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Application Of Elevated Temperatures On Cement Mortars With Fly Ash, Manufactured Sand And Polypropylene Fibers

Abdul Raheem.K[1], Chethan K[2], Akash Babu L.A[3], Bhagyashri. P[4], Sadath Ali Khan Zai[5]
[1]Research Scholar, Department of Civil Engineering, UVCE, Bangalore University, Bangalore 560056, India, arkhazi63@gmail.com
[2]Associate Professor, Department of Civil Engineering, UVCE, Bangalore University, Bangalore 560056, Karnataka, India
[3]Research Scholar, Department of Civil Engineering, UVCE, Bangalore University, Bangalore 560056, Karnataka, India
[4]Associate Professor, Department of Civil Engineering, Govt. SKSJTI, Bangalore 560001, Karnataka, India
[5]Professor, Department of Civil Engineering, UVCE, Bangalore University, Bangalore-56, Karnataka, India.

Abstract: *This study examines the effect of elevated temperatures on the mechanical properties of fiber-reinforced cement mortars incorporating supplementary materials. The experimental program focused on 1:3 and 1:4 mortar mixes, where cement was partially replaced by fly ash and river sand was partially substituted by manufactured sand (M-sand). Selected mixes also included 0.25 % (by weight of cement) Recron polypropylene fibers. After 28 days of curing, the cube specimens (70.6 × 70.6 × 70.6 mm) and prismatic specimens (160 × 40 × 40 mm) were subjected to temperature exposures of 200 °C, 400 °C, and 600 °C to simulate fire or severe thermal conditions. The specimens were tested at room temperature (27°C) also. Compressive and flexural strengths were determined for each condition. Results show that the inclusion of fibers, fly ash, and M-sand significantly improves residual strength and thermal resistance compared to control mixes. The findings contribute to the development of sustainable, fiber-reinforced mortars with enhanced performance under high-temperature environments.*
Keywords: *fiber-reinforced mortar, fly ash, manufactured sand, elevated temperature, compressive strength, flexural strength*

1. INTRODUCTION

Modern construction increasingly uses high-performance mortars and concretes that may be subjected to elevated temperatures during their service life, making it essential to understand their thermal behavior to ensure structural safety [17][26]. Structures such as industrial furnaces, chimneys, nuclear facilities, and high-rise buildings are prone to fire exposure, where mechanical properties and durability can be severely affected [15][30]. Elevated temperatures alter the surface characteristics, color, volume, and internal microstructure of cementitious materials, with strength degradation becoming significant beyond 400 °C and losses often exceeding 50% above 600 °C [21][28].

Incorporating mineral admixtures such as fly ash and using alternative fine aggregates such as manufactured sand (M-sand), along with fiber reinforcement, has been shown to improve thermal stability and delay strength deterioration by refining the pore structure and enhancing crack resistance [18][23][31]. This study specifically investigates 1:3 and 1:4 fiber-reinforced cement mortars with partial replacement of cement with fly ash, river sand with M-sand, and addition of polypropylene fibers (0.25% by weight of cement), subjected to room temperature (27 °C), 200 °C, 400 °C, and 600 °C [20][14].

The aim is to evaluate residual compressive and flexural strengths and to provide insights for optimizing sustainable mortars capable of maintaining performance in fire and high-temperature applications [16][25][29].

2. LITERATURE REVIEW

The durability and fire safety of modern cementitious materials are significantly influenced by their behavior under elevated temperatures, particularly as construction moves toward the use of sustainable alternatives such as manufactured sand, fly ash, and fibers [17][30]. Pereira et al. (2020) examined thermal mortars containing expanded clay, cork, and silica aerogel exposed to temperatures up to 250 °C, showing that mineral additions can enhance resistance to heat damage [21]. Cui et al. (2024) studied cement mortars with manufactured sand subjected to repeated thermal cycles, demonstrating that M-sand improves bonding strength and microstructural stability under fluctuating temperatures [26][13].

In the context of sustainable binders, Du et al. (2021) provided a comprehensive review of high-volume fly ash–based composites, highlighting their long-term strength benefits, low carbon footprint, and potential for application in thermally exposed structures [23][29]. Ge et al. (2024) specifically investigated fiber-reinforced cement composites (using both polypropylene and PVA fibers) at temperatures up to 500 °C and reported that fibers help bridge microcracks, improving residual strength and delaying spalling, with microstructural evidence from real-time SEM analyses [15][27]. Rahman et al. (2022) demonstrated that high-volume fly ash mortars containing polypropylene fibers and air-cooled slag aggregates retain better compressive and flexural strengths and exhibit superior sulfate resistance, which indirectly contributes to thermal resilience due to improved pore structure [18][31].

Similarly, Zhang et al. (2021) explored the effect of using desert sand in fiber-reinforced mortars and found that alternative fine aggregates significantly refine pore structure and improving post-cracking strength, attributes that are also relevant when manufactured sand is used [22][28]. Finally, Ali et al. (2016) presented a comprehensive study on polypropylene fiber-reinforced fly ash–based geopolymer composites, showing that fibers substantially enhance toughness and high-temperature endurance of alkali-activated materials [24][19].

Collectively, these studies affirm that (i) fly ash reduces environmental impact and improves microstructural stability, (ii) manufactured and alternative sands improve packing and bonding behavior, and (iii) fiber reinforcement enhances tensile performance, crack control, and residual strength after thermal exposure [20][16][14]. However, despite these advances, most available research has examined these factors either in isolation or in dual combinations, frequently using concrete or geopolymer matrices rather than traditional cement mortars [25][17]. Very few studies systematically evaluate the combined effects of polypropylene fibers, fly ash, and manufactured sand on 1:3 and 1:4 cement mortar mixes exposed to elevated temperatures (27 °C, 200 °C, 400 °C, 600 °C) [30][15].

Addressing this gap is essential to develop mix designs that can retain strength and integrity in fire-prone or high-temperature environments [32,33]. This study therefore focuses on quantifying the mechanical performance (compressive and flexural strength) of fiber-reinforced mortars made with fly ash and manufactured sand when subjected to elevated temperatures, providing insights into the design of sustainable, thermally resilient mortars [31][18][23].

3. MATERIALS AND MIX DESIGN

The materials used in the present study were: Class F fly ash, used as 20% partial replacement by weight of cement [18][30]; fine aggregates composed of river sand and M-sand (manufactured sand) [24][15]; Recron polypropylene fibers added at 0.25% by weight of cement [21][29]; and Ordinary Portland Cement (OPC) of 43 grade in accordance with IS 269:2015 [14][27]. Potable water was used for blending and curing [22].

Two mortar mix ratios—1:3 and 1:4 (Cement: Sand)—were taken under consideration [16][25]. Twelve different combinations were made, cast, and tested for each ratio in accordance with IS 2250:1981 to evaluate their mechanical performance [19][28]. Throughout the experiment, the ratio of water to cement was maintained at a constant 0.5 [17][31]. The mix ratios of the mortar samples are specified as follows:

Table 1 Mix Proportions for 1:3 Cement mortar mix

Mix1	30% Cement + 70% River sand
Mix2	30% Cement + 70% River sand + 0.25%PPF

Mix3	24% Cement + 6% Fly ash + 80% River sand
Mix4	24% Cement + 6% Fly ash+70% River sand+ 0.25%PPF
Mix5	30% Cement + 70% M-sand
Mix6	30% Cement +70 % M sand + 0.25%PPF
Mix7	24% Cement + 6% Fly ash + 70% M sand
Mix8	24% Cement + 6% Fly ash + 70% M sand + 0.25%PPF
Mix9	30% Cement + 35% M-sand+ 35% River sand
Mix10	30% Cement + 35% River sand + 35% M sand+0.25%PPF
Mix11	24% Cement + 6% Fly ash + 35% River sand + 35% M sand
Mix12	24% Cement + 6% Fly ash + 35% River sand + 35% M sand +0.25 PPF

Table 2 Mix Proportions for 1:4 Cement mortar mix

MIXES	**COMBINATIONS**
MIX-1	20%Cement+80%River sand
MIX-2	20%Cement+80%River sand+0.25%PPF
MIX-3	16%Cement+4% Fly ash+80% River sand
MIX-4	16 %Cement+4% Fly ash + 80% River sand+0.25%PPF
MIX-5	20%Cement+80% M-Sand
MIX-6	20%Cement+80%Msand+0.25%PPF
MIX-7	16%Cement+4% Fly ash + 80% M Sand
MIX-8	16%Cement+4%Flyash+80% M-sand+0.25%PPF
MIX-9	20%Cement+40% River sand+40%M-sand
MIX-10	20% Cement +40% river Sand+ 40% M-sand + 0.25% PPF
MIX-11	16% Cement +4% Fly ash + 40% River sand + 40% M Sand
MIX-12	16%Cement+4%Flyash+40% River Sand + 40%Msand + 0.25% PPF

4. METHODOLOGY

4.1 Compressive Strength

For the determination of compressive strength, mortar cubes of size 70.6 × 70.6 × 70.6 mm were prepared [15]. The dry components—Ordinary Portland Cement, Class F fly ash, river sand, manufactured sand, and Recron polypropylene fibers—were thoroughly mixed in accordance with the specified mix proportions to achieve a consistent blend [24][18]. Potable water was then gradually added while maintaining a constant water-to-cement ratio, and the materials were mixed until a uniform, workable mortar was obtained [19][30].

The fresh mortar was placed in pre-oiled steel cube moulds in three equal layers. Each layer was compacted using a tamping rod to remove air voids and ensure proper densification [25][21]. Once filled, the moulds were leveled using a trowel and kept under ambient laboratory conditions for 24 hours to allow initial setting [27]. After this period, the specimens were carefully demoulded and submerged in a curing tank containing clean water at room temperature for 28 days, 56 days, and 90 days. The other specimens were kept in the furnace for 24 hours at elevated temperatures of 200 °C, 400 °C, and 600 °C [22][16][29].

Compressive strength tests were conducted at 28, 56, and 90 days of elevated curing using a calibrated Universal Testing Machine (UTM), following the procedure specified in IS 4031 [23][31]. Each specimen was centered on the machine's loading platform, and a steadily increasing compressive load was applied until failure [20][26]. The maximum load borne by the specimen was recorded, and compressive strength was calculated by dividing this failure load by the cube's cross-sectional area [13][28].

4.2 Flexural Strength

Flexural strength was determined using prismatic mortar specimens of size 160 × 40 × 40 mm, prepared similarly to the compressive strength samples [16][27]. The dry materials were mixed thoroughly to achieve uniformity, after which water was added to reach the desired workability [18][23]. The fresh mortar was filled into pre-oiled prism moulds in two layers, with each layer compacted using standard tamping to eliminate air voids [21][29]. The top surface was leveled with a trowel, and the specimens were left undisturbed for 24 hours at room temperature [25][17].

After demoulding, the prisms were cured in water until testing at 28, 56, and 90 days. The other specimens were kept in the furnace for 24 hours at elevated temperatures of 200 °C, 400 °C, and 600 °C [20][30][15]. Flexural strength was evaluated using the three-point bending method as per IS 1607, with a Universal Testing Machine fitted with a flexural testing attachment [24][31]. The prisms were loaded at midspan until failure, and the maximum load was recorded to calculate the modulus of rupture using the standard formula [13][26].

5. RESULTS AND DISCUSSIONS

a. Compression test

Table 3 Compressive strength for 1:3 Cement mortar mix for 28 Days

Compressive Strength				
1:3				
	27°C	**200°C**	**400°C**	**600°C**
Mix 1	44.91	45.69	47.30	38.10
Mix 2	46.66	47.73	49.13	39.55
Mix 3	45.15	46.28	47.54	38.27
Mix 4	47.19	48.44	49.69	40.00
Mix 5	44.06	45.26	46.35	37.32
Mix 6	46.57	47.84	49.04	39.48
Mix 7	44.62	45.84	46.91	37.82
Mix 8	46.84	48.12	49.32	39.53
Mix 9	46.98	48.26	49.44	39.82
Mix 10	47.19	48.48	49.69	40.00
Mix 11	47.56	48.82	50.08	40.31
Mix 12	48.15	49.48	50.60	40.65

From table 3, The compressive strength of Mix 12 rose little from 48.15 MPa at 27°C to 50.60 MPa at 400°C, probably as a result of water evaporation and pozzolanic reactions. The strength was greatly reduced to 40.65 MPa at 600°C, a 15.6% drop brought about by thermal degradation and microcracking. The combination exhibits adequate stability up to 400°C, but its durability decreases at higher temperatures. This indicates that it can tolerate moderate heat exposure but not severe thermal conditions [34,35]

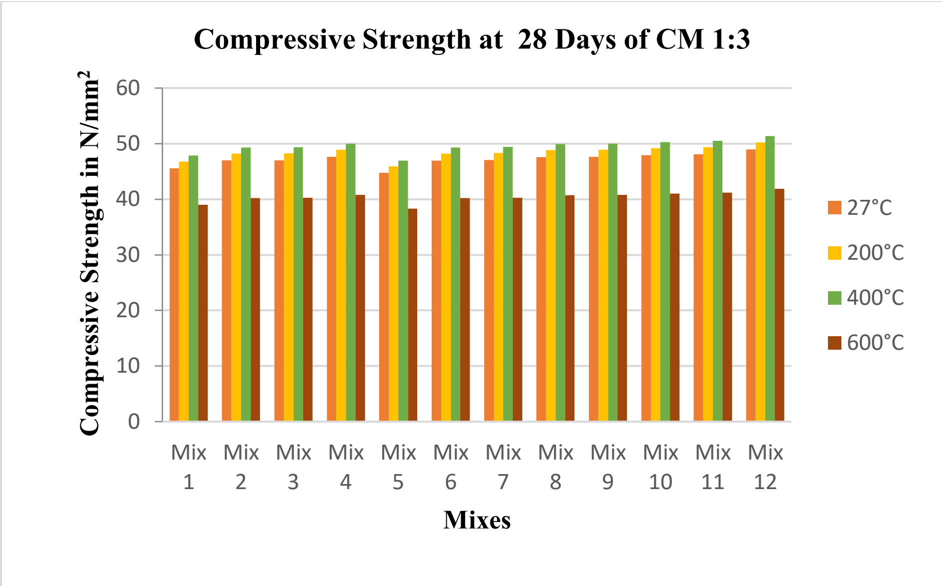

Fig. 1 Elevated Compressive strength at 28 days for different mixes for 1:3

Table 4 Compressive strength for 1:3 Cement mortar mix for 56 Days

Compressive Strength				
1:3				
	27°C	200°C	400°C	600°C
Mix 1	45.57	46.78	47.84	39.03
Mix 2	46.98	48.23	49.32	40.24
Mix 3	47.01	48.26	49.35	40.27
Mix 4	47.64	48.90	50.02	40.81
Mix 5	44.74	45.93	46.97	38.32
Mix 6	46.94	48.19	49.28	40.21
Mix 7	47.05	48.30	49.40	40.30
Mix 8	47.58	48.84	49.95	40.75
Mix 9	47.63	48.89	50.01	40.80
Mix 10	47.90	49.17	50.29	41.03
Mix 11	48.11	49.39	50.51	41.21
Mix 12	48.93	50.23	51.37	41.91

From table.4, The compressive strength of Mix 12 increases steadily from ambient temperature (27°C) to 200°C, reaching its highest value at 400°C. This improvement is mainly due to ongoing hydration and pozzolanic reactions, along with moisture evaporation, which together densify the mortar matrix. However, at 600°C, the strength declines sharply to 41.91 MPa, representing an 18.4% decrease from the peak at 400°C. This reduction is primarily caused by the thermal breakdown of cementitious materials, degradation of polypropylene fibers, and the development of microcracks, all of which weaken the structural integrity of the mortar.

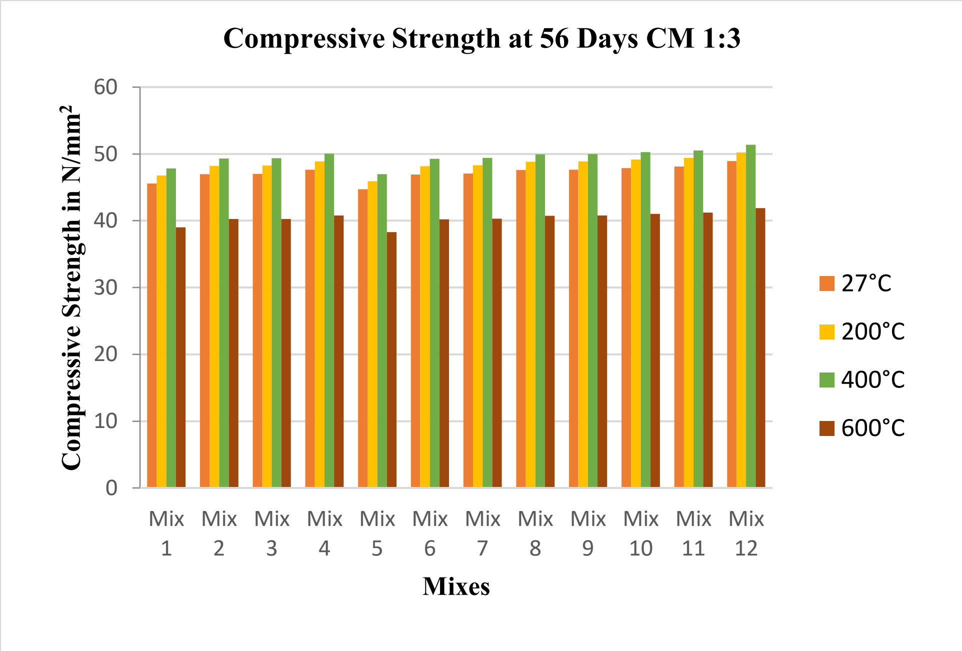

Fig. 2 Elevated Compressive strength at 56 days for different mixes for 1:3

Table 5 Compressive strength for 1:4 Cement mortar mix for 28 Days

Compressive Strength				
1:4				
	27ºC	200ºC	400ºC	600ºC
Mix 1	41.89	42.85	43.84	32.45
Mix 2	43.47	44.46	45.49	33.67
Mix 3	42.31	43.28	44.28	32.78
Mix 4	44.03	45.03	46.08	34.11
Mix 5	41.22	42.16	43.14	31.93
Mix 6	43.24	44.23	45.25	33.50
Mix 7	41.62	42.57	43.56	32.24
Mix 8	43.78	44.78	45.82	33.91
Mix 9	43.99	44.99	46.04	34.08
Mix 10	44.26	45.27	46.32	34.29
Mix 11	44.81	45.83	46.89	34.71
Mix 12	45.06	46.09	47.16	34.91

From table 5, Mix 12 (1:4 mortar) showed increased compressive strength from 45.06 MPa at 27°C to 47.16 MPa at 400°C due to matrix densification and continued hydration.At 600°C, strength dropped to 34.91 MPa, a 25.9% reduction from the peak value.This decline is attributed to thermal degradation and microcrack formation in the matrix.Thus, Mix 12 performs well up to 400°C but loses strength significantly at higher temperatures.

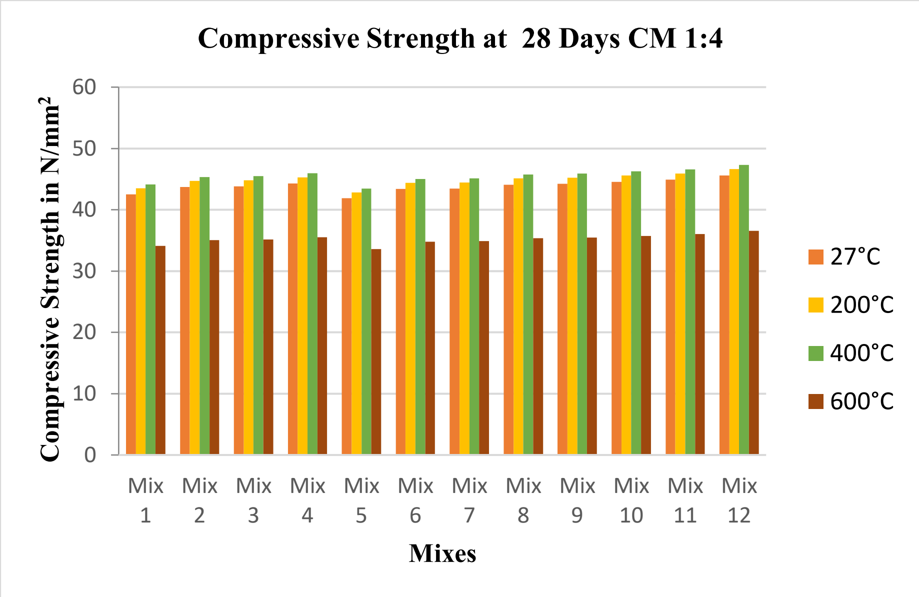

Fig. 3 Elevated Compressive strength at 28 days for different mixes for 1:4

Table 6 Compressive strength for 1:4 Cement mortar mix for 56 Days

Compressive Strength				
1:4				
	27°C	200°C	400°C	600°C
Mix 1	42.52	43.50	44.14	34.12
Mix 2	43.69	44.70	45.36	35.06
Mix 3	43.81	44.82	45.48	35.15
Mix 4	44.28	45.30	45.97	35.53
Mix 5	41.87	42.84	43.47	33.60
Mix 6	43.38	44.38	45.03	34.81
Mix 7	43.46	44.46	45.12	34.87
Mix 8	44.09	45.11	45.77	35.38
Mix 9	44.23	45.25	45.92	35.49
Mix 10	44.55	45.58	46.25	35.75
Mix 11	44.89	45.93	46.60	36.02
Mix 12	45.57	46.62	47.31	36.57

Mix 12 (1:4 mortar) showed increased compressive strength from 45.57 MPa at 27°C to 47.31 MPa at 400°C due to matrix densification and continued hydration. At 600°C, the strength dropped to 36.57 MPa, a 22.7% reduction from its peak.This decrease is caused by thermal degradation and microcrack formation.The mix performs well up to 400°C but loses structural integrity at higher temperatures.

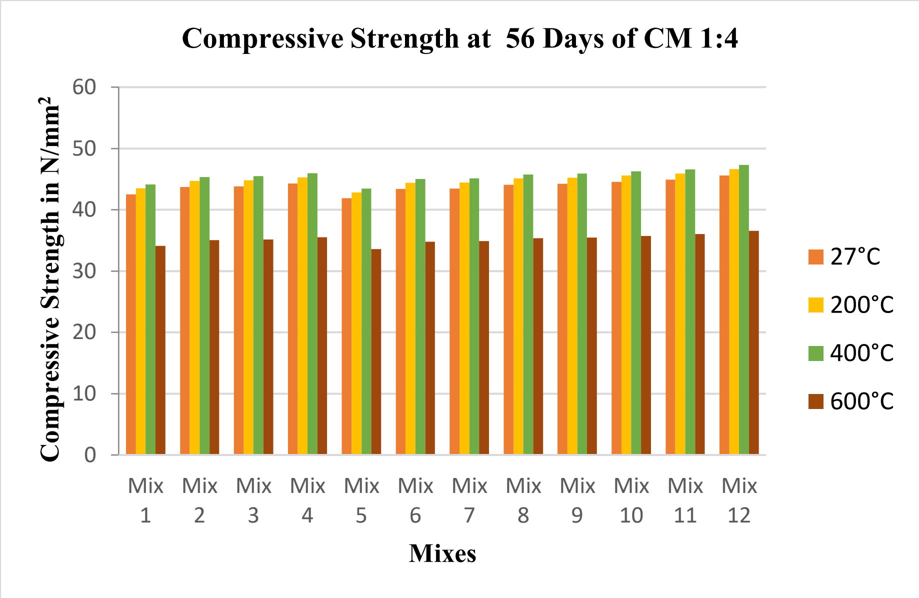

Fig. 4 Elevated Compressive strength at 56 days for different mixes for 1:4

b. Flexural test

Table 7 Flexural strength for 1:3 Cement mortar mix for 28 Days

Flexural Strength				
1:3				
	27°C	200°C	400°C	600°C
Mix 1	8.27	8.48	8.52	6.44
Mix 2	8.59	8.80	9.02	6.77
Mix 3	8.32	8.53	8.73	6.48
Mix 4	8.69	8.91	9.15	6.87
Mix 5	8.12	8.32	8.41	6.29
Mix 6	8.55	8.76	8.66	6.73
Mix 7	8.22	8.43	8.51	6.42
Mix 8	8.63	8.85	9.01	6.82
Mix 9	8.73	8.95	9.12	6.93
Mix 10	8.78	9.00	9.19	6.68
Mix 11	8.81	9.03	9.22	6.86
Mix 12	9.05	9.28	9.51	7.06

Mix 12 exhibited a progressive increase in flexural strength from 9.05 MPa at 27°C to 9.51 MPa at 400°C, indicating enhanced matrix cohesion and fiber-matrix interaction under moderate heat. At 600°C, strength decreased to 7.06 MPa, reflecting a 25.8% reduction due to thermal degradation and microcracking. The results suggest good flexural performance up to 400°C, with significant deterioration beyond this temperature. Overall, Mix 12 demonstrates limited durability under high-temperature exposure

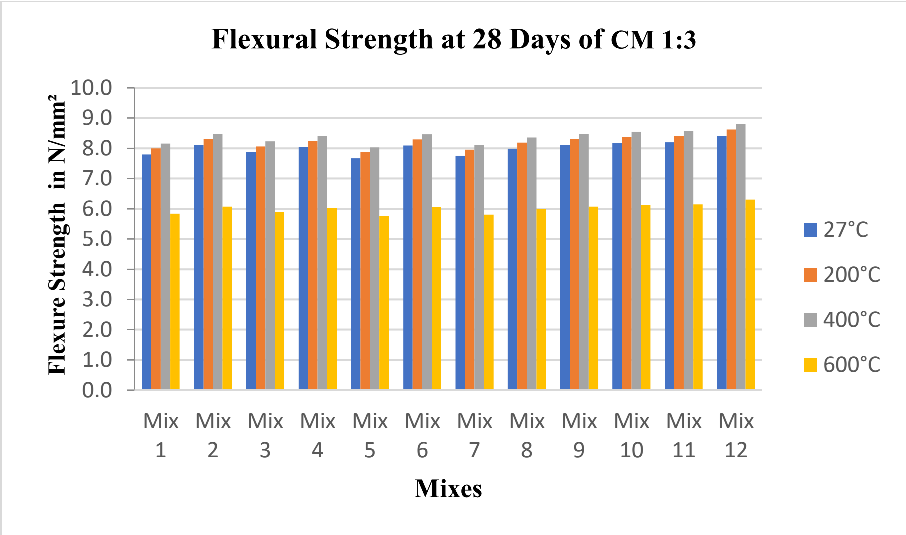

Fig. 5 Elevated flexural strength at 28 days for different mixes for 1:3

Table 8 Flexural strength for 1:3 Cement mortar mix for 56 Days

Flexural Strength				
1:3				
	27°C	**200°C**	**400°C**	**600°C**
Mix 1	8.40	8.53	8.67	6.90
Mix 2	8.53	8.66	8.80	7.01
Mix 3	8.66	8.79	8.93	7.11
Mix 4	8.83	8.97	9.11	7.25
Mix 5	8.25	8.38	8.51	6.78
Mix 6	8.49	8.62	8.76	6.97
Mix 7	8.59	8.72	8.87	7.06
Mix 8	8.78	8.91	9.06	7.21
Mix 9	8.87	9.01	9.15	7.29
Mix 10	8.92	9.06	9.21	7.33
Mix 11	9.01	9.15	9.30	7.40
Mix 12	9.20	9.34	9.59	7.55

Mix 12 showed a consistent increase in flexural strength from 9.20 MPa at 27°C to 9.59 MPa at 400°C, indicating improved matrix bonding and fiber reinforcement under moderate heat. At 600°C, the strength decreased to 7.55 MPa, reflecting a 21.3% reduction due to thermal degradation and microstructural damage. This behavior highlights good flexural resilience up to 400°C, with notable strength loss at higher temperatures. Overall, Mix 12 demonstrates limited high-temperature durability but strong performance under moderate thermal exposure.

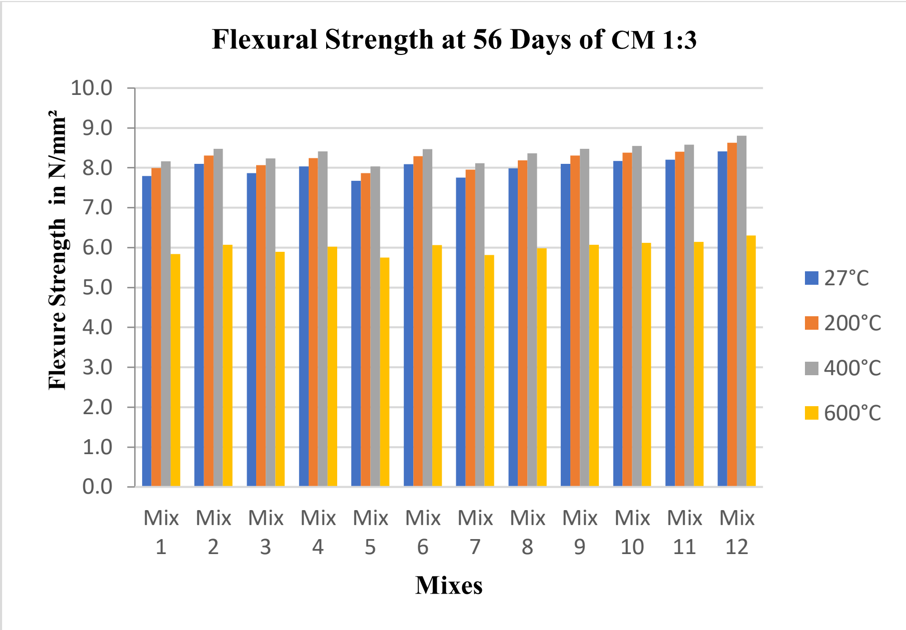

Fig. 6 Elevated flexural strength at 56 days for different mixes for 1:3

Table 9 Flexural strength for 1:4 Cement mortar mix for 28 Days

Flexural Strength				
1:4				
	27°C	200°C	400°C	600°C
Mix 1	7.72	7.96	8.12	5.63
Mix 2	8.02	8.27	8.44	5.90
Mix 3	7.79	8.03	8.19	5.72
Mix 4	7.96	8.21	8.37	5.88
Mix 5	7.60	7.84	7.99	5.64
Mix 6	8.01	8.26	8.43	5.95
Mix 7	7.68	7.92	8.08	5.58
Mix 8	7.91	8.16	8.32	5.87
Mix 9	8.02	8.27	8.44	5.95
Mix 10	8.09	8.34	8.51	6.01
Mix 11	8.12	8.37	8.54	6.03
Mix 12	8.33	8.59	8.76	6.21

Mix 12 exhibited a steady increase in flexural strength from 8.33 MPa at 27°C to 8.76 MPa at 400°C, indicating improved microstructural bonding and enhanced fiber-matrix interaction under moderate heat exposure. At 600°C, the strength declined to 6.21 MPa, reflecting a 29.1% reduction due to thermal decomposition and microcrack formation. This suggests that while Mix 12 maintains good flexural performance up to 400°C, its structural integrity is compromised at elevated temperatures. Overall, Mix 12 shows limited thermal resilience beyond moderate heating.

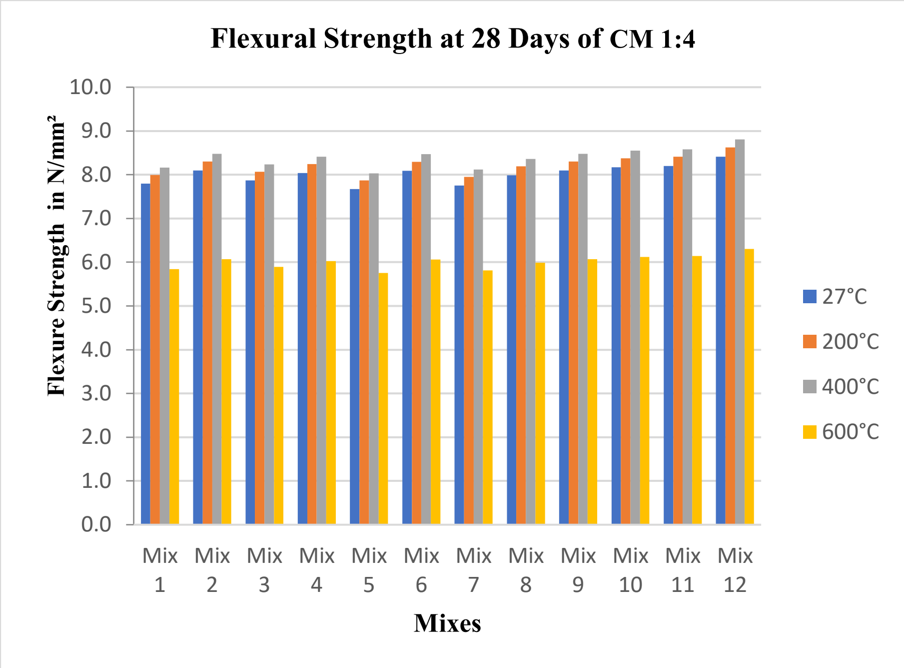

Fig. 7 Elevated flexural strength at 28 days for different mixes for 1:4

Table 10 Flexural strength for 1:4 Cement mortar mix for 56 Days

Flexural Strength				
1:4				
	27°C	200°C	400°C	600°C
Mix 1	7.80	7.99	8.16	5.84
Mix 2	8.10	8.30	8.48	6.07
Mix 3	7.87	8.07	8.23	5.89
Mix 4	8.04	8.24	8.41	6.02
Mix 5	7.68	7.87	8.03	5.75
Mix 6	8.09	8.29	8.47	6.06
Mix 7	7.76	7.95	8.12	5.81
Mix 8	7.99	8.19	8.36	5.99
Mix 9	8.10	8.30	8.48	6.07
Mix 10	8.17	8.38	8.55	6.12
Mix 11	8.20	8.41	8.58	6.14
Mix 12	8.41	8.63	8.80	6.30

Mix 12 showed a gradual increase in flexural strength from 8.41 MPa at 27°C to 8.80 MPa at 400°C, indicating enhanced matrix cohesion and effective fiber reinforcement under moderate heating. At 600°C, the strength decreased to 6.30 MPa, representing a 28.4% reduction due to thermal degradation and microstructural damage. These results demonstrate that Mix 12 retains good flexural performance up to 400°C but experiences significant strength loss at higher temperatures, limiting its suitability for high-temperature applications.

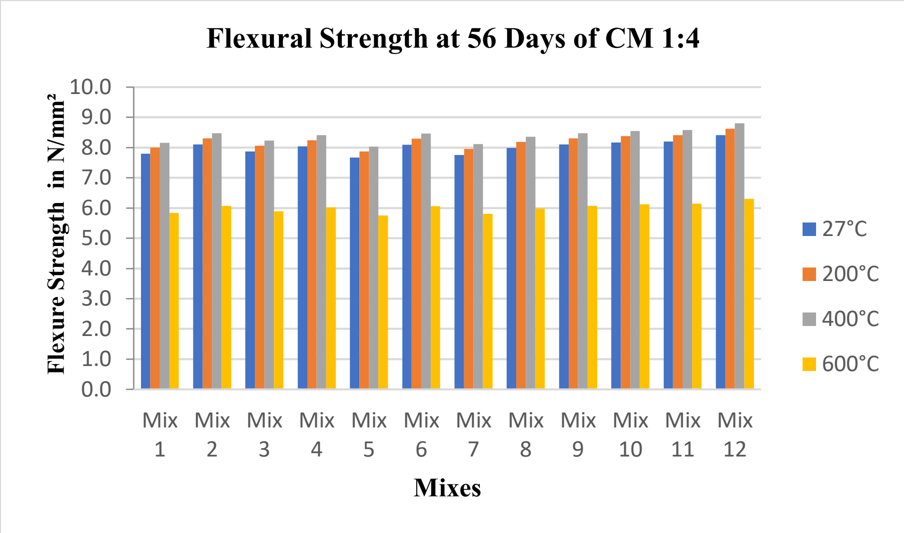

Fig. 8 Elevated flexural strength at 56 days for different mixes for 1:4

6. CONCLUSIONS

This study investigated the thermal performance of sustainable fiber-reinforced cement mortars incorporating Class F fly ash, manufactured sand (Msand), and polypropylene fibers, with two mix ratios (1:3 and 1:4) exposed to elevated temperatures of 200°C, 400°C, and 600°C. Mechanical properties were assessed through compressive and flexural strength tests at 28 and 56 days of curing. Among the 12 mix variants, Mix 12—comprising fly ash, river sand, Msand, and 0.25% polypropylene fibers—consistently outperformed the control mixes. It demonstrated a notable increase in strength up to 400°C, attributed to pozzolanic reactions, improved particle packing, and fiber-induced crack resistance. Compressive strength peaked at 50.60 MPa (1:3) and 47.16 MPa (1:4), while flexural strength also showed enhanced retention, indicating improved thermal stability and matrix integrity under moderate heat exposure.At 600°C, all mixes experienced a decline in mechanical performance, with Mix 12 showing a 15–29% reduction from peak values. This loss is linked to microcracking, thermal degradation of the cement matrix, and fiber melting. Despite this, fiber-reinforced mixes still outperformed conventional mortars, underscoring their relative resilience. In summary, the combined use of fly ash, River sand, M sand, and polypropylene fibers enhances both ambient and elevated temperature performance of cement mortars, particularly up to 400°C. These findings support the development of fire-resilient, sustainable mortar systems. Further research is recommended to explore hybrid fiber systems, microstructural behavior, and long-term durability under thermal cycling.

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