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EXPERIMENTAL INVESTIGATION ON THERMAL PERFORMANCE OF CEMENT PLASTER INCORPORATING INSULATING MATERIALS

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ABSTRACT

Thermal insulation is a major contributor and obvious practical and logical first step towards achieving energy efficiency, especially the buildings located in sites with harsh climatic conditions. The aim of this project was to evaluate the performance of different thermal insulation materials in cement plaster. In this context, five cement mortar slab samples were prepared; one was considered as control sample, two samples incorporating jute fibre and two samples incorporating Super Absorption Polymer (SAP). At first, alkali treatment was performed for jute fibres and the properties of fibre were investigated. Jute fibre was used in mortar with 1% of cement by mass dosage. For SAP, absorption capacity was determined and used in mortar with a percentage of 0.1% of cement by mass. 90 gm/gm extra water was added during the preparation of mortar in case of sample with SAP. Three companion 2 inch mortar cubes were cast for each slab sample to determine the compressive strength of the corresponding batch of mortar. Finally the thermal performance of five samples were investigated in a small-scaled rectangular shape box which was divided into two compartments by the sample. Six temperature sensors were used during the tests to measure the temperature of two compartments of the box: heat source compartment and opposite compartment, and one sensor was used to measure the temperature of the atmosphere. All the sensors were connected with an open-source electronics platform Arduino to record the temperature over time. The temperature of the heat source compartment was kept constant at 60 ºC (±2 ºC) and the consequent temperature of the opposite compartment was measured during the tests. 60 ºC temperature was remained constant in the side of heat source. For control sample the temperature was recorded as 46 ºC, for jute fibre it was 44 ºC and 39 ºC for SAP sample at 7 days. For 28 days, the temperatures were varied 45 ºC, 45 ºC and 43 ºC for control sample, jute sample and SAP sample respectively. Thermal performances of mortar containing SAP were found out to be better than that of other two types of samples.

***Keywords**: Arduino, Jute fibre, Mortar, Super Absorbent Polymer, Thermal performance.*

1. INTRODUCTION

Construction industry is now-a-days moving towards more sustainable and energy efficient solution. However, global warming has been triggering more usage of air conditioning system in residential as well as office area (Mallik, 1996). Therefore, energy consumption has been grown largely over the years. In this context, an economical solution is necessary to maintain the temperature of habitational area comfortable. Many natural and artificial materials have been used as thermal insulator over the years (Al-homoud, 2005, Jelle et. al., 2012, Papadopoulos, 2005). Jute fibre and Super Absorbent Polymer can be regarded as natural and artificial material, respectively, having thermal insulation properties (Jin et. al., 2000). The main objectives of this study was to establish an experimental setup for measuring thermal performance of cement plaster and to determine the performance of cement plaster incorporating natural fibre (jute fibre) and Super Absorption Polymer (SAP). In this context, five cement mortar slab samples were prepared; one was considered as control sample, two samples incorporating jute fibre and two samples incorporating Super Absorption Polymer (SAP) to determine the thermal performance of mortar plaster.

2. METHODOLOGY

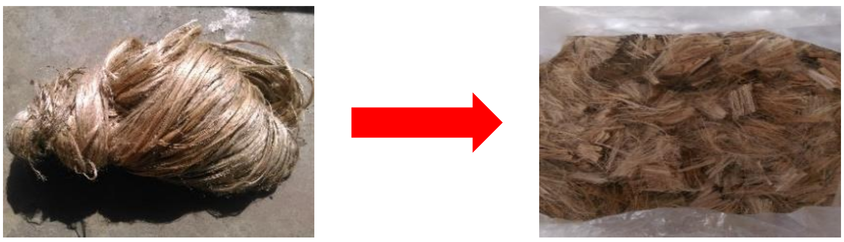
2.1 Insulating materials

2.1.1 Super Absorbent Polymer (SAP)

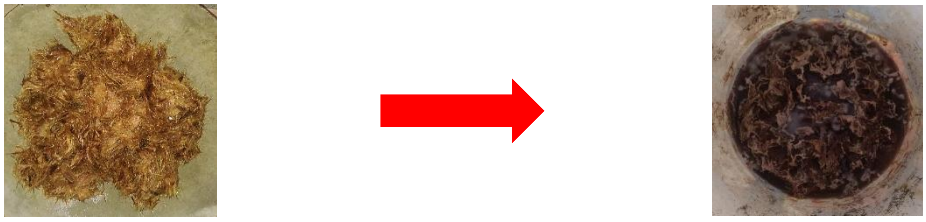
Super Absorbent Polymers are usually composed of ionic monomers and can absorb high amount of moisture using a low cross-linked density. They can absorb moisture up to several hundred times of its own weight under pressure (Mechtcherine, 2016). Considering the workability and strength of mortar, SAP dosage of 0.1% of the cementitious material was found to provide better result within the range of 0.1%~0.3% SAP of cementitious material used in mortar (Dang & Zhao, 2018). In this context, the dosage of SAP was adopted as 0.1% of binder material in this experiment.

2.1.2 Alkali treatment of jute fibres

Jute fibre was also utilized as the insulating material in this research work. However, hydrophilic properties of Jute fibre was the main challenge to use it in the mortar. To overcome this issue, the jute fibres were treated in alkali solution. A 5% NaOH solution with a liquor ratio of 15:1 was used and the temperature was kept constant at 30 ^{0}C (Figure 1). The jute fibre length was approximately 12 mm. Alkali treatment of Jute fibre was applied because of the increase in tensile strength of Jute fibre compare to that of untreated Jute fibre (Ray et al., 2002). After the alkali treatment process continued for 4 hours, Jute fibres were thoroughly washed by distilled water to remove the NaOH from the Jute fibre surface. Finally the Jute fibre were oven dried for 6 ^{0}C for 6 hours to remove any moisture content from the fibre.



(a) Jute fibres cut into small pieces (Approx.12 mm in length)



(b) Jute fibres soaked with 5% NaOH solution for 4h.

(c) Jute fibres after treatment

Figure 1: Alkali treatment of jute fibres

2.2 Specimen Preparation

Slab samples, made of cement mortar were used in this research work. Two insulating materials - SAP and jute fibres were used in this experimental work. Therefore, total five samples; two for each categories of insulating materials and one as control sample were used in this experimental work. All samples were identical in shape having dimension of 1000 mm × 1000 mm × 25 mm as shown in Figure 2. The thickness of sample was considered to be the representation of wall plaster. Three mortar cube samples were also prepared with each slab sample for determining their corresponding compressive strength.

Figure 2: Specimen with dimension

2.3 Mix proportions

For samples with SAP, 0.1% of cement and 90 gm of extra water per gram of polymer was used for this experimental work. For samples with natural fibres, 1% of cement by mass was used which is summarized in Table 1. For control sample, the mortar ratio was 1:4 according to ASTM C926 and the water-cement ratio was 0.485 according to ASTM C109.

Table 1: Specimen with different proportion of insulating materials

Specimen type	Insulating materials	No. of specimen
CS (Control Sample)	Controlled Sample	01
SS (SAP Sample)	SAP (0.1% of cement)	02
JS (Jute Sample)	Jute Fibre (1% of cement)	02

2.4 Preparation of the small-scaled box

A small-scaled box was prepared with wooden pieces of 1 inch thickness having dimensions of 2 m × 1 m × 2 m ($L \times H \times W$) as shown in Figure 5. Inside the box, there were two pairs of wooden bits to hold the specimen remaining upright vertically, which divided the box into two compartments and act as a thermal barrier between two compartments of the box. One part of the compartment was accommodated with heat source while the other was represented as an interior of a room. GLS (General Lamp Shape) bulbs of 800 watt were used as the source of heat to perform the entire test. Holes were made for the passage of wires from heat source, temperature controllers and sensors to outsides of the small-scaled box.

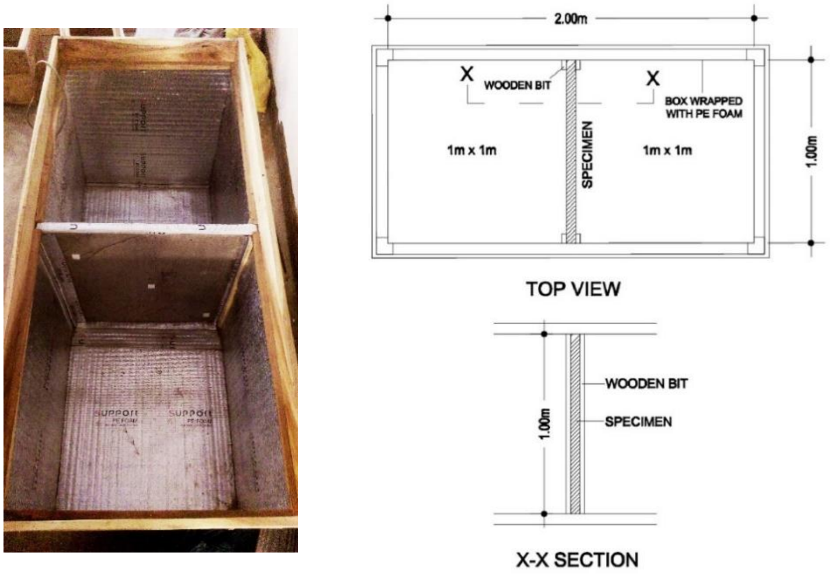


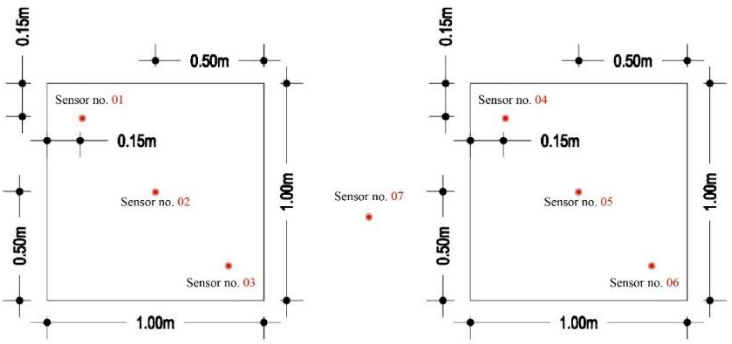
Figure 5: Small-scaled rectangular shape box with different views

The inner portion of the box was covered with PE foam with uniform addition of proper adhesives and the inner side of lid of the box was also covered with the foam to store heat inside the box as shown in Figure 6. The edges of the specimen with wooden bit were also being insulated properly ensuring heat will pass from heat source compartment to other compartment only through the mortar slab sample. All holes were filled with foams and tapes preventing escape of heat from inside to outside of the box.

Figure 6: Insulation of box with PE foam

2.5 Data collection process

Six DHT22 temperature and relative humidity sensors were attached on the slab sample to perform the test covering both the side of the heat source compartment and the opposite side as shown in figure 7 and one sensor was used to record the ambient relative humidity and temperature.



(a) Heat source side (b) Opposite side

Figure 7: Position of sensors over specimen

Each sensors were attached with serial numbers to identify readings they recorded. All data were collected and recorded from sensors with Arduino connected with a laptop as shown in Figure 8.

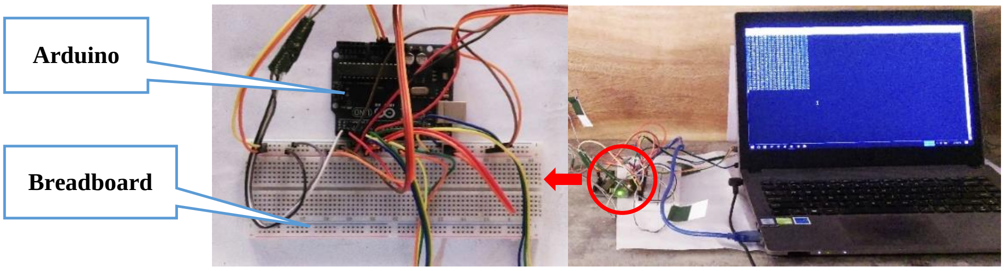


Figure 8: Data collection process from sensors

3. RESULTS AND DISCUSSION

The properties of fine aggregate, Jute fibre were determined according the corresponding standard tests and the obtained results are summarized in Table 2 and 3, respectively.

Table 2: Physical properties of fine aggregate

Test name	Results	Test method
Specific Gravity	2.4	ASTM C128
Fineness Modulus (FM)	2.67	ASTM C136
Moisture content (%)	3.5	ASTM C 70
Absorption (%)	4.6	ASTM C128
Unit weight (Kg/m^3)	1498	ASTM C 29

Table 3: Tensile Test results of Jute Fiber Composite

Tensile Parameters	Results
Maximum Deformation (mm)	0.98
Ultimate Strength (MPa)	88
Modulus of Elasticity (MPa)	4295

The cube samples were divided into several groups with according to the usage of insulating materials in mortar. Each set had different insulating materials. Compressive strengths were tested at 7 days and

28 days after casting. Water curing was carried out for all specimens with their companion cubes except the sample with SAP. SAP samples were air cured for 7 and 28 days after casting.
Cubic samples were tested with mortar ratio of 1:2.75 and water-cement ratio of 0.485 by following test method ASTM C109. The compressive strength of mortar containing the insulating materials along with the controlled samples are presented in Table 4 and 5.

Table 4: Mortar Compressive Strength of different samples at 7 days

Sample type	Mortar age (Days)	Curing medium	Avg. Compressive Strength (MPa)
Controlled Sample	7	water	17.50
Jute Sample -01			23.9
Jute Sample-02			22.3
SAP Sample-01		air	21.3
SAP Sample-02			21.5

Table 5: Mortar Compressive Strength of different samples at 28 days

Sample type	Mortar age (Days)	Curing medium	Avg. Compressive Strength (MPa)
Controlled Sample	28	water	47.6
Jute Sample -01			27.1
Jute Sample-02			27.2
SAP Sample-01		air	26.8
SAP Sample-02			27.1

3.1 Temperature variation at 7 days

Figure 9 shows the temperature variation graph for control sample. Temperature of two compartments of the box separated by the slab specimen were recorded over time during the test and presented in Figure 9 to Figure 13. Figure 14 also shows the comparison of temperature variation among Jute, SAP and control samples at 7 days.

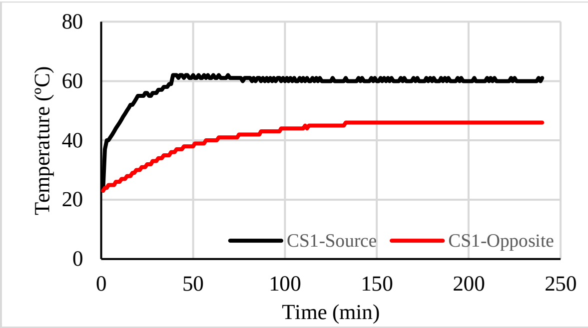


Figure 9: Temperature Variation for Control Sample at 7 days

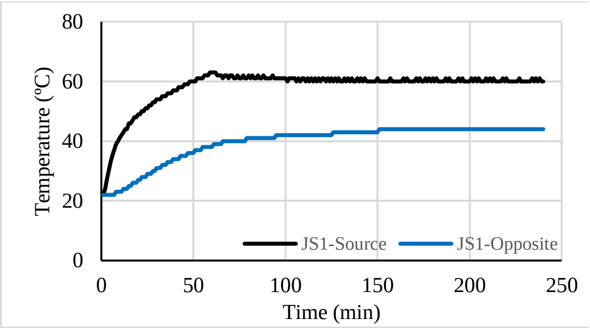


Figure 10: Temperature Variation for Jute Sample-1 at 7 days

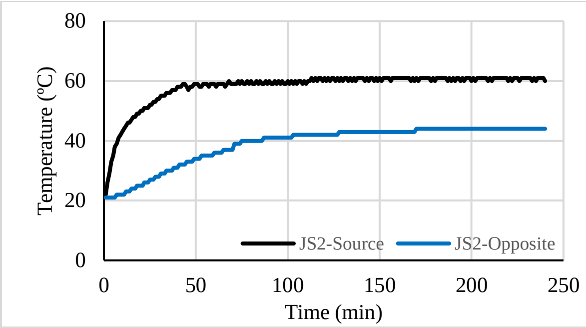


Figure 11: Temperature Variation for Jute Sample-2 at 7 days

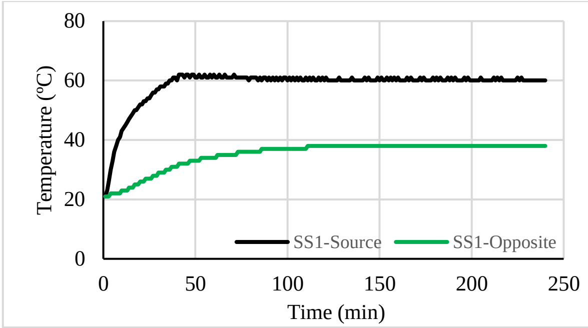


Figure 12: Temperature Variation for SAP Sample-1 at 7 days

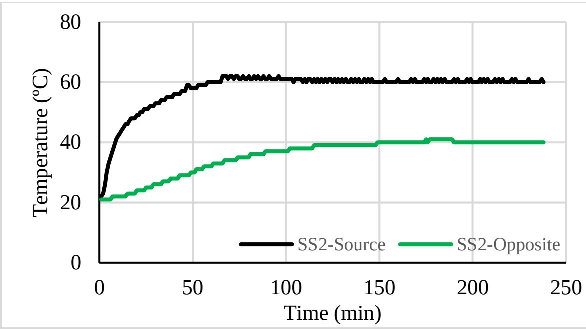


Figure 13: Temperature Variation for SAP Sample-2 at 7 days

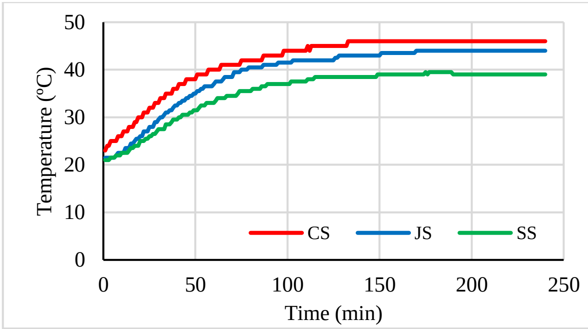


Figure 14: Temperature variation among different types of insulation at 7 days

3.2 Temperature variation at 28 days

Figure 15 reflects the temperature variation for control sample. Furthermore, Fig. 16 and Fig. 17 show the thermal variation of jute sample and SAP sample respectively after 28 days.

Figure 18 shows that the obtained temperatures are 45 ºC, 45 ºC and 43 ºC for control sample, Jute sample and SAP sample respectively. SAP sample shows 2 ºC temperature less than that of other samples. Therefore, it is clearly demonstrated that the thermal performance with SAP sample was better than that of jute sample and control sample after 28 days.

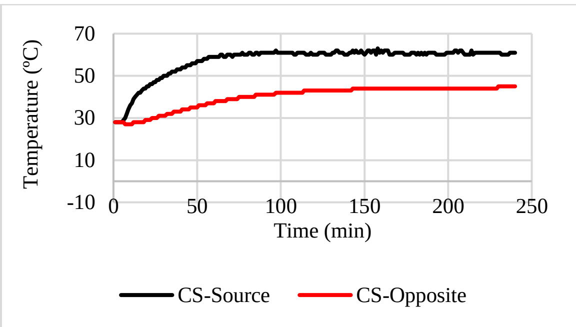


Figure 15: Temperature Variation for Control Sample at 28 days

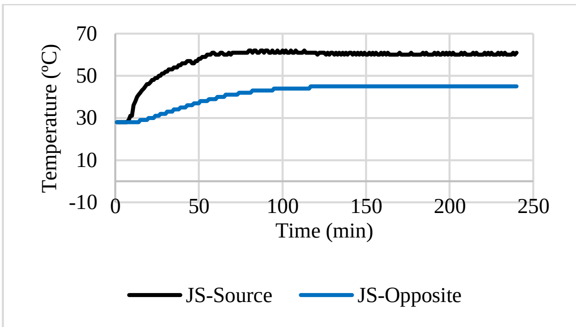


Figure 16: Temperature Variation for Jute Sample at 28 days

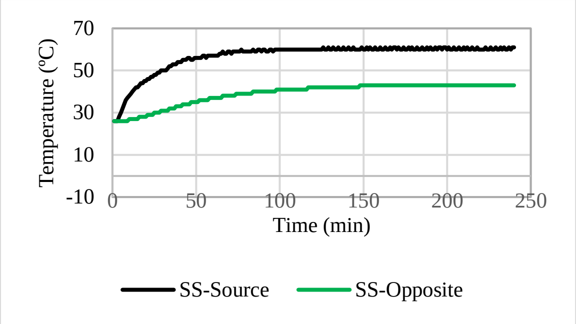


Figure 17: Temperature Variation for SAP Sample at 28 days

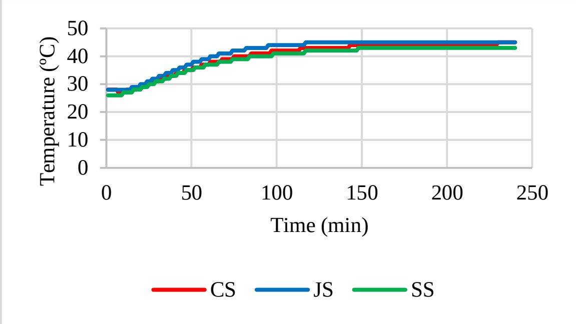


Figure 18: Temperature variation among different types of insulation at 28 days

4. CONCLUSIONS

The following conclusions were drawn from the experiments conducted and the results obtained –

- It was observed that the compressive strength of mortar with jute fibre was higher than the rests.
- It was also found that thermal performances of mortar containing SAP and sample incorporating jute fibres were better than that of control sample.
- The compressive strength of the samples with SAP was almost close to the conventionally cured sample for 7 days test.
- In terms of thermal insulation and mechanical properties, sample made with super absorbent polymer appears to be the best.

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