Experimental study on mechanical properties of modified concrete prepared with M-sand, Silica fume and Steel fiber

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ABSTRACT: This experimental study is aimed at finding the effect of reducing the usage of conventional materials for concrete. The mechanical properties of modified concrete prepared with manufactured sand (M-sand), silica fume and steel fiber are tested and compared with that of conventional concrete. For modified concrete, cement is replaced by silica fume, river sand by manufactured sand and steel fibers are also added. The objective of using M-sand is to reduce the usage of river sand as it is becoming uneconomical in the field of construction. The benefits of using silica fume is to increase the strength of concrete. Steel fibers are added to concrete to increase the tensile strength of concrete. The percentage replacement of river sand by M sand is 40%, cement by silica fume is 5% and hooked end fibers are added at 0.6% to concrete mix during concrete mix preparations. The optimum value of % replacement is decided with the results obtained and it can be concluded that the use of unconventional materials in production of concrete can be encouraged. Key words: M-sand, silica fume, steel fiber, conventional concrete

1. Introduction
Silica fume, manufactured sand and steel fibers are used to get modified concrete and the mechanical properties are studied. Silica fume is an amorphous mineral material composed of extremely small, chemically active partially of SiO2 that appears as a byproduct in silicon production [1]. It is observed that silica fume usage results in the improvement of split tensile strength due to initial filling of voids [2]. Addition of silica fume shows that the microstructure of the material becomes more homogenous and denser than the concrete without silica fume [3]. The use of silica fume in concrete increases the resistance of concrete to acid and sulphate attack thus it improves durability of concrete by reducing porosity and permeability of cement paste material and it makes the concrete more resistant to abrasive forces and reduces the expansion generated by alkali-aggregate expansion [4]. Manufactured sand is a substitute of river sand for preparation of concrete. It is produced from hard sand or granite stone by crushing. The particle characteristics of manufactured sand influences the flow resistance of mortar on fresh concrete and this will affect the workability of concrete and change the structure of influential transition zone [5]. M-sand has special morphological features such as rough surface, irregular particle shape and angular edges. Usage of increased quantity of river sand in concrete leads to depletion of natural resources destroying environment. Concrete prepared with M-sand is treated as green building material [6]. Hooked end steel fiber-reinforced concrete exhibits the best flexural behavior compared to plain concrete, the peak load deflection and toughness of concrete increases with increasing fiber volume fraction and aspect ratio [7]. In order to overcome the drawbacks of conventional concrete, such as low tensile strength, low deformation capacity, and poor post cracking ductility etc., steel fibers are added [8]. Addition of fibers can enhance the tensile flexural and impact strengths of concrete and consequently improve the static, seismic and fatigue performance of concrete structural elements. Short length fibers included in concrete can provide resistance to the initiation and growth of cracks and improve the tensile strength and ductility of concrete. It helps in longer useful working life and reduces maintenance cost.
This experimental study deals with the comparison of mechanical properties of modified and conventional concrete. The compressive, split tensile and impact strength tests are the three types of tests which had been carried out on the modified concrete to examine the enhancement of properties with respect to conventional concrete. The compressive strength test is carried out on cubes, split tensile strength test on cylinders. The impact test is standardized high strain rated test carried out on discs which determines the amount of energy absorbed by a material during fracture [9].

2. Experimental Study

This experimental investigation includes the comparative study of mechanical properties of modified concrete prepared with materials replacing conventional constituent materials with that of conventional concrete. This section includes the information regarding properties of materials, concrete mix proportion, casting and testing of concrete specimens.

2.1 Material properties and concrete composition

In this experimental study, steel fibers are used for enhancement of tensile strength. The length and diameter of hooked end steel fibers used in this research is 30 mm and 0.3mm respectively (Figure 1). Cement is an essential binding material for concrete production. In this experimental study, OPC 53 grade cement along with silica fume (Figure 2) which replaces cement partially is used (with the water/binder ratio of 0.4). The physical and chemical properties of both silica fume and cement are listed in Table 1. A good quality sand with rounded grains gives better concrete. In this research work, river sand and manufactured sand (Figure 3) are used as fine aggregate with coarse aggregate of uniform size (20mm). The properties of fine and coarse aggregate are given in Table 2. A total of 45 specimens were cast to test for compression, split tension and impact strength whose composition of constituent materials are given in Table 3.

| Chemical Properties | Cement | Silica fume |
|---------------------|--------|-------------|
| SiO₂                | 21.87  | 85-95       |
| Al₂O₃               | 5.39   | 0.5 – 1.7   |
| Fe₂O₃               | 3.85   | 0.4 – 2     |
| MgO                 | 1.08   | 0.1 – 0.9   |
| Na₂O₇               | -      | 0.15 – 0.2  |
| K₂O                 | 0.6    | -           |
| C₆O₇                | 62.81  | -           |
| C₃S                 | 51.46  | -           |
| C₃A                 | 22.00  | -           |
| C₄AF                | 10.36  | -           |
| Specific Gravity    | 3.1    | 2.21        |
| Specific Surface    | 3000   | 14.000      |

| Properties of Aggregates                  | Specific Gravity | % Water Absorption | Bulk Density kg / m³ |
|-------------------------------------------|------------------|--------------------|---------------------|
| Fine Aggregate (FA)                       | 2.59             | 1.2                | 1727.64             |
| Coarse Aggregate (CA)                     | 2.65             | 1.8                | 1633.80             |
The control mix has been designated as CC (conventional concrete) which involves the usage of traditional materials for concrete preparation. The modified concrete mixes were designated as MC1, MC2, MC3 and MC4 which involves the replacement/addition of materials other than traditional materials for concrete preparation. For example, for preparation of MC1 concrete, 40% of fine aggregate is replaced by M-Sand.

2.2. Casting of concrete specimens
Cubes, cylinders and discs were cast using steel moulds. Each specimen is marked for identity and soaked in water for curing. Five types of mixes are prepared and a total of 45 specimens were prepared in this experimental study. Some of the cast specimens are shown in Figure 4. The concrete cube, cylinder and disc specimens were tested after 28 days of curing for its property.
2.3. Testing of hardened concrete

2.3.1. Compressive strength test
The compression test was performed on cubes using Compression Testing Machine of 1000 kN capacity, until cube cracks and breaks completely. For each mix proportion, three cubes were tested. Total number of specimens tested was 15. The testing method is shown in Figure 5.

2.3.2. Split tensile strength test
The split tensile strength test was performed on cylinders using Compression Testing Machine of 1000 kN capacity. This test is required to find out the exact load at which concrete starts cracking. The cylinders must be kept in horizontal position between the loading plates and the load is applied till it breaks. For each mix proportion, three cylinders were tested. Total number of specimens tested was 15. The testing method is shown in Figure 6.

2.3.3. Impact strength test
The impact strength test was performed on discs. The test set-up consists of a drop hammer and a ball. The discs were placed in between the plates below the hammer and ball and the blows were given to the discs. The initial and final cracks were noted. The impact energy delivered by the hammer per blow was calculated [9]. The testing method is shown in Figure 7.

3. Results and Discussion
Within the limited experimental investigation conducted, a comparative study on properties of concrete, conventional and modified, with the usage of Manufactured sand, Silica fume and Steel fiber was performed. Compressive, Split tensile and Impact strength test results of concrete specimens for all five mix proportions under consideration including conventional concrete, were summarized in Figure. 8, 9 and 10 respectively.
The variation of compressive strength of conventional and modified concrete prepared with M-Sand, Steel fiber, Silica fume and combination of all ingredients mixes shows that addition of supplementary materials to concrete adversely affect the compressive strength. Of all mix proportions, MC3) Silica fume replaced concrete) showed better property due to its reaction mechanism with the Portland cement. The values of compressive strength of MC3 increased up to 18.6% when compared to conventional mix. Mix MC4 showed 15% improvement in compressive strength compared to conventional concrete.

The variation of split tensile strength of conventional and modified concrete prepared with M-Sand, Steel fiber, Silica fume and combination of all ingredients mixes shows that addition of steel fiber with the concrete mix increased the resistance against tensile failure. Of all mix properties, MC2 (addition of steel fibers in concrete) showed better resistance. The values of split tensile strength increased up to 22.3 and 25.9% for MC2 and MC4 respectively. When compared to conventional mix.

The variation of impact strength of conventional and modified concrete prepared with M-Sand, Steel fiber, Silica fume and combination of all ingredients mixes shows better energy absorption properties for MC4 mix. The values of impact strength increased up to 17.8% for MC4 when compared to conventional mix. The concrete mix proportion MC4 showed better results in all cases of compressive split tensile and impact strength.

![Figure 8.Compressive strength of concrete cubes](image1.png)

![Figure 9.Split tensile strength of concrete cylinders](image2.png)
4. Conclusion
This experimental study was planned to reduce the change of getting brittle failure of concrete (to use steel fiber) and to utilize the unconventional materials, such as M-sand to assess the performance of concrete. The usage of silica fume as a replacement of cement by 5% exhibited better compressive strength than CC. Considering the acute shortage of river sand, huge cost and environment impacts, the use of M-Sand can be encouraged in the construction industry. The replacement of river sand by M-Sand by 40% proved to provide better strength properties. Almost 7-13% of increase in strength is observed for compressive, split tensile and impact strength, compared to CC. This study also analyses the effect of addition of steel fiber to counteract the brittle failure. 0.6% of steel fiber is added to the volume of concrete mix. This results in increase in split tensile strength by 22% compared to CC. Combination of silica fume, steel fiber and M-Sand also showed better strength properties when compared to CC mix, where all supplementary materials used are found to promote concrete strength. Hence it can be concluded that use unconventional materials in production of concrete can be encouraged.

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