

Curing of novel Geopolymer brick using phase change material (paraffin wax) in passive solar dryer and comparison of properties with conventional Geopolymer brick

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Abstract: Conventionally, in Geopolymer bricks (GPBs), fly ash from power plants and ground granulated blast furnace slag (GGBS) are converted into bricks by chemical treatment. In this work, a novel GPB has been obtained by adding nano silica and rice husk ash along with conventional ingredients of GPB. In solar drying, paraffin wax is employed for accelerating the curing time by utilizing its latent heat stored in the form of phase change. It has been experimentally found that solar drying method with paraffin wax utilizes shorter curing time when compared to electrical oven curing and open sun drying. The properties of novel GPB are evaluated by mechanical testing and compared with conventional GPB. It has been experimentally observed that novel GPB exhibits higher mechanical properties when compared to conventional GPB. Also in this study, SEM images ($2\mu\text{m}$, 5 KX), ($3\mu\text{m}$, 4 KX), ($10\mu\text{m}$, 1 KX), ($20\mu\text{m}$, 500X), ($100\mu\text{m}$, 250X) and EDX analysis of novel GPB obtained from test results have been furnished. Smart quantitative results from EDX analysis show that O K has the highest weight percentage and atomic percentage.

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Keywords: geopolymer brick (GPB), phase change material (PCM), fly ash, ground granulated blast furnace slag (GGBS), nano silica, rice husk ash, scanning electron microscopy (SEM), energy dispersive X-ray Spectroscopy (EDX)

1. Introduction

Energy from the sun is a potential candidate, compared to other sources in several areas like agriculture, distillation, construction and other industries [1]. Green house energy is an open method when compared to other modes of drying [2]. Open sun drying and its risk factors pose a threat to the drying process [3]. The risk factors of green house energy method can be eliminated by convection based solar dryers which is also safe for the environment [4]. A solar dryer was proposed as a substitute for electric dryer; to prove its efficiency [5]. Phase change materials are materials to regulate a bandwidth of temperatures, by utilizing its latent heat, in several applications like buildings to minimize consumption of energy [6]. Phase change material like paraffin suffers negligible volume changes during phase change process making it easier to incorporate it in equipments [7]. Paraffin wax can maintain a hotter environment than the ambience at least for a span of five hours after the sunset, thereby reducing the curing time [8]. Composite phase change material is used as coatings on building wall to regulate indoor temperature [9]. Paraffin wax absorbed into fly ash ceramsite is used as PCM to tackle massive energy consumption [10]. In construction industries GPBs are a potential threat to sand and cement bricks

with good structural properties even at elevated temperatures [11]. Also in comparison with other conventional bricks, GPBs are affordable while economy and eco-friendliness is concerned [12]. Author investigated strength, microstructure and curing time of GPBs [13]. Authors suggested efficient drying range of temperatures between 40°C to 60 °C for evolving GPBs in construction industries. [14]. Polymer composites are finding applications even in construction areas, like use of polymer in bricks [15,16]. Construction industries need bricks of less energy consumption and pollution which inculcates hybrid solar dryer in building applications [17]. Rice husk ash is finding applications in manufacturing of sustainable GPBs [18]. Nano clay and granite dust are alternative replacement for cement mortars to bring down carbon dioxide emissions [19]. Use of GPBs in terms of strength compared to the conventional bricks comes under the modified guidelines of GPBs concrete mix design using Indian standards [20].

This work deals with the preparation of a novel GPB, comparison of drying methods like electrical drying, solar drying with a PCM (Paraffin Wax) and solar drying without a PCM, in terms of curing time and mechanical property comparison of novel GPB with conventional GPB.

2. Materials and methods

At Kalasalingam Academy of Research and Education, Tamil Nadu (India), a solar dryer of dimensions (710 * 310 * 310) with all dimensions in millimeters was fabricated as shown in Figure 1. The dryer set up contains iron stand drying chamber and UV-coated parabolic polycarbonate sheets for absorbing incident solar energy. An aluminum frame is used to structurally support the polycarbonate sheet. A Cudappah stone of dimension (695 mm * 295 mm) is kept below polycarbonate sheet to constrain transfer of heat in downward direction for obtaining uniform drying temperature. The dryer shows four nylon wheels at the bottom to move the dryer for convenience. Solar powered photovoltaic (PV) panel fan is provided to remove saturated air and allow fresh atmospheric air into the chamber. On the basis of curing temperature, this fan automatically turns on and off during the process. Latent heat storage material like paraffin wax is kept in a steel container above the Cudappah stone has 57.5 °C as melting point temperature. Material properties of paraffin wax are predicted in Table 1.

PCM	Melting Temperature (°C)	Density (kg/m ³)		Specific Heat (J/Kgk)		Thermal Conductivity (W/mK)		Latent Heat of Fusion (kJ/kg)
		Solid	Liquid	Solid	Liquid	Solid	Liquid	
Paraffin wax	57.5	915	815	2005	2095	0.225	0.245	205

Table 1. Properties of paraffin wax



Figure 1. Solar dryer

Material	Weight in kg/m ³
Fly ash	286
GGBS	166
M sand	580
Coarse aggregate 20 mm	865
AAS—alkaline activated solution	336
SSS—sodium silicate solution Na ₂ SiO ₃	240
NaOH	96
NaOH molarity	12
Alkaline/binder ratio	0.61
Rice husk ash	82.5
Nano silica	16.5

Table 2. Raw material composition of GPB

Precursor	SiO ₂	Al ₂ O ₃	CaO	MgO	K ₂ O	Fe ₂ O ₃	TiO ₂	Na ₂ O	SO ₃
Fly Ash	52	27	3.5	9.25	7.5	1.55	0.845	0.725	0.545
Ground granulated blast furnace slag	35	14	36	7.5	0.545	0.45	0.725	0.25	1.65
Nano silica	90.5	0.082	0.059	0.081	0.011	0.02	-	0.89	0.23
Rice husk ash	85.85	0.19	1.95	0.375	1.98	0.09	-	0.39	-

Table 3. Chemical composition of GPB

Test	Geometry	Length	Breadth	Height	Diameter	STANDARD
Tensile split strength	Cylindrical	20			10	ASTM C496-96
Compressive strength	Cubic	10	10	10		ASTM E9-19
Flexural strength	Rectangular	50	10	10		ASTM D790-17

Table 4. Specimen standards (dimensions in cm)



Figure 2. Photos of ingredients of Novel GPB

2.1. Electric oven drying

The specification of electric oven used for curing is shown below:

- Power rating = 3600 Watts,
- Voltage rating = 225 V,
- Frequency = 50 Hz.



Figure 3. Final mixture and mixture poured into mould



Figure 4. Specimen for testing



Figure 5. Novel GPB (cubic and cylindrical) specimen kept in electric oven



Figure 6. Novel GPB along with (PCM) paraffin wax placed in solar dryer



Figure 7. GPB under tension split test

At the beginning of curing process, the GPB exhibits fluctuations in weight. As it gets stabilized, the moisture content had been completely cured. The time consumed for drying moisture content is 24 hours. Further the GPBs were allowed to develop proper



Figure 8. GPB under compression test



Figure 9. GPB under flexural test

strength at room temperature for 28 days. This same procedure was applied for all curing methods mentioned below.

2.2. Solar drying (PCM)

The drying process took 22 hours.

2.3. Open-sun drying

The drying process took 24 hours.

3. Results

Results of mean value of two specimens in each test have been established in Figures 10-13 with the following inference: The temperature in electric oven drying was around 65°C while temperature in solar drying operates at around 60°C, with variations depending on atmospheric conditions. As per the observations from Figure 10, it is understood that solar drying with a PCM consumes almost two hours less curing time among all curing methods for novel GPB.

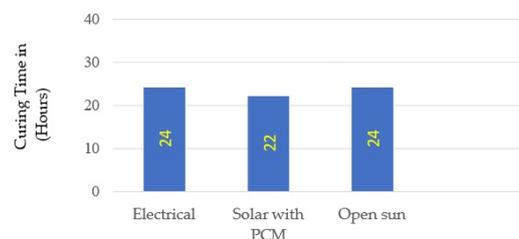


Figure 10. GPB curing time comparisons of all three methods

According to Indian standards, compressive strength for conventional GPB is around 30 MPa [20]. In this work, the compressive strength from experiment, predicts a value of 45 MPa for novel GPB in solar drying with a PCM, as shown in Figure 11. Also for novel

GPB, tensile split strength of 4.5 MPa and flexural strength of 6.5 MPa was obtained in solar drying with a PCM, as shown in Figure 12 and 13 respectively.

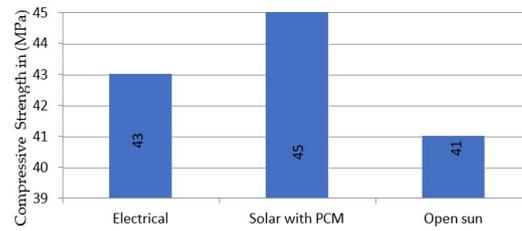


Figure 11. Compressive strength comparison

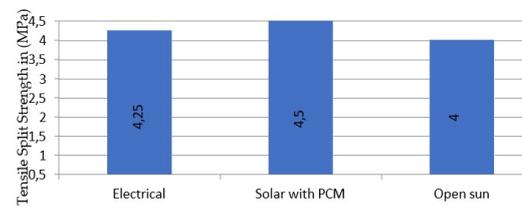


Figure 12. Tensile split strength comparison

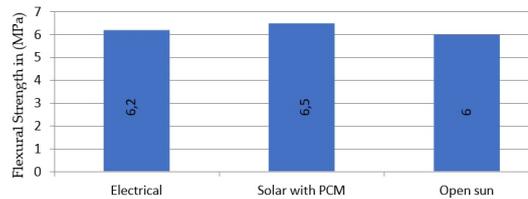


Figure 13. Flexural strength comparison

Experimentally, it is evident from Figure 11-13 that novel GPB under solar drying with a PCM exhibit 4.65% and 9.76% higher compressive strength, 5.88% and 12.5% higher tensile split strength, and 4.84% and 8.33% higher flexural strength when compared to electrical drying and open sun drying respectively. Specimen under solar dryer with PCM has been selected for SEM and EDX analysis. Specimen and surface topographical images of tensile split strength test, compression test and flexural test captured by SEM have been shown below in Figures 14 and 17, 19, 21 respectively to have an idea of microstructure. An EDX analysis of specimen under tensile split strength, compression test and flexural test have been shown in Figure 18, 20, and 22 which predicts O K as the highest by weight and atomic percentage in all the three test.



Figure 14. Specimen (Solar dried with PCM) after Tensile Split Strength test



Figure 15. Specimen (Solar dried with PCM) after Compression Strength test



Figure 16. Specimen (Solar dried with PCM) after Flexural Strength test

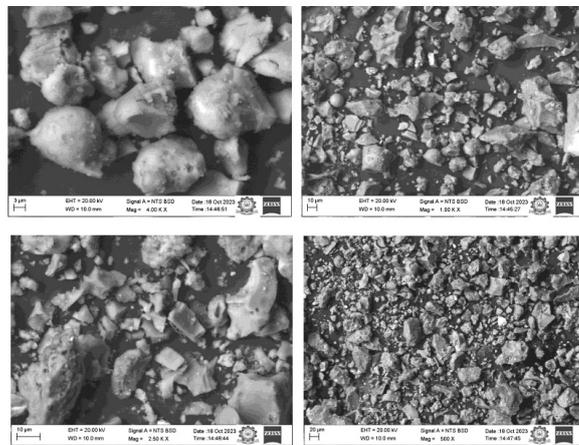


Figure 17. Surface Topography of Specimen (Solar dried with PCM) under Tensile Split Strength test



Figure 18. EDX analysis of Specimen (Solar dried with PCM) under Tensile split strength test

4. Discussion

It is evident from Table 4, that novel GPB under solar drying is the most efficient with 22 hours of curing time due to latent heat storage [5,21]. It is evident from Tables 5-8 that novel GPB exhibits higher tensile split strength, higher compressive strength and higher Flexural Strength when compared to conventional GPB for all the curing methods [21]. This is due to the presence of Nano silica and Rice Husk Ash in the novel GPB which gives

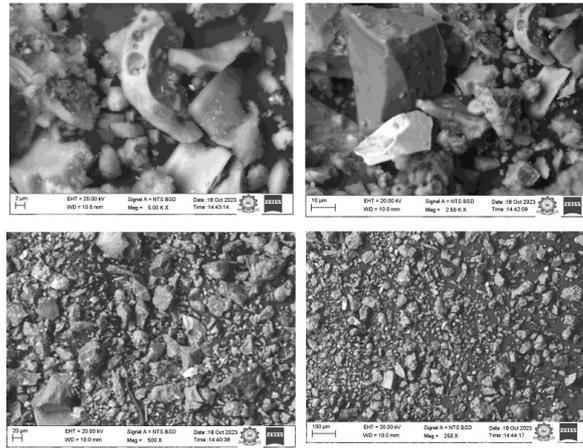


Figure 19. Surface Topography of Specimen (Solar dried with PCM) under Compression Strength test

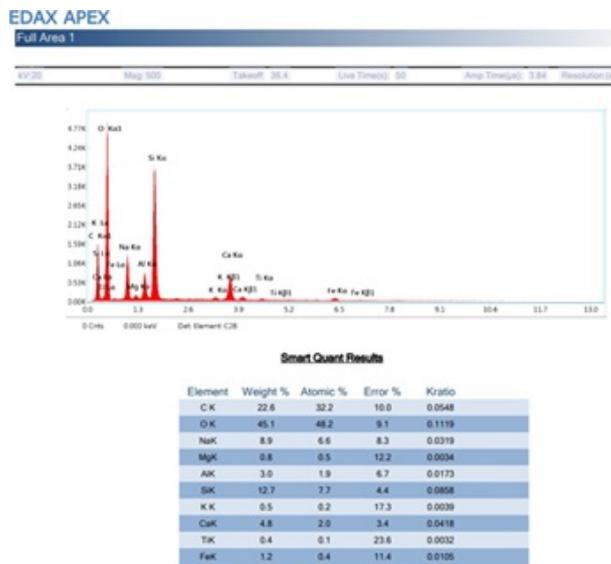


Figure 20. EDX analysis of Specimen (Solar dried with PCM) under compression strength test

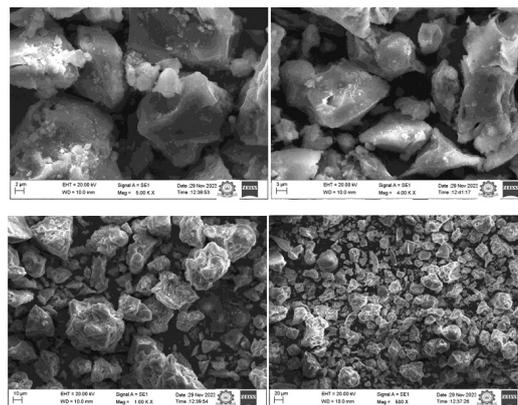


Figure 21. Surface Topography of Specimen (Solar dried with PCM) under Flexural Strength test

better bonding effect when compared to conventional GPB. Also for novel GPB, solar drying with a PCM shows higher compressive strength, tensile split strength, and flexural strength when compared to electrical drying and open sun drying due to higher latent heat storage [21].

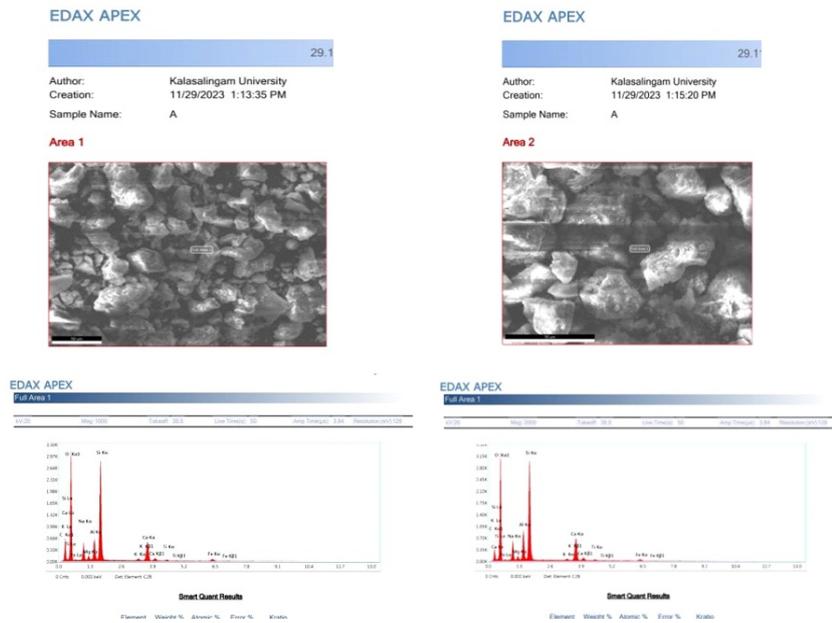


Figure 22. EDX analysis of Specimen (Solar dried with PCM) under Flexural strength test

	Conventional GPB	Novel GPB
Drying Method	Curing Time (Hours)	Curing Time (Hours)
Electrical drying	24	24
Solar drying (PCM)	22	22
Open-sun drying	24	24

Table 5. Curing time comparison for Novel GPB and Conventional GPB

	Conventional GPB	Novel GPB	Percentage Difference
Drying Method	Compressive Strength (MPa)	Compressive Strength (MPa)	
Electrical drying	38.5	43	11.68
Solar drying (PCM)	41.5	45	8.43
Open-sun drying	37	41	10.81

Table 6. Compressive strength comparison for novel GPB and conventional GPB

	Conventional GPB	Novel GPB	Percentage difference
Drying Method	Tensile Split Strength (MPa)	Tensile Split Strength (MPa)	
Electrical drying	3.10	4.25	37.09
Solar drying (PCM)	3.35	4.5	34.32
Open-sun drying	2.9	4	37.93

Table 7. Tensile split strength comparison for Novel GPB and Conventional GPB

	Conventional GPB	Novel GPB	Percentage difference
Drying Method	Flexural Strength (MPa)	Flexural Strength (MPa)	
Electrical drying	4.95	6.2	25.25
Solar drying (PCM)	6.20	6.5	4.83
Open-sun drying	6.70	6	10.5

Table 8. Flexural strength comparison for Novel GPB and conventional GPB

5. Conclusions

- For novel GPB, solar dryer with a PCM consumes 22 hours of curing time which is less than all other methods [5,21].

- As per Indian standards, compressive strength for conventional GPB is 30 MPa [20,22]. In this work for novel GPB under a solar-dried with PCM, the experiment value shows 45 MPa which is favourable for construction industries.
- The presence of nano silica and rice husk ash proves that novel GPB exhibits higher compressive strength, tensile split strength, and flexural strength when compared to conventional GPB [21,23], for all curing methods respectively, except for open sun drying method under flexural strength test, which may be due to increase in brittleness due to the addition of nano silica.
- Novel GPB, under solar drying with a PCM shows higher compressive strength, tensile split strength, and flexural strength when compared to electrical drying and open sun drying which promotes the use of PCMs in curing of bricks and enhancing the strength of bricks in construction industries on large scale basis [21].
- Due to the important contribution of silica in construction industries, silica has been used as a target to predict its contribution in GPBs.

Author Contributions

Conceptualization, Ashok Kumar J. and Muthuvel S.; methodology, Ashok Kumar J and Muthuvel S.; software, R.S.P.; validation, Ashok Kumar J. and Muthuvel S.; formal analysis,.; investigation, Ashok Kumar J.; resources, Ashok Kumar J.; data curation, Ashok Kumar J.; writing—original draft preparation, Muthu- vel S.; writing—review and editing, R.S.P., Velmurugan and Gianpaolo Di Bona; visu- alization,.; supervision, Muthuvel S.; project administration, .; funding acquisition,. All authors have read and agreed to the published version of the manuscript.

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