Length wise the panel is of 500 mm, width and height approximately equal to 350 mm and 180mm (Fig. 1). The thickness is 30 mm which will be sufficient to hold the reinforcement and mesh wrapped around it. Slope length in which the panel is turned to form the trapezium shape is about 142 mm leaving a offset of 50 mm on both sides. Ferrocement consists of skeletal reinforcement and wire mesh placed inside. For reinforcement skeleton in panels 6 mm diameter steel rods are used as main rods. Stirrup rods in trough shape were made using 6 mm diameter rod bars. It is used in the form of tied reinforcement, to impart structural strength in case if it carries some loads. Reinforcement used is free from dust, rust and other impurities. Welded wire mesh has hexagonal or rectangular openings and available as Woven/interlocking mesh and welded mesh. Here welded wire mesh used has Interlocking mesh with hexagonal openings. The wire mesh consists of galvanized steel wires of diameter 0.5 to 1.5 mm, spaced at 6 to 20 mm centre to centre. No. of layers of wire mesh is maintained as constant i.e., two layers of wire mesh was wrapped around to cover the reinforcement skeleton on both sides. (Fig. 1). Super plasticizers (SP's), also known as high range water reducers, are additives used in making high strength concrete. Since the skeleton is made of congested reinforcement while placed inside the moulds these plasticizers when mixed with meshcrete would promote the easy flow of meshcrete during the casting of trough shaped panels. Plasticizers are chemical compounds that enable the production of concrete with approximately 15% less water content. These additives are employed at the level of a few weight percent. Super plasticizers also retard the curing of concrete. Super plasticizer-CONPLAST SP430 from FOSROC was added to improve the workability of fresh mortar. Based on the Indian standard code book for building materials testing, basic tests for all the materials used was conducted. Cement mortar mix ratio of 1:2 and water cement ratio of 0.45 was adopted for casting all the mortar cubes using mortar mould of size (70 mmx70 mmx70 mm). The Control specimen cement mortar cubes were prepared using cement and river sand (CMC-RS). Subsequently mortar cubes were made using cement, clay silica sand and river sand in which cement was partially replaced with clay silica sand (CMC-RS) of 0%, 5%, 10%, 15%, 20% and 25% by weight of cement and were casted. These mortar cubes were cured and tested for 7-days and 28-days compressive strength (Fig. 2). Water absorption percentage of all the mortar cubes were also found. With the inclusion of clay silica sand the strength of mortar cubes gradually increased up to a certain limit but then gradually decreased when the clay silica sand percentage replacement for cement was increased. Hence based on the results obtained from the mortar cubes, optimum percentage of clay silica sand replacement was found for cement. This optimum percentage of clay silica sand replacement for cement was kept constant for casting all the ferrocement cement trough shaped panels (FCTSP). Based on the proportions arrived, ferrocement panel casting was done, for smooth flow of the mortar mix, mould was cleaned and the inner surface thoroughly applied with grease oil. Skeleton was made using steel rod of 6 mm diameter as main rods and as distribution rods to form the shape of trough and connected using binding wires. Once the skeleton is made ready two layers of hexagonal chicken wire mesh of 0.7 mm thickness is wrapped around the skeleton. After the mould is set properly the skeleton reinforcement setup was kept inside the mould very carefully without disturbing its shape. Once done cement was dry mixed with river sand, M-sand, Clay silica sand for about 3 minutes and the required amount of water and super plasticizer was added, which was mixed for 4 min. According to mix proportions, preparation of fresh concrete was done and all ingredients were mixed with a total mixing time of 10minutes by hand mix. Once mixing is finished the mixture was poured inside the mould. Preparation of meshcrete was done keeping 10% of clay silica sand as constant for replacement of cement for preparation of Ferrocement Trough shaped panel (FCTSP).With reference 0%, 10%, 20%, 30%, 40%, 50% and 60% replacement of river sand with manufacturing sand (MS) was made to evaluate the trough shaped panels under various testing conditions. Subsequently separate control specimens (FCTSP) using cement with replacement of clay silica sand and river sand were made (Fig. 1). As the thickness of the mould is small and with the placement of reinforcement inside will be congested, compaction was done with tamping rod and vibration was made using vibration table as per standard procedure and the mould was allowed to set with meshcrete (Fig. 1). Proper de moulding was done after

Table 1. Various constituents (ingredients) of an Ordinary Portland cement (OPC).

Chemical name	Component	%
CaO	Lime	62%
SiO_2	(Silica)	22%
Al_2O_3	Alumina	5%
$CaSO_4$	Calcium sulphate	4%
Fe_2O_3	Iron oxide	37%
MgO	Magnesium oxide	2%
SO_3	Sulphur trioxide	1%
Alkalis		1%

Table 2. Chemical composition of clay silica sand material.

Sl. no	Components of Clay Silica Sand in %	
1	Silica SiO_2	97.5-99.8%
2	Alumina Al_2O_3	0.05-2%
3	Ferric oxide Fe_2O_3	0.02-0.05%

24 hours and then specimens were soaked in water for curing until test (Fig. 1). The slabs were tested under a loading frame. The load was applied by means of a load cell 100T capacity (Fig. 1). The specimens were tested by simulating simply supported conditions. The load was applied as a single central point load. A hydraulic jack was used for loading, and an LVDT was fixed at the bottom center to measure the deflection. Identifications were made on the slabs, which made it easier to trace the cracks. The tested trough panel's test setup can be seen below. During the loading process up to failure, the deflection at the panel's center was simultaneously recorded. The load is applied in small increments. LVDT is used to measure the mid-span deflection (Fig 1). Breaking was painstakingly checked all through the application of load and the relating breaking load is additionally noted. Control specimen trough shaped panels were compared with the ferrocement cement trough shaped roof panels casted by using cement and river sand partially replaced with manufacturing sand.

Experimental Techniques

The objective of this work is to study the load vs deflection content of the Trough shaped panels made clay silica sand replaced for cement and manufacturing sand replaced for fine aggregates for certain percentage. Before casting ferrocement panels, mortar cubes were prepared in the ratio of 1:2 in which water cement ratio of 0.45 was kept as constant. Mortar cubes were casted varying the percentage replacement of clay silica sand for cement starting from 0%, 5%, 10%, 15%, 20% and 25%. After casting and curing in each variation an average of three 70 mm cube specimens as per IS 516-1959 [33] at age of 7days and 28 days were tested for compressive strength. Optimum percentage replacement of cement with clay silica sand was found. After completion of testing, small concrete samples were soaked in isopropanol for one day for micro structural analysis to prevent hydration and remove excess water. Following that, the special instruments were used to take a micrograph of the dried concrete surfaces in accordance with ASTMC1723-16.

Keeping this optimum percentage of clay silica sand replacement obtained from mortar cubes testing, the ferrocement panels were casted. Based on references the size of the ferrocement roof panel was fixed and mould was made ready using mild steel plates in which the size of trough shaped roof panels approximately with length breadth and height as 500 mm x 350 mm x180 mm.

The flexural strength, the maximum load carrying capacity and deflection of ferrocement trough shaped panels was found with an average of three trough shaped panel for each proportions of mix having clay silica sand replacement for cement as constant and varying the proportion of river sand replaced with manufacturing sand in 0%, 10%, 20%, 30%, 40%, 50%, 60% as per IS code No. 13356:1992 at 14 days and 28 days. After 28 days of curing, the ferrocement panels were tested using a specific setup in loading frame and required results were noted.

Results and Discussions

Basic tests were conducted for all the materials used for casting mortar cubes and Trough shaped ferrocement panels.

Table 3. Properties of M-Sand, River sand and Clay silica sand.

Sl.No	Property	M-sand	R-sand	CS-sand
1	Specific Gravity	2.56	2.59	2.53
2	Water Absorption	2.26%	1.56%	1.0%
3	Fineness modulus	2.75	2.44	1.52

Fig. 1. Preparation, casting and testing of panels.

Compressive Strength

Mortar cubes casted using clay silica sand replaced for cement were tested for compressive strength. The result of replacement of clay silica sand for cement in various percentage and the determined compressive strength of mortar cubes is presented in (Fig. 2). It can be seen that the compressive strength in control mix mortar cubes was 15.36 MPa and 23.106 MPa at the age of 7 days and 28 days, respectively. With the increased content of clay silica sand by various percentage in replacement of cement gradually increased the compressive strength until 10%. After 10%, increase in the replacement of clay silica sand reduced the compressive strength to 16.07 Mpa and 26.946 Mpa at 7th day and 28th day respectively. The CMC-RS3 mix, exhibits higher strength of 18.36 Mpa and 33.67 MPa at 7th day and 28th day respectively when compared with the control mix this is about 19.53% increment at 7th day and about 45.72% increment in the 28th day. Based on the results obtained after 10% the compressive strength started to decline and hence the optimum level of Clay silica sand replacement for cement in ferrocement panels was taken as 10%- CMC-RS3 mix to attain the better mechanical properties when compared to CMC-RS4, CMC-RS5 and CMC-RS6 mix (Fig. 2). Further increase of silica sand replacement for cement reduces the strength of concrete this is due to the finer sand mainly act as a pore filler material, but reduces the formation of water cement gel matrix which is responsible for strength contribution in the concrete when used beyond the optimum level of 10% replacement.

Microstructure Analysis

Microstructure analysis was done for control specimen mortar cubes CMC-RS1 and the mortar cubes which exhibited higher compressive strength CMC-RS3 after 28 days testing. The difference in the microstructure analysis done indicates the porous nature of the control mix CMC-RS1 specimens without clay silica sand. The replacement of 10% of clay silica sand content in mortar mix CMC-RS3 show enhanced dense microstructure and refined pores in the microstructure (Fig. 3). This enhancement mainly attributed due to the filler effect and pozzolanic reactivity of clay silica sand. Therefore, 10% of clay silica sand replacement for cement was kept constant for ferrocement panel mixes to achieve the maximum gain in mechanical properties.

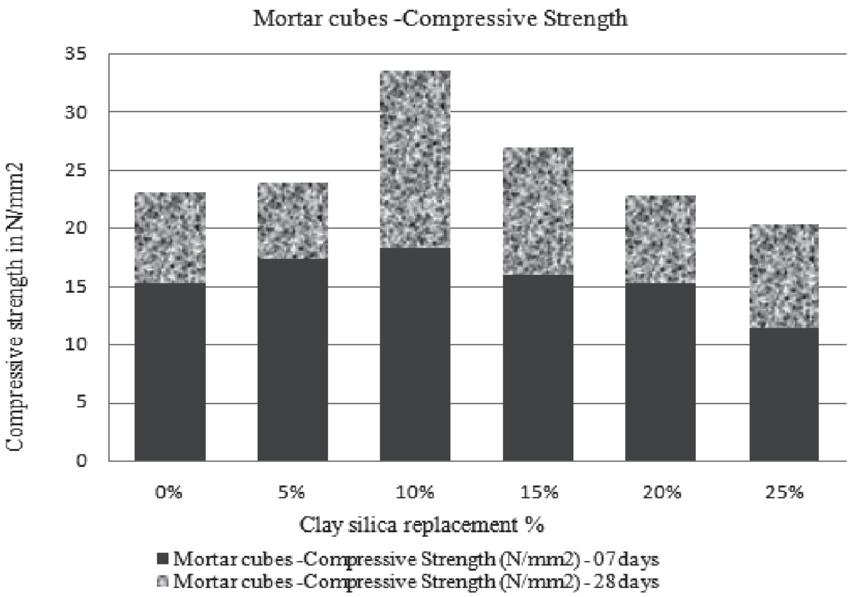

Fig. 2. Effect of clay silica in replacement of cement on the compressive strength of mortar cubes.

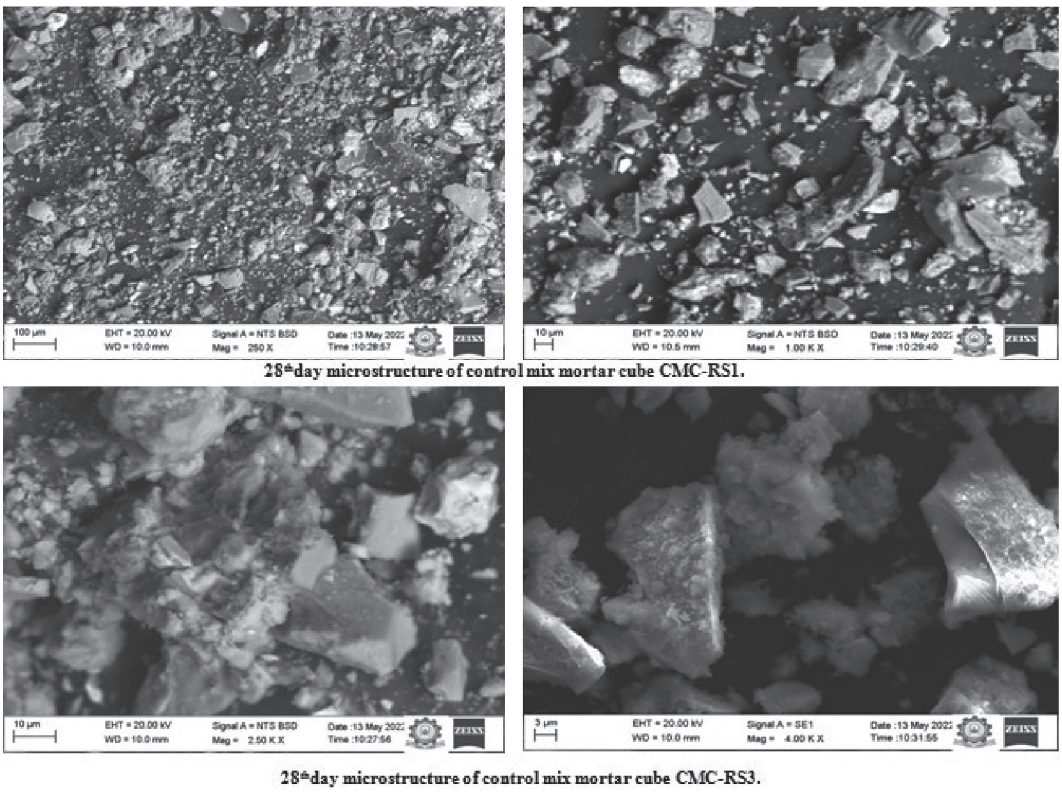

Fig. 3 Microstructure of control mix mortar cubes (CMC-RS1 and CMC-RS3).

Ferrocement Panels - Load Capacity vs Deflection

Fig. 4 shows the load capacity vs deflection of ferrocement panels casted with 10% percentage of clay silica sand replacement for cement and varying percentage of manufacturing sand for river sand. Special setup was made in loading frame to test the trough shaped panels and to note the maximum load carrying capacity and the maximum deflection of the ferrocement panels. The load gradually increased for the tested ferrocement panels and started to decrease with increasing percentage of replacement of manufacturing sand in panels. The test results shows that the cracking load capacity observed was 8 kN, 10 kN, 11 kN, 12 kN, 19 kN, 22 kN and 19 kN for FRCTSP-01, FRCTSP-02, FRCTSP-03, FRCTSP-04, FRCTSP-05, FRCTSP-06, FRCTSP-07 with noted deflections of 4 mm, 6 mm, 7 mm, 8 mm, 10 mm, 11 mm and 8 mm

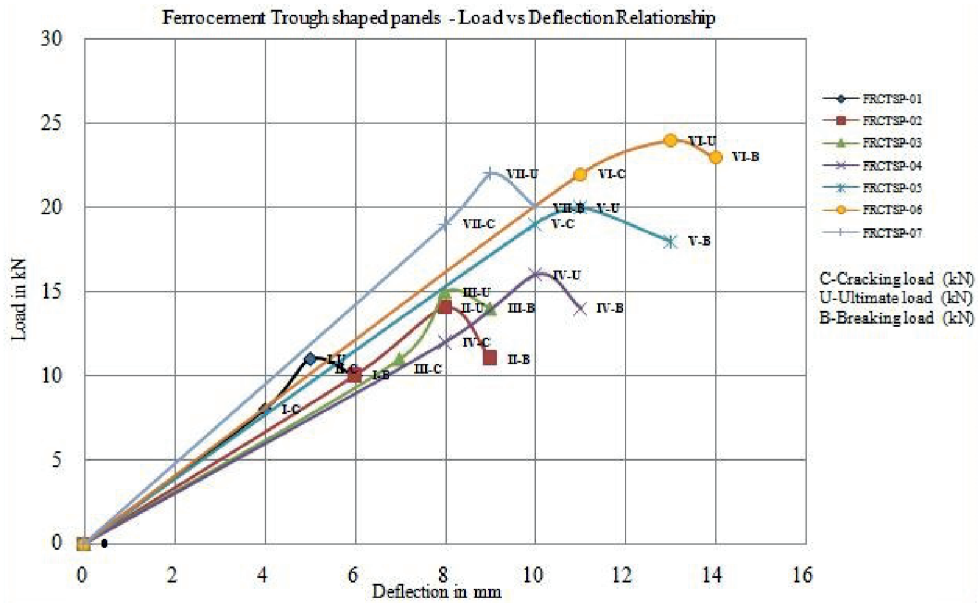

Fig. 4. Load capacity vs deflection of ferrocement panels.

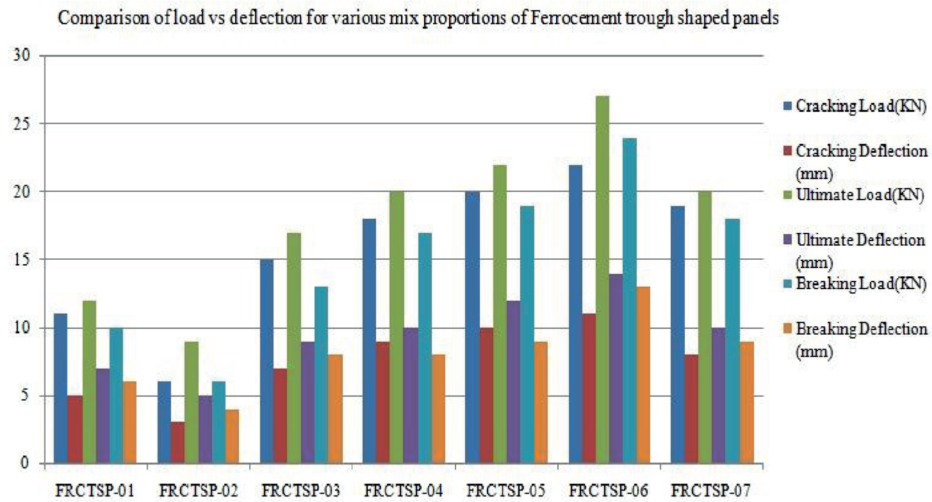

Fig. 5. Comparison of load vs deflection for various mix proportions of ferrocement trough shaped panels.

respectively at 28th day in cracking stage. FRCTSP-01 acts as control specimen in which no replacement of manufacturing sand done instead of river sand and it showed minimal load capacity at all stages of loading. Compared with the control specimen the load capacity of the specimen in FRCTSP-06 showed 93.333% increase in load capacity at cracking stage similarly with 74.286% and 78.788% increase in load capacity in ultimate and breaking stages. The maximum load capacity observed was for the FRCTSP-06 panel made with 50% of manufacturing sand and 50% of river sand with constant percentage content of clay silica sand replaced for cement. It is about 22 kN, 24 kN and 23 kN with deflections of 11 mm, 13 mm and 14 mm respectively in cracking, ultimate and breaking stages of ferrocement panels. However in other panels tested, the highest load carrying capacity was noticed in the FRCTSP-06 mix, after which the increasing percentage of manufacturing sand showed a slightly reduced load capacity. The best way to increase the load-carrying capacity of panels made with cement mortar-clay silica sand mix is to use 50% manufactured sand with 50% natural sand. Anything else, like 60 percent manufactured sand and 40 percent river sand, will slightly lower the load-carrying capacity, and 100 percent manufactured sand will have a lot of fines, which will lower the strength of the concrete. The manufactured sand has improved properties in terms of strength because it contains very little clay. Due to the low strain and low clay content, the drying shrinkage values are lower. Fig. 5 shows the comparison of the cracking load-deflection, Ultimate load-deflection and breaking load-deflection of the ferrocement panels FRCTSP-01 to FRCTSP-07. The maximum load capacity observed in all cases was for

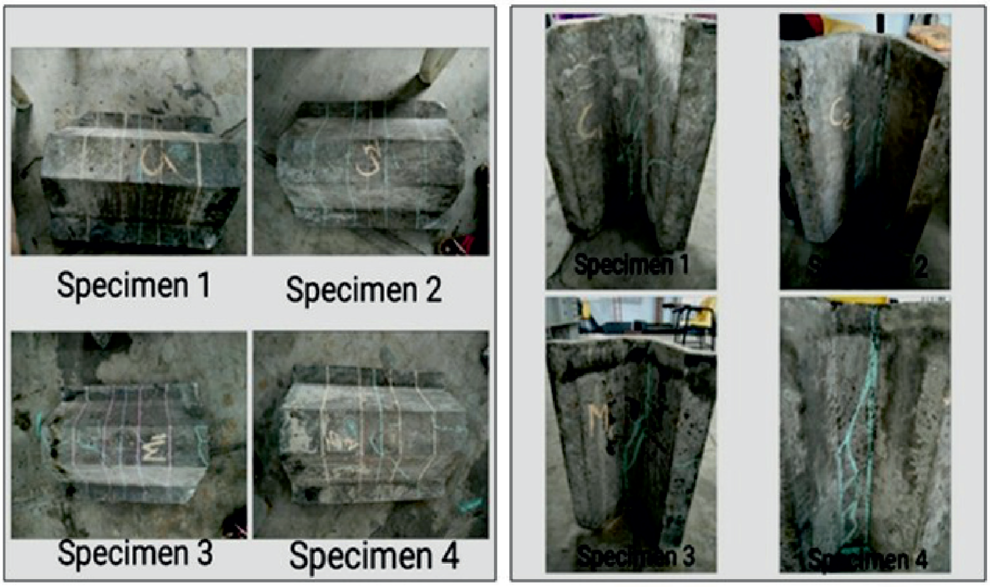

Fig. 6. Tested ferrocement panels with identified Crack pattern.

the FRCTSP-06 panel made with 50% of manufacturing sand and 50% of river sand with constant content of clay silica sand replaced for cement. Clay silica sand plays a major role in the bonding between cement and sand. Voids and Pores in the mortar mixture is been filled with the clay silica sand content and the fineness of the manufactured sand.

Cracking Pattern of Trough Shaped Panels

The crushing of mortar follows the failure of the panel specimen caused by the yielding of the wire mesh reinforcement. At first, fine flexural cracks appeared at the specimen's bottom. Regularly spaced vertical cracks were observed as the load increased, and they extended from the specimen's bottom to its top (Fig. 6). The load was increased all the way up to the final stage. When compared with the control specimen ferrocement panel made with river sand alone had minimum load capacity when compared with the panel containing 50% replacement of manufacturing sand. This enhancement in load capacity attribute is due to the coupling effect of clay silica sand and correct percentage of manufacturing sand, which leads to even distribution cement matrix and arrests crack. With inclusion of clay silica sand it was noticed that the minimal cracks were observed in all the panels as seen in the figure. The experimental result demonstrates that the trough shaped folded panels, outperforms the flat panels, and other types of panels in terms of ultimate strength and crack initiation.

Conclusions

From the results of the various tests, the following conclusions can be drawn.

- When compared to compressive strengths of mortar cubes casted with 0%, 5%, 10%, 15%, 20%, and 25% replacement of cement with clay silica sand, the strength rises to a peak value of 33.67 Mpa at 10% replacement and decreases with each additional percentage point increase in replacement.
- By passing through a sieve of 90 microns, powdered and crushed silica sand acts as a filler between cement and fine aggregate, increasing the density of the concrete. For long-lasting concrete, clay silica sand should replace 10% of cement in every ratio.
- Compared with the control specimen the load capacity of the specimen in FRCTSP-06 showed 93.333% increase in load capacity at cracking stage similarly with 74.286% and 78.788% increase in load capacity in ultimate and breaking stages respectively.
- Blending of 50 % manufactured sand and 50% natural sand suits as best option for increase in load carrying capacity of panels made with mortar mix beyond which 60% replacement of manufactured sand and 40% river sand reduces the load carrying capacity slightly and 100% manufactured sand contains large amount of fines which reduces the strength of concrete. The manufactured sand contains very less amount of clay content which is the reason for improvement of strength and load carrying characteristics. The micro fines are reduced when the manufactured sand is blended with the natural sand which increases the strength of the concrete.
- Scanning electron microscopic images reveals development of denser cement matrix with 10% of clay silica sand replacement, compared to control mix micrographs. The even distribution of cement mortar matrix was observed in microstructure of CMC-RS3 mix, the inclusion of clay silica sand seals the micro cracks and pores in matrix, which

improves interfacial transition zone leading to denser microstructure concrete. This is mainly attributed due to pozzolanic activity of clay silica sand improving friction coefficient between cement matrix and interface of MS.

– Utilizing additional cementitious materials like silica sand, the concept of green concrete reduces concrete's impact on the environment. By reducing pollution in the environment, using these waste by-products as a partial substitute for cement would be even better for the environment.
– The research can be further extended by studying the Cyclic load application and Impact resistance of Trough shaped ferrocement panels with specific loading setup suitable for carrying any type of loading. Furthermore, the corrosion study of the panels made with clay silica and M-sand can also be done for durability applications.

Conflict of Interest

The authors declare no conflict of interest.

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