



Performance studies of fiber-reinforced municipal solid waste incineration bottom ash amended with cement for Geotechnical applications

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Abstract. This paper presents a study to quantify the optimum augmentation of cement and randomly allocated polypropylene fibers on the achievement of cement stabilized and fiber-reinforced MSWI ash mixes. Five specimens of the mixes were examined in this study. For each sample, fiber contents were varied from 0.5, 0.75, and 1% and the MSWI ash was compensated by 2, 4, 6 and 8% cement, respectively. The specimens were cured for the age of 7, 14 and 28 days, respectively. For the purpose of the investigation, tests for unconfined compressive strength (UCS) and split tensile strength (STS) were conducted. The results obtained indicate that the inclusion of cement and fibers leads to significant advancement in strength. The study underlines the effective utilization of Municipal solid waste incineration (MSWI ash), a common pozzolanic waste, as an important civil engineering material. The outcomes of the study also validate that enhancement of fiber used to stabilize MSWI ash introduces a drop in stiffness and compressive strength values, and also, the loss of strength declines after a peak hence the behaviour changes from brittle to more ductile.

Keywords. Cement; fiber; MSWI ash; UCS; STS.

1. Introduction

Limited land resource in big townships and populated metro cities creates a new challenge for environmentalists and governmental agencies working in the field of safe and cost-effective solid waste disposal solutions [1–3]. Land-filling of MSW is a very common and years-old practice being practiced for solid waste management in low-lying areas. This procedure is followed under strict guidelines related to the environmental rules and regulations of the dumping locations. On average, 94% of the total MSW collected is directly dumped on land, and 5% is decomposed [4, 5]. With the rising population, MSW production causes two significant waste management issues: a lack of storage and treatment facilities and a negative environmental impact [6–8].

Additionally, the land has become a valued asset, and landfills are dwindling in the metropolitan cities. Hence the outskirts are the new favorite location for solid waste dumping. Incineration of MSW is the next possible solution to target the piles of uncontrolled dumping. The only real alternative to limit the refuse produced from incineration

plants and to control the amount of daily waste in dumping grounds is the reuse in civil engineering applications [9, 10].

Common MSW incinerator ash is being used in countless geotechnical applications to attain effective and safe disposal [11, 12]. When cement is added to bottom ash, it may result in heavy metal containment and also a significant improvement in strength characteristics has been studied in the case of clays [13, 14]. Researchers have recommended the addition of reinforcement to further improve the strength of expansive soils in the form of synthetic or natural fibers. Past studies have confirmed the application of Polypropylene fiber to attain the required improvements in strength characteristics of both soils and ash [15–18].

Following the past studies, the behavioral change of MSWI bottom ash is studied when cement 2, 4, 6, and 8% and fiber content 0.5, 0.75, and 1% is added by weight. Heavy compaction tests were performed to obtain W_{opt} and γ_{dmax} values. A series of UCS and STS tests were achieved to evaluate compressive strength under a definite period duration of 7, 14, and 28 days.

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2. Materials

2.1 MSWI bottom ash

The MSWI ash used in the current study was appropriated from the Chandigarh treatment Plant. The engineering properties of MSWI ash are (effective size: 0.15, uniformity coefficient: 4.66, coefficient of curvature: 0.857, specific gravity: 2.05, maximum dry density: 16.8, moisture content: 11). Following the ASTM D6913-04, the bottom ash under the particle, classified as poorly graded sand (SP) per USCS criteria, was used [19]. The particle size distribution curve of MSWI ash has shown figure 1 [20].

2.2 Cement

Ordinary OPC cement of 43 grades is used in the current study and the properties are the same as the previous research paper [21].

2.3 Fiber

The polypropylene fibers with cut lengths of 6, 12 and 18 mm were used. The characteristics of fiber of specific gravity: 0.9–0.91, diameter: 0.02 mm, water absorption: 0.3%

3. Testing program

3.1 Compaction test

Heavy compaction tests were carried out on the MSWI ash, with cement and fibers or as an individual were thoroughly

mixed with various moisture contents and allowed to equilibrate for 24 h prior to compaction. Following the recommendations of ASTM, D1557-78, values for W_{opt} and γ_{dmax} of bottom ash blended with cement and fiber. The general equation of an MSWI bottom ash-cement-fiber mixture is [22].

$$W = W_{MSWI \text{ bottom ash}} + W_C + W_f \quad (1)$$

Where, $W_{MSWI \text{ bottom ash}}$ = Weight of MSWI ash, W_C = Weight of cement, W_f = Weight of Fiber

3.2 UCS test

According to ASTM, D2166-98, standard UCS tests were performed on cylindrical specimens of recommended height and diameter of 76 mm and 38 mm [23]. The MSWI ash, with cement and fibers or as an individual mixture was compacted at OMC and maximum dry unit weight in standard moulds. Tests were performed at W_{opt} and γ_{dmax} of each mix which was obtained from the Heavy compaction test results.

3.3 STS test

Split tensile tests according to ASTM, C496-11 (2005) were performed at the lab facility for the exact mixes as in the case of the UCS test with the same W_{opt} and γ_{dmax} values [24]. The recommendations were strictly followed for the test, and the curing duration was 7, 14, and 28 days. The following equation is followed for the calculation of STS values.



Figure 1. Particle size distribution curve of MSWI ash [20].

$$T = \frac{2P}{\pi DL} \tag{2}$$

P = load, L = length, D = diameter.

4. Results and discussion

4.1 Effect of cement and fiber on compaction

The results of MSWI bottom ash stabilized with different cement and fiber contents on maximum dry unit weight (γ_{dmax}) and optimum moisture (W_{opt}) are presented in figures 2, 3. On the enhancement of cement contents 0 to 8% and fiber content 0.5 to 1% of 6, 12, and 18 mm sizes, stabilized in MSWI ash, the γ_{dmax} curtailed and W_{opt} increases. This is due to the reason that incinerated ash has low specific gravity and curtails the dry density. Fiber causes water retention thus, the W_{opt} value rises [21, 25].

4.2 Effect of cement content on UCS and STS

The casted specimens were tested for UCS and STS tests after the age of 7, 14, and 28 days. Experiments confirm that both the value of UCS and STS, the casted sample boosted with the increased value of cement content. The value for UCS and STS tests for ash specimens stabilized with 2% cement after the age of 7 days was 343 kPa and 18 kPa. Considering these results as a base value, the UCS values improved 38.43, 51.60, and 72.01%, and 83.67, 96.79, and 117.20%, for 4, 6, and 8% cement content (14 and 28 days). Similarly, after 14 and 28 curing, STS results were 188, 244.45, and 272.24% and 366, 422.24, and

444.45% [21]. These stated values, with the inclusion of cement at different proportions, are due to the pozzolanic property of the cement content.

4.3 Effect of fiber length on UCS and STS

Analyzing the graphs shown in figures 4, 5, increasing the length of the fiber, UCS and STS values were found at peak values of 1180 kPa and 146 kPa for the fiber length of 18 mm. When the identical specimens were tested during the 28 day curing period, the enhanced values for both the strength tests were 41.61, 49.66, and 58.38% and 24, 39, and 49% for fiber dimensions raised from 6 to 12 and 18 mm resp. High anchorage action leads to better resistance towards higher mobilization and pullout forces hence the improvement in UCS and STS value in fiber length can be explained [25]. This inflation in the value for the STS with the increased fiber length is due to the improved contact area of the composite, causing increased friction.

4.4 Effect of fiber content on UCS and STS

Figures 6 and 7 depict the results of variation in fiber content 0.5 to 1% on the UCS and STS values of increased ash mixed with various cement content 2 to 8% for 6, 12 and 18 mm length of fibers and curing period of 7, 14 and 28 days, respectively. At the curing period of 28 days, the UCS and STS values are 1025, 1125 and 1180 kPa and 130, 142 and 146 kPa, when ash is treated with 8% cement and 0.5 to 1% fiber content (18 mm). The improvement in UCS is found to be 86.59 to 153.64%, 106.99 to 182.79% and 115.74 to 198.83% and 131.78 to 199%, 152 to 228% and

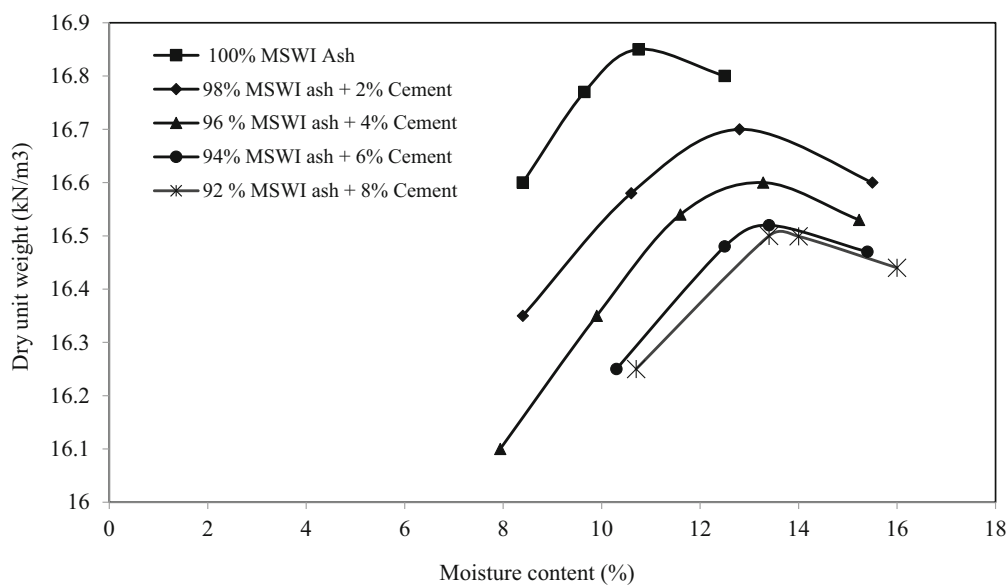


Figure 2. Graphical representation of compaction curves for MSWI bottom ash and cement content.

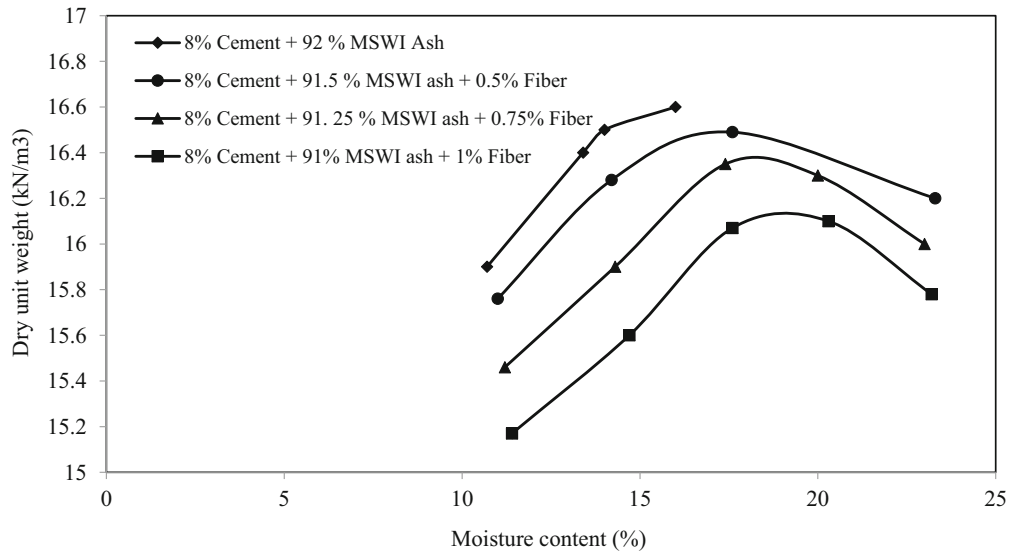


Figure 3. Graphical representation compaction curves for MSWI ash blended with Cement and fiber length 18 mm.

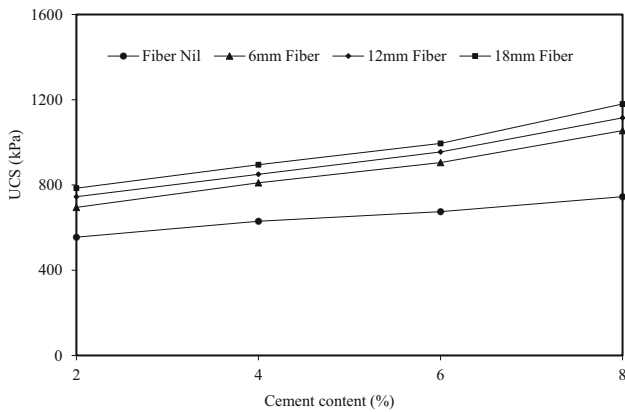


Figure 4. Graphical representation UCS with cement content at fixed fiber 1% after 28 days.

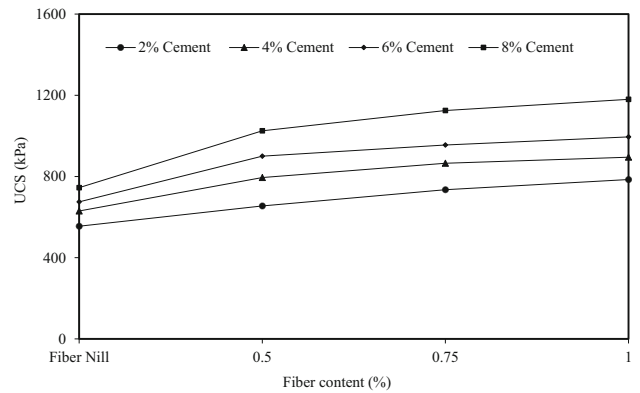


Figure 6. Graphical representation UCS with fiber content for various combinations of MSWI ash at fixed fiber length 18 mm after 28 days.

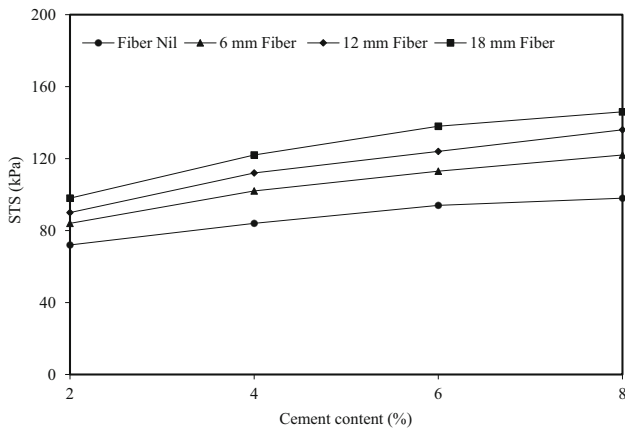


Figure 5. Graphical representation STS with cement content at fixed fiber 1% after 28 days.

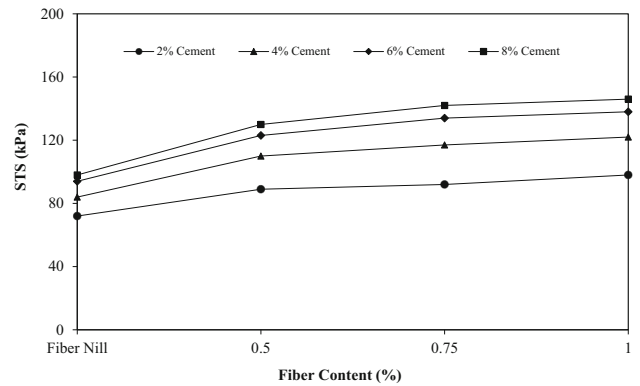


Figure 7. Graphical representation STS with fiber for various combinations of MSWI ash at fixed fiber length 18 mm after 28 days.

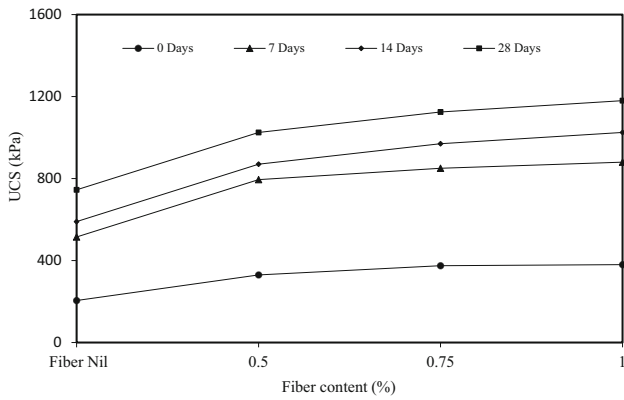


Figure 8. Graphical representation UCS with Curing period for various combinations of fiber length 18 mm at fixed 8% cement after 28 days.

160.93 to 244%, for 18 mm fibers content 0.5 to 1% and cement percentage of 4, 6 and 8% over the age of 14 and 28 days. Similarly, the STS values improved from 333 to 494.45%, 372 to 511% and 400 to 544%, and 511 to 622%, 550 to 688.89%, and 578 to 711% when cured for 14 and 28 days, respectively [25, 26].

4.5 Effect of curing period on UCS and STS

The lab experiments helped study, the effect of cement addition 0 to 8% and fiber content 0.5 to 1% in stabilizing MSWI bottom ash mixes on the UCS and STS values after curing periods 7, 14, and 28 days. It was noted that the values of UCS and STS tests of the mixes (stabilized bottom ash blended fiber and cement) were increased. The increment in values for UCS and STS tests are shown in figures 8, 9, where UCS and STS values of 380, 880, 1025, and 1180 kPa and 98, 116, and 146 kPa after 0, 7, 14, and 28 days were attained (8% cement and 1% fiber content) for 18 mm fibers [25, 26]. The increment may be due to formation of cement-ash composite due to the pozzolanic nature of the cement and fiber addition, which further adds strength to the final structure. The advancement in UCS and STS are found to be 115.74, 144.89 and 198.83%, and 160.93, 190.08 and 244%, and 400, 477.78 and 544.45%, and 578, 666.67, and 711% using 18 mm fibers after the age of 14 and 28 days for 4, 6 and 8% cement and 1% fiber respectively.

4.6 Strain analyses

The effect of fiber content 0.5%, 0.75% and 1% on the stress-strain behavior of MSWI ash when mixed with different cement contents 2, 4, 6 and 8%, different length of fibers 6 mm, 12 mm and 18 mm at different curing periods

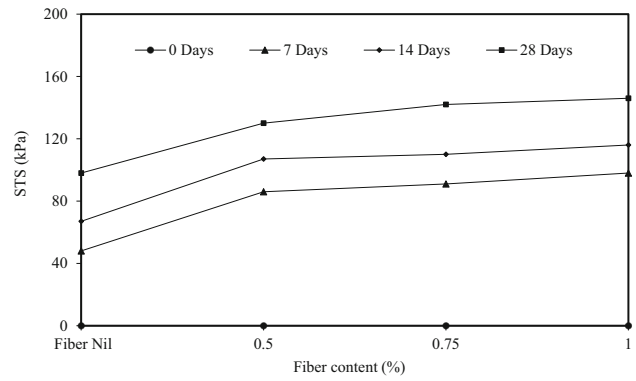


Figure 9. Graphical representation STS with Curing period for various combinations of fiber length 18 mm at fixed cement 8% after 28 days.

7, 14 and 28 days. From these figures 10 and 11, it can be observed that as the fiber content is increased there is a considerable increase in the peak strength. Moreover, the inclusion of fiber in MSWI ash not only increases the peak strength but also maintains post peak strength up to larger strains and thereby changing the brittle behavior of sample to a ductile one [27].

4.7 SEM test results

From the micrographs it can be clearly seen that both bottom ashes amended with cement only and another combination with fiber. When a comparison is made among each other, it shows many pores and big packets of ash particles as indicated in figure 12 (a–d). In addition to this, both MSWI ash stabilized with cement and the fiber-cement treated MSWI ash have the fabric with cementations gel between aggregated ash particles in figure 12 (b–d).

5. Cost-benefit analysis

The MSWI ash can be used as an alternative to conventional construction building material and can help in achieving an environmental friendly development scenario. The same composition is tested for the preparation of standard-sized non-fired bricks, and the results were found promising. The major component in the final product was ash only, whereas the cement was used in very less concentration. The labor expenses and the transportation charges were found almost the same as applicable to the conventional bricks. When compared with conventional clay bricks available in the market, the MSW bricks were found to be the cheapest as the bottom ash was available free of cost as shown in figure 13 [28].

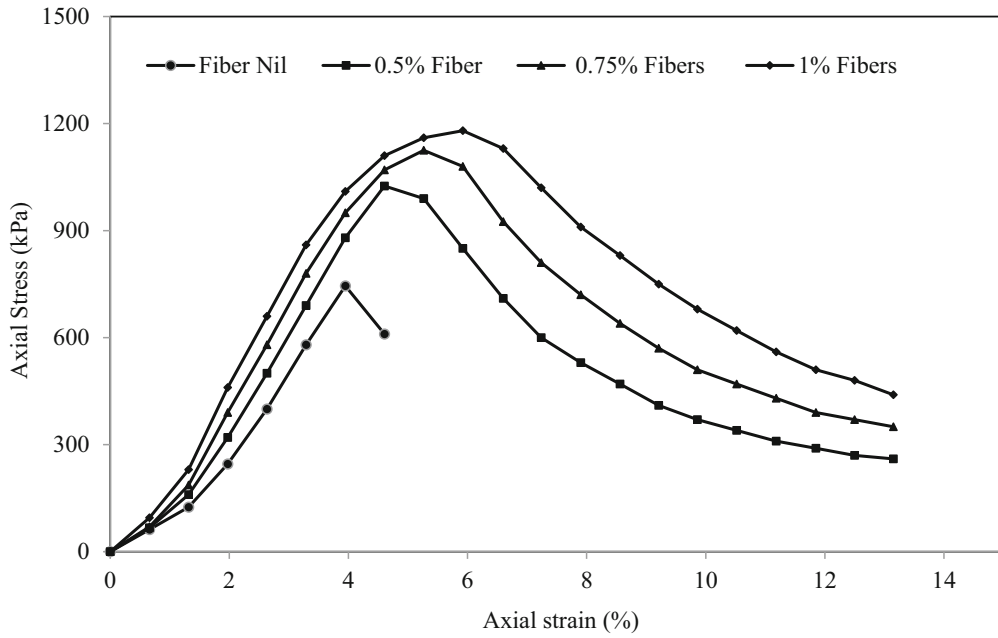


Figure 10. Stress-strain curves for different combinations of MSWI ash, cement and fibers after 28 days of curing (8% cement 18 mm fibers).

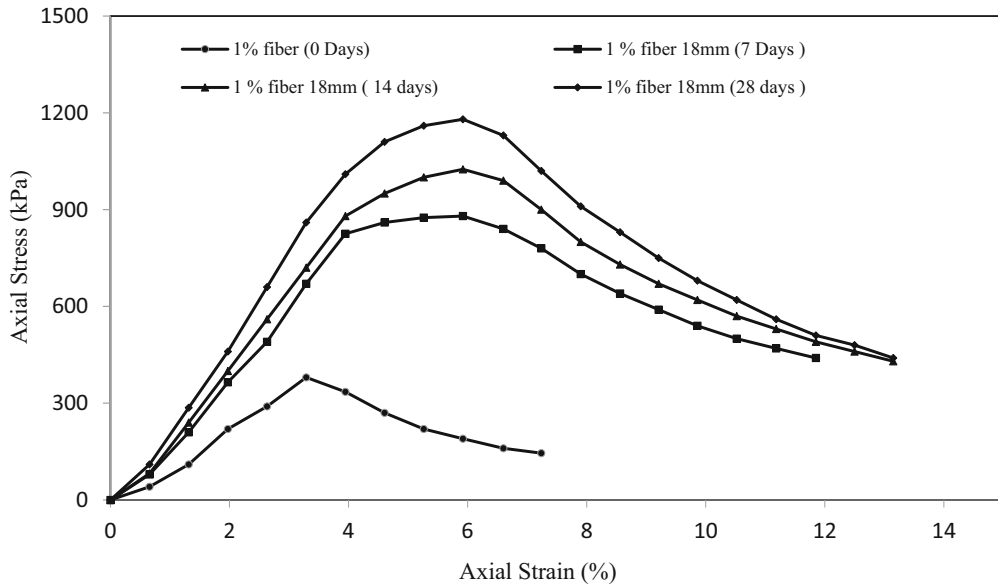


Figure 11. Stress strain curves for different combinations of MSWI ash and cement content 8% (Fiber content 1%) after curing 0, 7, 14, and 28 with fiber length 18 mm.

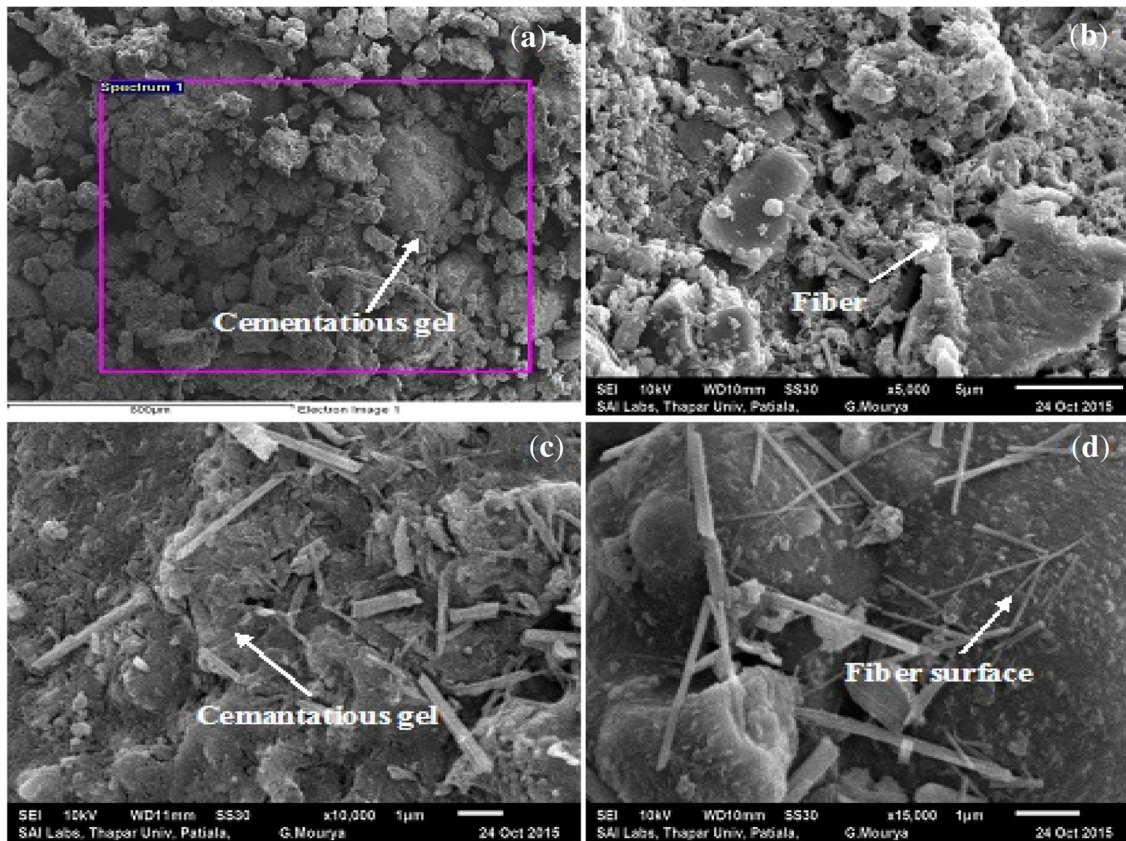


Figure 12. Stabilized MSWI bottom ash SEM micrographs (a) 8% cement (b) 8% cement and 0.5% fiber (c) 8% cement and 0.75% fiber (d) 8% cement and 1% fiber after 7 days Curing.

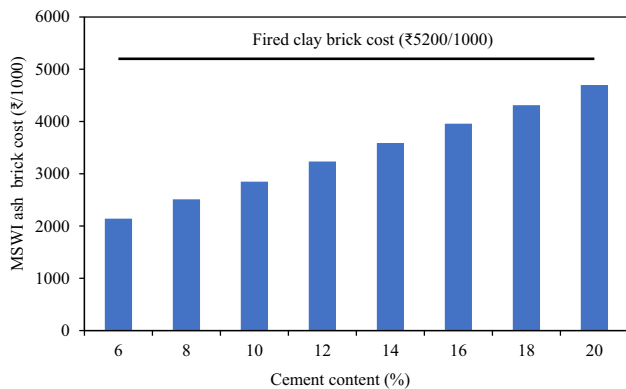


Figure 13. Variation combination in cost per brick with cement.

6. Conclusions

The following distinguished conclusions are made from the experimental investigations:

1. It was observed that OMC increases and the Maximum dry unit weight decreases with increased cement content when added with fibers to stabilize MSWI bottom ash.

2. The observed value for UCS and STS tests for the stabilized ash specimens increased with the increased curing duration. In most cases, the percentage of improvement in durability was expeditious for the curing period 7 day.
3. The observed value for the UCS test for stabilizing MSWI bottom ash after 7 days curing period (2% cement content) was 343 kPa. Using this as a baseline, the increment in UCS is calculated to be 115.74, 144.89 and 198.83% and 160.93, 190.08 and 244%, for 4, 6 and 8% cement and 1% fiber of (18 mm) at 14 and 28 days.
4. The improvement in UCS is found to be 86.59 to 153.64%, 106.99 to 182.79% and 115.75 to 198.83% and 131.78 to 199%, 152 to 228% and 160.93 to 244%, for 4 to 8% cement and fiber content 0.5, 0.75 and 1% fiber content of (18 mm) after 14 and 28 days curing, respectively.
5. The STS value of stabilized MSWI bottom ash after 7 days curing period (2% cement content) was 18 kPa. Using this value as the baseline, the improved results for STS were 400, 477.79 and 544.46%, and 578, 666.67 and 711% for 1% fiber of 18 mm and 4 to 8% cement after 14 and 28 days of curing, respectively.

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