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Feasibility of stone slurry powder and admixtures in cement mortar

Kiran Devi[1], Babita Saini[2], and Paratibha Aggarwal[2]*

[1] Department of Civil Engineering, SGT University, Gurugram, India
[2] Department of Civil Engineering, National Institute of Technology, Kurukshetra, India

***Corresponding author**:*
Kiran Devi
kiranbimbhra@gmail.com

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ABSTRACT

The present study has focused on altering the properties of its composites to achieve robustness in concrete with high speed of construction. The different types of chemical admixtures are used to produce mortar/concrete with an accelerated setting time and early-age strength. Stone waste can be converted into mortar and concrete as an alternative to cementitious materials to overcome their ill effects, resulting production of sustainable end products. The present study investigated the influence of the stone slurry powder, calcium nitrate, and triethanolamine at various proportions in the different mortar mixes. The viability of using the additional materials in cement mortar based on strength, cost and environmental aspects was also investigated. The results demonstrated that incorporation of stone slurry powder in mortar enhanced the strength by 6–17%, which may be due to its pore filling ability. The cost of mortar construction also declined by 7% due to its free availability. The cost index and carbon emission index of mortar mix containing stone waste declined by 24% and 26%, respectively, compared to other mixes, due to reduced cement content.

Keywords: additives; compressive strength; environmental assessment; cost

1. INTRODUCTION

A rise in population and industrial growth has demanded lower construction times to deal with the infrastructure requirements. To speed up the construction, additional materials or chemicals are added to enhance the setting and hardening of cement composites. At low temperatures, difficulties in the setting of cement composites and strength development problems are experienced after the placement or pouring in the formworks. To resolve this, accelerating admixtures are added to cement-based materials to expedite the stiffening and early-age strength development. Non-chloride accelerating admixtures are added to cement composites due to their corrosion-inhibiting nature. Calcium nitrate (CN) and triethanolamine (TEA) are commonly used admixtures to accelerate the hardening and early-age strength. They also reduce construction time and cost by the early removal of formworks (Aggoun et al., 2008).

On the other hand, the safe disposal of huge quantities of industrial waste has become a significant environmental concern requiring adequate solutions. One of the solutions is to reuse and recycle the industrial by-products in the construction industry since this huge industry absorbs large amounts of materials. This approach is sustainable as it utilizes industrial waste, to a certain extent, and reduces construction costs (Devi et al., 2018a; Chen et al., 2023; Jahangir et al., 2023; Kontoni et al., 2022; Liu et al., 2023; Marinelli et al., 2023; Onyelowe et al., 2022; Devi et al., 2019, 2022). The addition of marble slurry in concrete reduces its environmental impact (Singh et al., 2017); the incorporation of marble powder in cement mortar and concrete also reduces other negative impacts (Khodabakhshian et al., 2018).

In the present study, varied amounts of the admixtures CN and TEA were used in cement and stone slurry powder (SSP) was used as a fractional substitution to cement to examine the feasibility in terms of strength, environmental impact, and cost. The study evaluates the practicality of the additional materials in the cement mortar in different aspects. The environmental impact, normalized energy index

(NEI), normalized carbon emission (NCE) and normalized cost (NC) of different mortar mixes were also evaluated. The novelty of the work is to assess the individual and cumulative effect of admixtures and Kota stone slurry powder on the strength, cost and environmental in the different cement mortar specimens.

2. MATERIALS AND METHODS

In the present study, 43 grades of Portland cement and coarse sand as aggregate were used in the cement mortar, according to both IS:8112-1989 and IS:383-2016. CN (0%, 1%) and TEA (0%, 0.025%, 0.1%) were used as cement additives and SSP (0%, 5%, 7.5%, 10%) was used as a partial cement substitution (Devi et al., 2018b). The images of ordinary Portland cement (OPC) and SSP along with their scanning electron microscopy (SEM) and energy dispersive X-ray (EDS) analyses are shown in Figure 1 (Devi et al., 2019). The designated mixtures of the different mortar is given in Table 1.

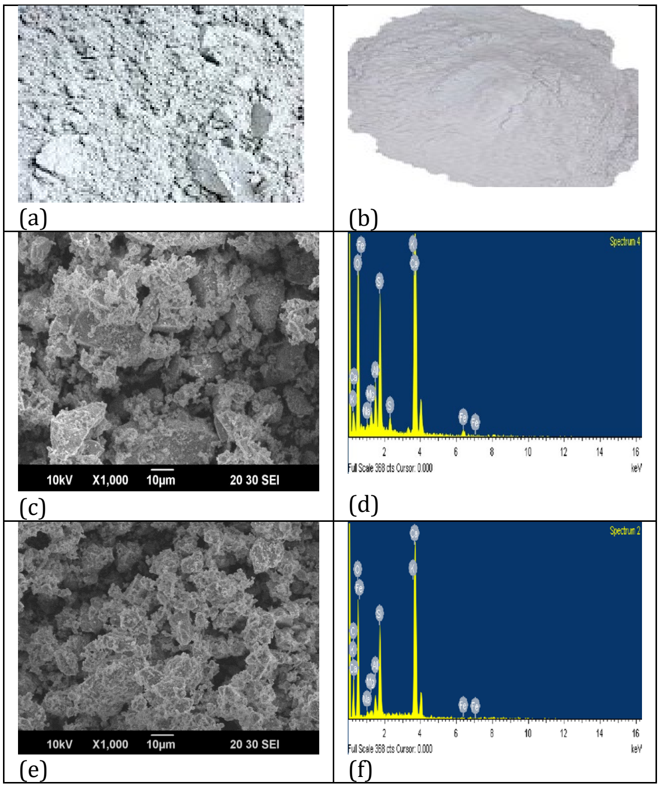

Figure 1. (a) Ordinary Portland Cement; (b)Stone slurry powder; (c) Scanning electron microscopic (SEM) image of ordinary Portland cement; (d) energy dispersive X-ray (EDS) image of ordinary Portland cement; (e) SEM image of stone slurry powder; and (f) EDS image of stone slurry powder

Table 1. Mixtures of cement mortar (Devi et al., 2018b)

Mix No.	Cement (kg/m³)	Sand (kg/m³)	Water (kg/m³)	CN (kg/m³)	Tea (l/m³)	SSP (kg/m³)
CM1	575.00	1725	158.25	0	0	0
CM2	580.75	1725	158.25	5.75	0	0
CM3	575.14	1725	158.25	0	0.14	0
CM4	575.58	1725	158.25	0	0.58	0
CM5	546.25	1725	158.25	0	0	28.75
CM6	531.88	1725	158.25	0	0	43.13
CM7	517.50	1725	158.25	0	0	57.50
CM8	552.00	1725	158.25	5.75	0	28.75
CM9	537.63	1725	158.25	5.75	0	43.13
CM10	523.25	1725	158.25	5.75	0	57.50
CM11	580.89	1725	158.25	5.75	0.14	0
CM12	581.33	1725	158.25	5.75	0.58	0
CM13	552.14	1725	158.25	5.75	0.14	28.75
CM14	537.77	1725	158.25	5.75	0.14	43.13
CM15	523.39	1725	158.25	5.75	0.14	57.50
CM16	552.58	1725	158.25	5.75	0.58	28.75
CM17	538.20	1725	158.25	5.75	0.58	43.13
CM18	523.83	1725	158.25	5.75	0.58	57.50

The environmental impact analysis of additives in the cement mortar mix was carried out. The inventory of raw materials for the environmental analysis (energy, CO_2 emission and cost) was taken from previous studies (Flower and Sanjayan, 2007; Devi et al., 2022) and is given in Table 2. Batching, transportation and placing of concrete also have less contribution to CO2 emission (Devi et al., 2019).

Table 2. Inventory data for energy consumption (EE), carbon emission (ECO_2) and cost

No.	Materials	EE (MJ/kg)	ECO_2 ($kgCO_2$/kg)	Cost (US$/kg)
1	Cement	4.8	0.83	0.073
2	Sand	0.022	0.001	0.012
3	Water	0.01	0.0002	-
4	CN	0.1368	0.481	5.22
5	TEA	-	-	12.88

The energy consumption (EE), carbon emission (ECO_2) and cost of the different mortar mixes at day 28 were calculated using Equation 1 (Devi et al., 2022). The NEI, CF and normalized cost index (CI) were calculated (Tahwia et al., 2022).

$$EE / ECO_2 / Cost = \Sigma g_i m_i \tag{1}$$

where g_i = EE per unit mass of materials and m_i indicates the mass of concrete ingredients *i* per unit cubic meter.

3. RESULTS AND DISCUSSION

The study investigated the effects of additional materials (CN, SSP, and TEA) on cement mortar mixes in terms of strength, cost, and environmental impact. The economic feasibility was assessed by calculating the cost of the low cement content mixtures and comparing them with the reference mix. The NC index is the ratio of cement mortar price to that of the reference mortar mix.

The 28-day compressive strength of the cement mortar mixes was studied. It was found that the addition of stone waste enhanced the strength of the mortar mixes due to their pore filling ability and dense matrix formations. The addition of CN enhanced the strength due to the presence of lime, while TEA reduced the strength of the mortar owing to its retarding effect on C_3S (Devi et al., 2019). The variation in compressive strength at day 28 is shown in Figure 2. The incorporation of CN, SSP and their combinations in the cement mortar enhanced the compressive strength by 3%, 7–17% and 3–17%, respectively, due to the combined effect of a dense matrix formation and high lime content.

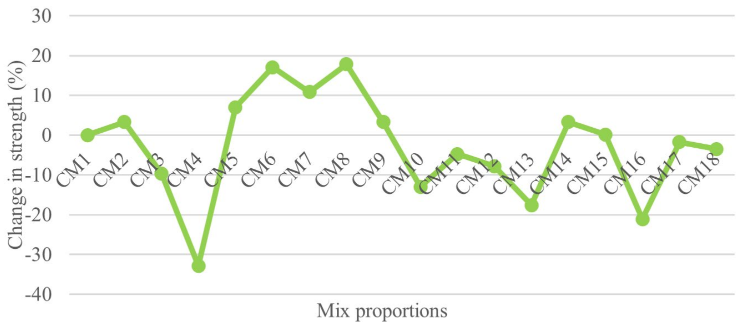

Figure 2. Variation of compressive strength of different mortar mixes

The environmental analysis of the different cement mortar mixes was evaluated. The energy consumption and CO_2 emission of different mortar mixes varied from 57.4 to 108 MJ/m^3 and 9.8 to 15.2 kgCO_2/m^3, as shown in Figures 3 and Figure 4, respectively. The cost of different mortar mixes varied from 58.5 US$/m^3 to 100.6 US$/m^3. The usage of SSP in mortar reduced the EE and ECO_2 due to a reduction in cement content and also the presence of industrial by-products. SSP had a lower or negligible EE, carbon emission and cost, compared to other materials such as CN, TEA and cement among all of the materials. The EE, ECO_2, and cost of mortar mixes containing SSP were reduced by 5–11%, 5–11% and 8%, respectively, whereas the addition of CN enhanced them by 1%, 2% and 32%. TEA had a negligible impact on EE and ECO_2 due to lesser amount in the mortar; however, it raised the cost of mortar construction by 2%, as observed from the Figures 3–5. The combination of these additives in cement mortar has a lesser effect on these environmental assessment parameters, possibly due to the presence of SSP or TEA. The value of NEI, NCI, and NC indexes for the mortar mixes consisting of SSP were lower than the reference mix by 12–26%, 12–26% and 11–24%, respectively. This was because of the presence of finer SSP particles enhancing the mortar strength by densifying the matrix. However, the mixes containing TEA had the highest values for normalized energy consumption index, carbon emission index and cost index at 10–33%, 10–33% and 11–40% among all mixes due to reduction in compressive strength. The addition of CN raised the cost index by 30%, but reduced the energy consumption and carbon emission indexes by 2% and 2%, respectively. The lower values of normalized energy consumption, CO_2 emissions and cost of mortar mixes lead to a more eco-friendly construction product that could be used for different applications.

Figure. 5 illustrates that the addition of chemical admixtures hikes the cost of mortar production, whereas the utilization of SSP in the mortar mixes can cut the cost of construction by up to 7%.

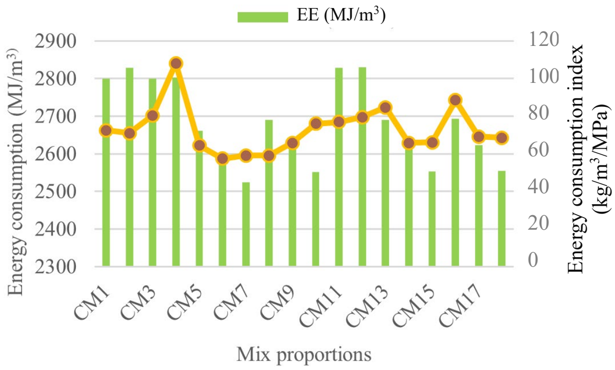

Figure 3. Energy consumption and energy consumption index of mortar mixes

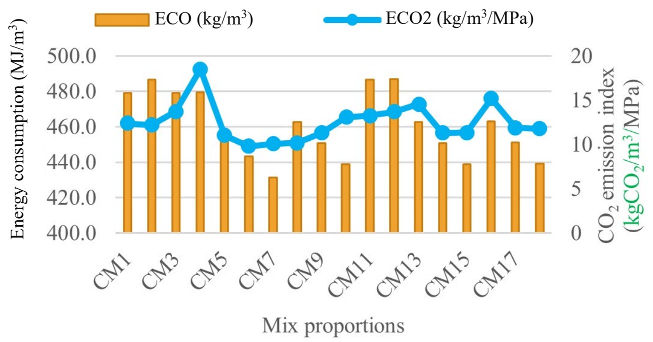

Figure 4. CO_2 emission and CO_2 emission index of different mixes proportions of mortar mixes (CM1 to CM18)

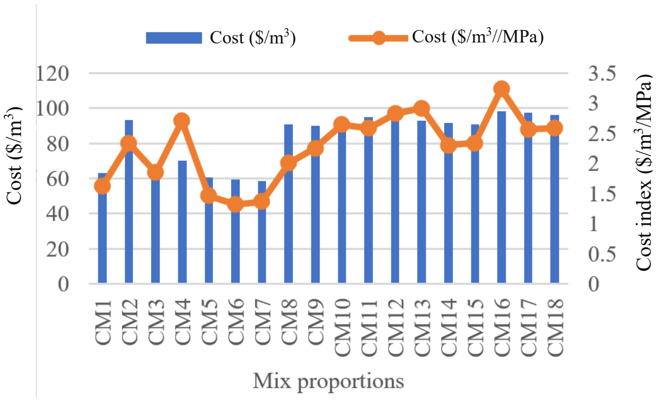

Figure 5. Cost and cost index of different mortar mixes

4. CONCLUSION

In the present study, the admixtures (CN and TEA) and SSP at various percentages were used in mortar to evaluate the strength, cost and environmental effect, compared to the reference mix. The EE index, CO_2 emission index and cost index of the different mortar mixes were evaluated by considering the 28-day compressive strength under water curing condition. The following conclusions were found from the above study:

The incorporation of SSP, CN and their combinations in the mortar mixes enhanced the compressive strength by 6–17%, 7–17% and 3–17%, respectively, due to the pore filling capability of SSP and the high lime content in CN. The addition of TEA reduced the strength, possibly because of its retarding effect on the C_3S hydration process compared to the control mix.

The addition of CN, TEA and their combinations in the different mortar mixes hiked the cost of construction due to their high (additional) price by 48%, 2.5–11% and 51–60%. TEA in cement mortar had little effect on the energy consumption and CO_2 emissions due to lower quantity. The addition of CN in the mortar enhanced the energy consumption and CO_2 emission by 1% and 1.5%, compared to the plain mix.

The utilization of SSP up to a certain percentage (7.5%) produced mortar with a higher strength and lower energy consumption, CO_2 emissions and cost, producing a sustainable end product. Reusing the stone waste in mortar construction reduced the problems related to waste disposal to land and water courses.

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