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Thermal Properties of Concrete Prepared with Water Absorbing Beads

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Abstract:

Heat islands and extreme weather changes are the major problems faced in urban areas. The usage of water absorbing beads in concrete enhances its thermal properties. Water absorbing beads are the superabsorbent polymers that can absorb and retain water hundreds of times of their masses. In this research, six concrete mixes containing 180 nos. of concrete cube specimens of size 150mm were prepared using water absorbing beads as a replacement of aggregates by volume. Water absorbing beads submerged in water for 24 hours were used to prepare concrete mixes. Percentage of replacement of aggregates by volume of water absorbing beads were kept as 0%, 4%, 8%, 12%, 16% and 20% in mixes C, B1, B2, B3, B4 and B5 respectively. All in aggregate of 20mm nominal size as per table 10 of Indian standard IS 383: 2016 was used. M30 mix was used to prepare control mix designated as "C". Specimens were tested for compressive and split tensile strength at curing age of 7 days, 28 days, 56 days and 120 days. Temperature absorption pattern of concrete prepared with water absorbing beads under direct sunlight was observed for the specimens after curing age of 120 days. Mass of concrete cubes were also noted. It was observed that the lightweight concrete was obtained with the use of water absorbing beads in concrete. Testing results show that the use of water absorbing beads in concrete reduces its compressive and tensile strength with improvement in thermal properties of concrete which is beneficial to control the surface temperature of concrete in extreme hot and cold weather. At last, we can say that the use of water absorbing beads in concrete improves sustainability and thermal comfort of the buildings.

Keywords: superabsorbent, sustainability, aggregates.

1. Introduction

The phenomenon of urbanization is increasing at the global level, and this leads to an increase in population density and changes in the use of land. A major side effect of this shift is the formation and worsening of the urban heat islands (UHIs). On the latter, numerical modelling was employed to investigate the spatiotemporal dynamics of the UHIs in the cities of Greater Cairo, Alexandria, and Suez in Egypt, with a focus on the impacts of construction materials on UHI development. The use of such materials results in the generation of the UHIs because they accumulate and reinject heat energy (Ziaeemehr et al., 2023; Carpio et al., 2020). In addition to temperature changes, severe weather events, including heat waves and cold spells, affect the resilience and usability of urban infrastructure (Nakayama and Fujita, 2010; Mohajerani et al., 2017). Owing to these challenges, the thermal efficiency of concrete structures has become an important subject of research interest to researchers, urban planners, and construction personnel.

In the recent past, a number of innovative solutions have been proposed to solve the thermal problems. Porous and pervious concretes have been studied to decrease surface temperatures by increasing the porosity and thus the water infiltration and evaporation rates (Marinelli and Rasheed, 2024, Latif et al., 2023, Yang et al., 2022). The use of lightweight aggregates such as pumice, expanded polystyrene (EPS) and waste tire rubber reduces the density and the thermal conductivity therefore reducing the heat gain while at the same time contributing to waste management (Deng et al., 2024, Shabbar et al., 2024, Momeen et al., 2023). Superabsorbent Polymers (SAP) have also been incorporated into the concrete to store and release heat or moisture according to their phase change temperatures, thereby decreasing the amplitude of temperature fluctuations within the concrete matrix (Lee and Park, 2024; Shah et al., 2018). These approaches underscore a broader industry shift toward materials that not only provide necessary mechanical performance but also deliver enhanced thermal regulation and sustainability benefits (Qin, 2015; Taleghani, 2018).

Nevertheless, the main problem has not been solved; the problem of the optimal combination of mechanical properties and thermal characteristics of the structures remains actual. A number of lightweight or porous mixtures, which are characterized by low compressive and tensile strength, are unacceptable for many applications that require high load bearing capacity (Marinelli and Rasheed, 2024; Canbaz and Türeyen, 2022). In addition, some high albedo or evaporative pavements, for instance, have been found to reduce the surface temperatures during the day, but they may lead to increased night time heating or poor thermal comfort for pedestrians (Qin and Hiller, 2014; Takebayashi and Moriyama, 2009). Hence, the search for more integrated approaches that can address these competing effects while enhancing resource productivity and environmental sustainability continues (Kumar et al., 2022; Oktay et al., 2015).

At the moment, there is an increasing focus on water-absorbing beads, a type of superabsorbent polymer, which can potentially enhance the thermal behavior of concrete. When pre-soaked and embedded in the concrete mixture, these beads can slowly release the moisture that they have retained, thus creating an evaporative cooling effect that decreases the surface temperatures (Lee and Park, 2024; Shah et al., 2018). Besides the regulation of temperature, the use of SAP also appears to have the potential to decrease microcracking through preventing self-desiccation in more compact mixes with lower water-cement ratios (Shafigh et al., 2018). Nevertheless, the consequences for the compressive and tensile strengths and, in particular, the consequences of substituting larger volumes of aggregates are not yet fully understood. Some research indicates that there is a significant decrease in mechanical performance with rising SAP concentrations, which highlights the importance of mix design optimization (Canbaz and Türeyen, 2022).

Against this background, the present research investigates the use of water absorbing beads on the mechanical and thermal properties of M30 grade concrete. The study systematically evaluates compressive and tensile strength losses against improvements in temperature absorption and thermal comfort by replacing aggregates volumetrically with these beads at varying percentages (0%, 4%, 8%, 12%, 16%, and 20%). To capture short and long-term performance characteristics, 180 concrete cube specimens were produced and tested at multiple curing ages (7, 28, 56 and 120 days). In direct sunlight after the 120-day curing period, temperature absorption patterns were also measured, which helped to complement mass and strength evaluations to give a fuller picture of how the beads are affecting concrete density, insulation properties, and sustainability. This work is an extension of superabsorbent polymers used as a partial aggregate replacement to reconcile lower thermal conductivity with acceptable structural performance. The findings of the study have direct implications for designing lightweight, thermally optimized concrete, which is particularly beneficial in regions suffering from extreme heat or cold. In the end, the research demonstrates the feasibility of incorporating water absorbing beads into concrete not only to improve sustainability and occupant thermal comfort, but also to create a foundation for new standards of climate resilient urban infrastructure.

2. Materials and Methods

2.1 Materials

- **Cement:** Portland Pozzolana Cement of grade 43.
- **Aggregates:** All in aggregate of 20mm nominal size as per table 10 of IS 383: 2016 was used in the study. 50% of particles retained on 4.75mm sieve plus 50% of particles finer than 4.75mm IS sieve was used in the study
- **Water-Absorbing Beads:** Superabsorbent polymer (SAP) beads with a particle size of 1mm expended to 12mm after soaking was used in the study.
- **Water:** Potable water fit for drinking was used.

2.2 Mix Design

- Six concrete mixes were prepared, designated as C (0% beads), B1 (4% beads), B2 (8% beads), B3 (12% beads), B4 (16% beads), and B5 (20% beads).
- The M30 mix design was used for the control mix (C).
- Water-absorbing beads were submerged in water for 24 hours before mixing

2.3 Specimen Preparation

- A total of 306 concrete cube specimens (150 mm × 150 mm × 150 mm) were casted.
- Specimens were cured for 7, 28, 56, and 120 days.

2.4 Testing Methods

- **Compressive Strength:** Six cube samples of size 150mm x 150mm x 150mm were tested for determination of compressive strength at curing age of 7, 28, 56, and 120 days as per IS 516:1959 for each mix.
- **Split Tensile Strength:** Six cube samples of size 150mm x 150mm x 150mm were tested for determination of split tensile strength at curing age of 7, 28, 56, and 120 days as per IS 5816:1999 for each mix.

- **Surface Temperature Absorption:** Measured using Laser/infrared thermometer under direct sunlight after 90 days of curing. Three cube samples of size 150mm x 150mm x 150mm from each mix was tested after 120 days of curing age.
- **Unit Weight:** Measured using the density method at 28 days of curing.

3. Results and Discussion

It was found that the strength properties of the concrete mixes reduced with an increasing percentage of beads. Compressive and tensile strengths decreased as the bead content increased, attributed to reduced aggregate interlocking.

3.1 Compressive Strength

The compressive strength results are presented in Table 1 and Figure 1. Figure 2 shows the reduction in compressive strength with addition of water absorbing beads at 28 days curing age.

Table 1: Compressive Strength of Concrete Mixes at Different Curing Ages

Mix	7 Days (MPa)	28 Days (MPa)	56 Days (MPa)	120 Days (MPa)
C	22.53	34.87	36.24	37.38
B1	21.86	33.55	35.01	36.23
B2	20.55	31.23	32.84	33.95
B3	19.08	29.08	31.37	33.15
B4	17.53	26.88	28.98	30.27
B5	15.81	25.53	27.51	29.38

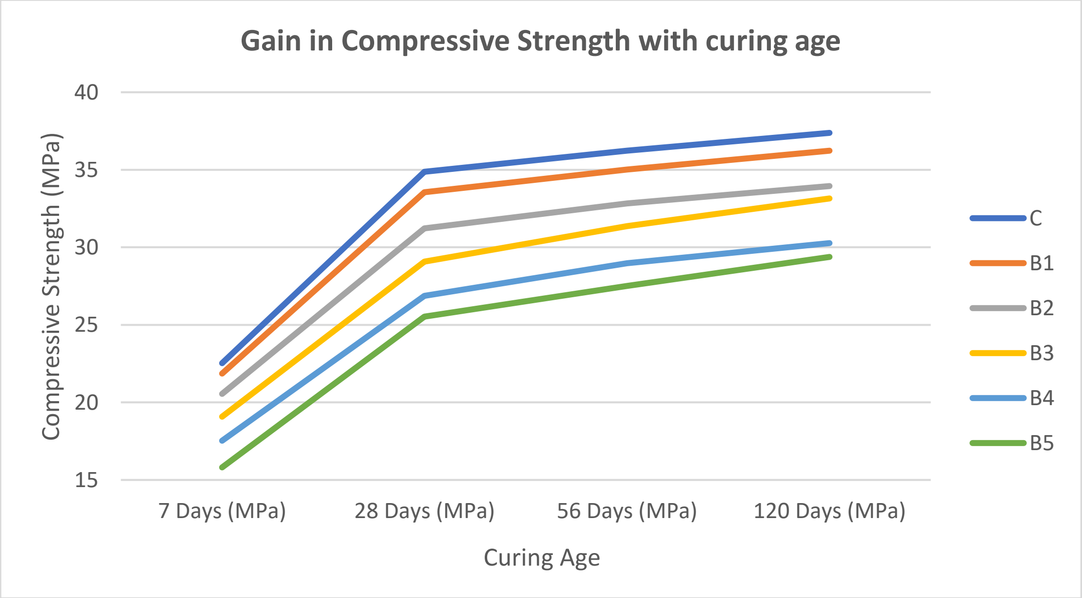

Figure 1: Compressive Strength vs. Curing Age

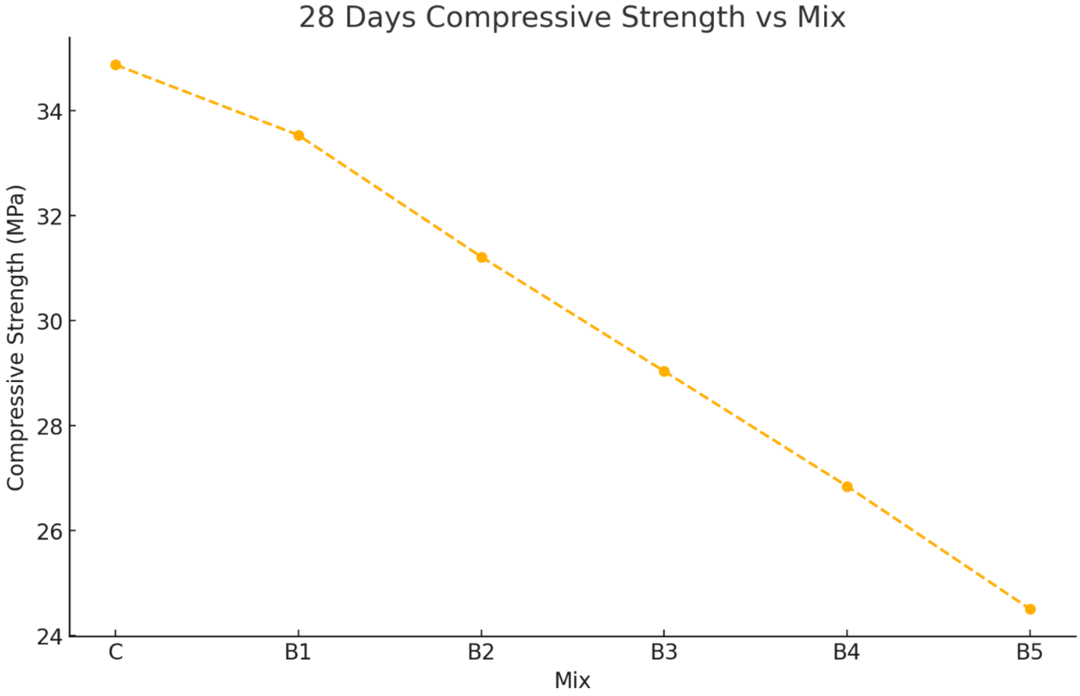

Figure 2 Reduction in compressive strength with addition of water absorbing beads at 28 days curing age.

The compressive strength decreased with an increase in the percentage of water-absorbing beads. At 20% replacement (B5), the compressive strength at 120 days was 29.38 MPa, a 21.40% reduction compared to the control mix (C).

3.2 Split Tensile Strength

The split tensile strength results are presented in Table 2 and Figure 3. Figure 4 shows the reduction in split tensile strength with addition of water absorbing beads at 28 days curing age.

Table 2: Split Tensile Strength of Concrete Mixes at Different Curing Ages

Mix	**7 Days (MPa)**	**28 Days (MPa)**	**56 Days (MPa)**	**120 Days (MPa)**
C	2.81	3.58	3.78	3.85
B1	2.74	3.46	3.65	3.77
B2	2.53	3.28	3.48	3.53
B3	2.33	3.01	3.21	3.38
B4	2.02	2.96	3.05	3.19
B5	1.81	2.64	2.71	2.80

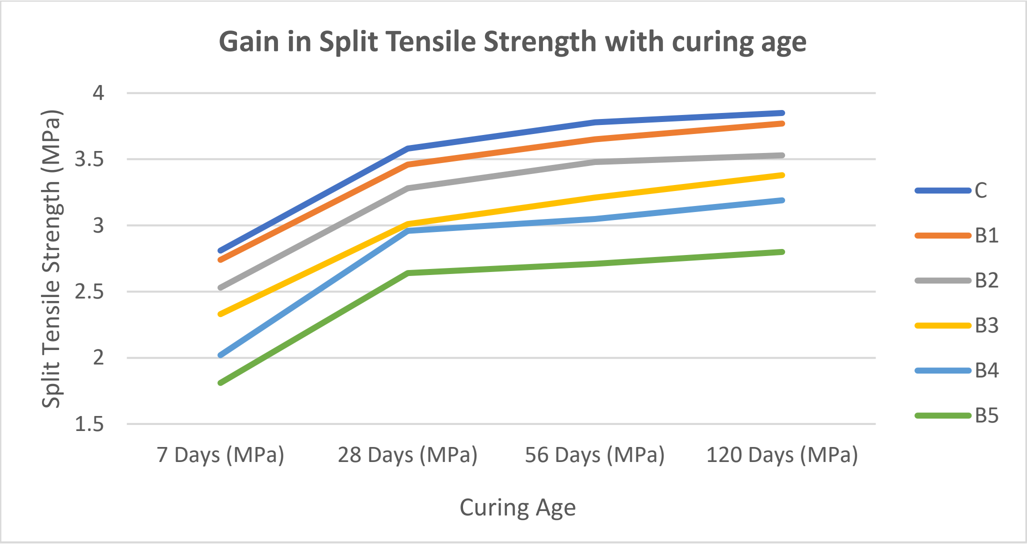

Figure 3: Split Tensile Strength vs. Curing Age

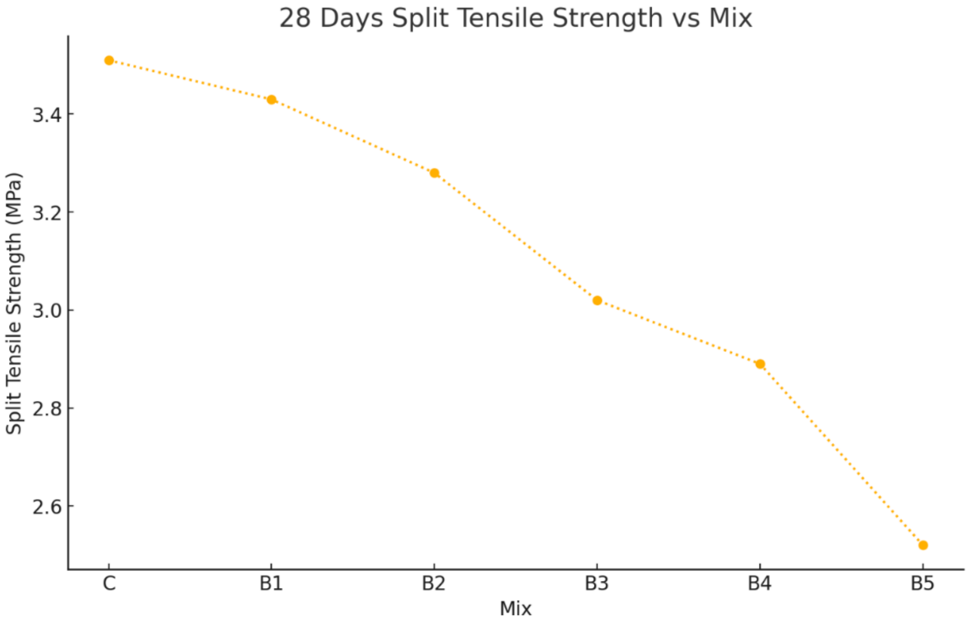

Figure 4 Reduction in split tensile strength with addition of water absorbing beads at 28 days curing age.

Similar to compressive strength, the split tensile strength decreased with an increase in bead content. At 20% replacement (B5), the split tensile strength at 120 days was 2.80 MPa, a 27.27% reduction compared to the control mix (C).

3.3 Unit Weight

The unit weight results are presented in Table 4 and Figure 5. The replacement of aggregates with water-absorbing beads resulted in a reduction in unit weight, indicating the formation of lightweight concrete.

Table 4: Unit Weight of Concrete Mixes

Mix	C	B1	B2	B3	B4	B5
Bead Replacement (%)	0	4	8	12	16	20
Unit Weight (kg/m³)	2400	2343	2287	2230	2174	2118

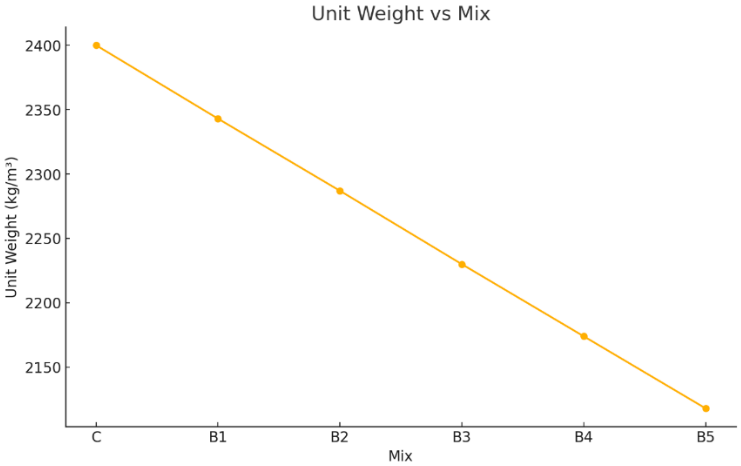

Figure 4: Unit Weight vs. Bead Replacement Percentage

This plot shows the reduction in unit weight with increasing percentages of water-absorbing beads in the concrete mix. The unit weight of concrete decreased linearly with the increase in bead content. At 20% replacement (B5), the unit weight was 2118 kg/m³, a 11.75% reduction compared to the control mix (C).

3.4 Thermal Performance

Surface temperatures of the mixes under direct sunlight were observed under different environmental conditions. The temperature absorption results for all the mixes are shown in Figure 5. It was observed that the bead content improved thermal resistance, reducing surface temperature.

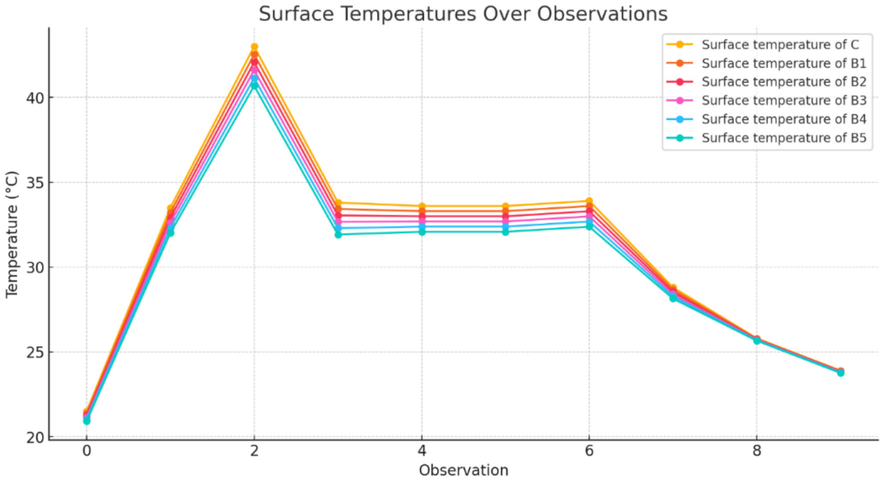

Figure 5: Surface Temperature of Concrete Specimens Under Direct Sunlight

As seen from above line chart of temperatures, all surface temperatures (C, B1 to B5) exhibit a similar trend across observations and reflecting a strong correlation. The temperatures decrease progressively from C to B5, indicating a spatial or layered relationship. Average reduction in surface temperature per 4% replacement ranges from -0.028°C (low environmental temps) to -0.464°C (high environmental temps).

Figure 6 shows scatter plot between environment temperature and surface temperature of mix 'C'. A positive correlation exists between the environment temperature and the surface temperature of C. As the environment temperature increases, the surface temperature of C also rises. (e.g., 19°C → 21.5°C vs. 39.8°C → 33.9°C for 0% replacement).

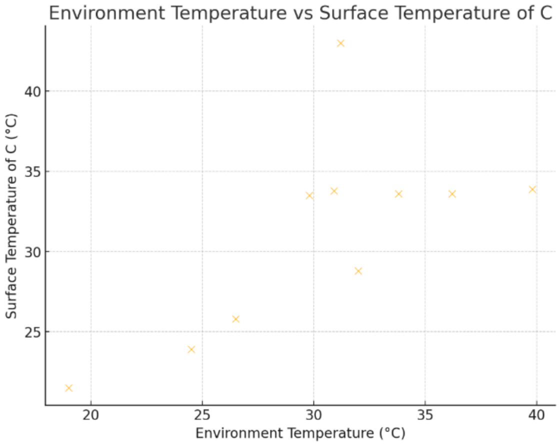

Figure 6: Environment Temperature Vs Surface Temperature of C

Figure 7 shows scatter plot between Humidity and surface temperature of mix 'C'. A negative relationship is visible, with surface temperature of C decreasing as humidity increases. Lower humidity amplifies the cooling effect of replacement materials.

For example:

At 31.2°C, 47% humidity (Row 3): Slope = -0.464°C/4%.

At 32°C, 33% humidity (Row 8): Slope = -0.132°C/4%.

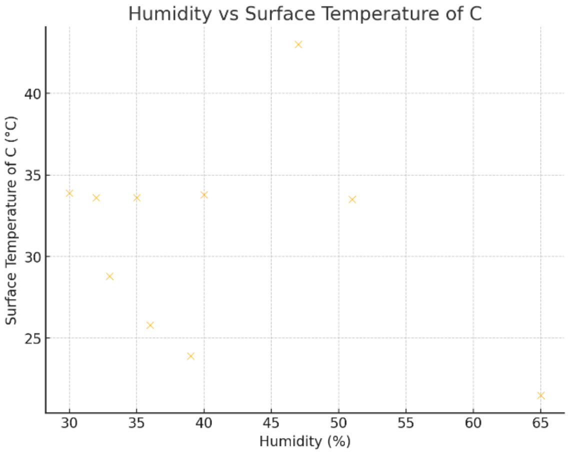

Figure 7: Humidity Vs Surface Temperature of C

Figure 8 shows correlation between surface temperature, environment temperature and humidity.

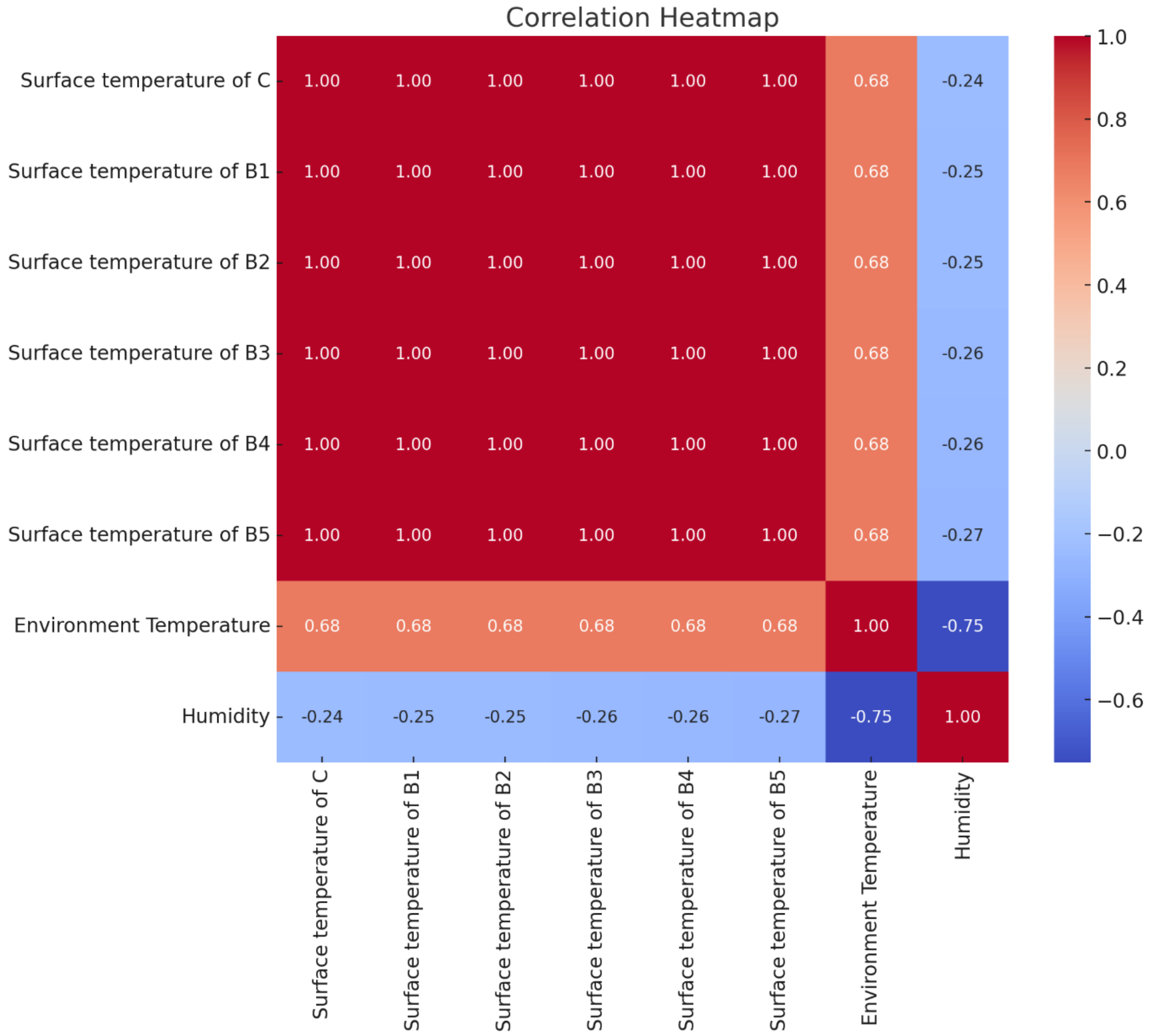

Figure 8 Correlation Heatmap

It is observed that surface temperatures (C, B1 to B5) are highly correlated (correlation values close to 1), confirming the trend observed in the line chart. Environment temperature has a moderate positive correlation (0.68) with surface temperatures. Humidity shows a negative correlation with surface temperatures and environment temperature, indicating lower humidity in warmer conditions. All the surface temperatures (C, B1-B5) are closely related, likely due to proximity or similar environmental influences showing strong correlation among surface temperatures. It is seen that the environment temperature's positively influences surface temperatures, aligning with expectations as external temperature affects surface readings. Humidity's plays negative correlation with temperatures, suggesting that higher humidity is associated with cooler surface and environmental conditions. The cooling effect of replacement materials is most effective in hot, dry environments (e.g., 31.2°C, 47% humidity). In cooler or more humid conditions (e.g., 24.5°C, 39% humidity), replacement materials have minimal impact on surface temperature.

5. Conclusion

The results demonstrate that the incorporation of water-absorbing beads in concrete reduces its compressive and tensile strength but significantly improves its thermal properties. The lightweight concrete produced with water-absorbing beads has a lower unit weight and surface temperature, making it suitable for applications in extreme weather conditions. The reduction in surface temperature can help mitigate heat island effects and improve the thermal comfort of buildings. This research demonstrates the potential of water-absorbing beads in enhancing the thermal properties of concrete while reducing weight. Although strength properties are slightly compromised, the improved thermal behavior and sustainability make this material suitable for specific applications in urban construction. Water-absorbing beads can be effectively used as a partial replacement for aggregates in concrete to improve its thermal properties. The optimal replacement percentage is 12%, providing a balance between thermal performance and mechanical strength. The use of water-absorbing beads in concrete contributes to sustainability and thermal comfort in urban areas.

6. Future Work

- Investigate the long-term durability and shrinkage properties of concrete with water-absorbing beads.
- Explore the use of beads in high-performance concrete and self-healing applications.
- Explore the use of water absorbing beads in agriculture sector. For example: for making esthetic pots and for improving yield in hot and cold climate.

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