Article

Not peer-reviewed version

Mechanical Properties Comparison of Geo Polymer Brick Dried by Electrical and Passive Solar Devices With Phase Change Material (Paraffin Wax)

Ashok Kumar Jeevan , Muthuvel Sattanathan * , Rajay Vedaraj Issac Selvaraj , Monsuru Ramoni , Ragavanantham Shanmugam , Sudhakara Pandian Ranjitharamasamy *

Posted Date: 25 October 2023

doi: 10.20944/preprints202310.1648.v1

Keywords: geo polymer brick (GPB); solar dryer; compressive strength; tensile strength; flexural strength; sustainability; PCM (phase change materials); paraffin wax; specific heat; thermal conductivity; latent heat of fusion

Article

Mechanical Properties Comparison of Geo Polymer Brick Dried by Electrical and Passive Solar Devices with Phase Change Material (Paraffin Wax)

Jeevan Ashok Kumar [1], Sattanathan Muthuvel [2,*], Rajay Vedaraj Issac Selvaraj [3], Monsuru Ramoni [4], Ragavanantham Shanmugam [5] and Ranjitharamasamy Sudhakara Pandian [6,*]

1. Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, India; bjashokias@gmail.com
2. Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, India; s.muthuvel@klu.ac.in
3. School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamilnadu, India; rajay@vit.ac.in
4. School of Engineering, Math and Technology, Navajo Technical University, New Mexico,USA; mramoni@navajotech.edu
5. Department of Engineering Technology, Fairmont State University, West Virginia,USA;rshanmugam@fairmontstate.edu
6. School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamilnadu, India; sudhakarapandian.r@vit.ac.in

* Correspondence: sudhakarapandian.r@vit.ac.in, s.muthuvel@klu.ac.in (RSP, SM)

Abstract: In Geo Polymer bricks (GPB), fly ash content which is a waste from power plants is converted into bricks by chemical treatment. GPB can be dried by using appropriate curing methods. Conventionally electric oven curing is one of the prominent methods. Using solar dryer instead of electrical oven gives added advantage of saving high grade electrical energy. So in this work solar dryer with PCM (Phase Change materials) Paraffin Wax and without PCM is used for curing application. GPB are gaining added advantage when compared to conventional bricks like cement and sand bricks in terms of strength. GPB has been taken as specimen for comparing the compressive, tensile split strength and flexural strength by electrical energy based curing and solar energy based curing. It is experimentally observed that solar energy based curing with PCM and without PCM exhibits higher compressive strength, higher tensile split strength and flexural strength when compared to electrical energy based curing. Solar curing with PCM shows higher compressive strength, higher tensile split strength and flexural strength when compared to Solar curing without PCM. Open solar curing is a traditional technique but nowadays aggressive climatic conditions can lead to severe damage of Geo polymers. The novelty of this work is to suggest to study the effect of PCM like paraffin wax in solar drying on curing time, mechanical properties of GPB.

Keywords: geo polymer brick (GPB); solar dryer; compressive strength; Tensile Strength; flexural strength; sustainability; PCM (Phase Change materials); paraffin wax; specific heat; thermal conductivity; and latent heat of fusion

1. Introduction

Solar energy stands as an excellent alternate source of energy when compared to other forms of energy in thermal applications especially in the areas like drying and heating [1]. The recent progress in the use of solar energy has sparked broad interest in a variety of applications such as drying, heating, cooling, and purifying. Solar energy applications can be divided into two categories: electrical and thermal applications. Solar thermal systems have traditionally been used in agriculture to preserve vegetables, fruits, cereals, and other products. It is considered inexpensive and widely known among farmers; yet, it is utilized significantly less frequently in the manufacturing sector [2].

 doi:10.20944/preprints202310.1648.v1

Removing moisture from a substance is generally termed as drying which finds applications in construction, food processing, agro and other industries [3]. Also, it can be employed in preserving agricultural food products like pepper and pumpkin seeds [4,5]. Usually hot air between 45°C and 60°C will remove moisture content kept inside solar thermal system for drying of grapes [6]. Conventional drying methods like direct exposure to sun are a simpler method for drying agricultural food products like preservation of kiwifruit and preparing dry grapes in farmyard respectively [7,8]. Open exposure to sun drying method is a green house energy method free from technological aspects and economical when compared to other methods of drying [9]. Under unexpected severe climatic conditions open drying process may encounter some damages in drying of food and vegetable products which is evident in agricultural industries [10,11]. Open exposure to sun drying proposes certain risk factors like slow rate of drying time, development of microbial activities, whether forecast etc., [12]. The risk factors of Open sun drying can be eliminated by thermal based solar drying which is free from fuel usage [13]. As thermal based solar drying uses natural convection it doesn't pose any treat to the ecosystem [14]. Thermal based solar dryers doesn't alter the color or texture of the products and hence more feasible for drying than open drying [15]. In thermal based solar dryers, buoyancy based pressure which is the resultant of natural convection consumes some time for the completion of drying. Also forced convection based thermal solar dryers can be employed in which fan is used to force the air for drying which is charged by electric current, solar energy or fuels [16]. GPBs are inorganic materials similar to zeolites but possess an amorphous structure. They can seen as manmade rocks. GPBs are gaining advantage in construction industries due to their comparable strength with conventional bricks. Compared with concrete bricks, GPB offers economy and eco-friendliness [17]. Hao Shi et al. investigated the effect of microwave curing on the mechanical strength and microstructure of metakaolin geo polymers with quartz sand and shortening the curing time [18]. Mohammed Rihan Maaze, Sandeep Shrivastava recommended curing temperature between 40°C – 60°C for efficient curing and good physical and mechanical properties of GPB [19,21]. A solar dryer was used as an alternative and compared with Conventional Electric Convective Drying time [20]. Various advancements in fiber polymer composites are emerging because of their increased use in a myriad of applications like polymer in bricks for construction applications [22]. Phase Change Materials are used to store latent heat during phase shifts at a controlled temperature within a certain range [23]. Low-cost, non-corrosive, and chemically stable below 500 °C, paraffin melts with a small volume difference [24]. As a thermal energy storage structure, PCMs like paraffin wax may sustain a greater temperature than the surrounding area for at least five hours following active sunlight hours, which reduces the absolute drying time of the crops [25]. The PCM charges with solar energy for around 8 hours during the day and releases the stored energy at night [26]. The PCM achieves its melting point when the ambient temperature rises; as a result of the endothermic process, the PCM absorbs energy, melts, and transitions from a solid to a liquid state, which is a charring process. The PCM solidifies, converting from liquid to solid, which is a discharging process, and releases energy during the exothermic process [27]. When compared to open sundry products, the quality of solar-dried products shows good quality [28]. By using a sun dryer, the product's drying time was significantly reduced [29]. Currently, research studies have reported on many drying systems that use sun energy to improve crop drying efficiency. The primary goal of this research is to minimize absolute drying time and lengthen drying during off-sun hours, as well as to reduce staff engagement and incorrect drying during the winter. According to studies, using solar energy in the dryer is more cost effective and compelling as a sustainable drying solution. The current investigation attempts to combine paraffin wax, a phase change substance, into a solar dryer for drying seedless grapes. The drying properties and quality of PCM-dried items were compared and evaluated. The suggested framework provides a feasible method of integrating energy utilization and lowering the carbon footprint in the drying process. The current design of the solar dryer with PCM is relatively simple and inexpensive. It can be utilized by rural farmers because the materials are widely available and unique. To prevent food spoilage and to store agricultural commodities for an extended period of time without loss in quality. The solar dryer has a wide range of applications, including drying agricultural products such as shredded

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 October 2023 doi:10.20944/preprints202310.1648.v1

cabbage, granulated mashed potato, tomato, grapes, apple, coconut, chili, banana, ladies finger, and mango pulp, as well as drying marine products such as small fishes and prawns textiles, wood, food processing, paper and pharmaceutical. The limitations of traditional open sun drying can be overcome by selecting an efficient drying system. The requirement for high fuel or power to run the drying system has encouraged sunlight-based drying systems. Here a solar dryer which works on the principle of natural convection is employed for curing process of GPB. Buoyancy driven pressure of air is used to dry the GPB kept inside the chamber. Phase Change Materials are gaining advantage in many areas of engineering as thermal energy storage systems in the form of latent heat in between states by vaporization and condensation. During the daytime, the PCM is charged using solar energy and discharges the stored energy during night time which can be employed in construction sectors for curing of GPBs. PCMs like paraffin wax as thermal energy storage in solar dryers can maintain a higher temperature than surrounding for several hours even if there is sudden reduction in temperature which decreases the drying time of the GPBs.

The current work deals with GPB drying in open sun, electric oven and solar drying with PCM (Paraffin Wax) and solar drying without PCM. The time taken for drying in all the four methodologies has been compared. Also mechanical properties like compressive strength, tensile split strength and flexural strength of the GPB has been compared in the above stated four curing methods. Also this study predicts the effect of PCM like Paraffin wax in solar drying application on curing time and mechanical properties.

2. Materials and Methods

At Kalasalingam Academy of Research and Education (9.5747° N, 77.6798° E), Tamil Nadu (India) in Tamilnadu (India), a solar dryer (700 mm x 300 mm x 300 mm) was created and installed. The arrangement containing the drying chamber is supported by an iron stand. It is made of double-layered polycarbonate sheets that have been UV-coated. To focus and absorb the solar energy that is received inside the drying chamber, the polycarbonate sheet is bent in the shape of a parabola. Better thermal insulation is provided by the polycarbonate sheet, which is 60% more effective than glass. To protect the underlying material from damaging radiation, the UV coating is essential. The parabolic polycarbonate sheet is supported and attached by aluminum framing. A Cudappah Black Stone slab (700 mm * 300 mm) is set at the bottom of the polycarbonate sheet. The transfer of heat energy from PCM across the base of the stand was constrained by the Cudappah stone. The stand includes four nylon wheels at the bottom that may be easily utilized to load and unload GPBs as well as move the drying chamber. At one end of the drying chamber, a solar-powered exhaust fan is permanently installed. The electrical energy needed to run the fan is provided by a solar Photo Voltaics (PV) panel that is attached to the fan. The drying chamber's saturated air was removed using the exhaust fan, which then let fresh air from the atmosphere into the space. Based on temperatures inside the drying chamber, the exhaust fan is automatically turned on. The PCM employed in the study as a thermal storage medium was paraffin wax, which was set on a Cudappah stone and coated with a stainless steel sheet. Natural paraffin wax is in solid state, which has a melting temperature of 58°C as shown in Table 1. Also other properties like density, specific heat, thermal conductivity and latent heat of fusion are listed below in Table 1. It is an organic PCM which was purchased at Spectrum Reagents and Chemicals Private Ltd, Ernakulum, Kerala, India.

Table 1. Properties of Paraffin Wax.

PCM	Melting Temperature (°C)	Density (kg/m³)		Specific Heat (J/kg.K)		Thermal Conductivity (W/m.K)		Latent Heat of Fusion (kJ/kg)
		Solid	Liquid	Solid	Liquid	Solid	Liquid	
Paraffin Wax	58	910	810	2000	2100	0.228	0.25	204

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 October 2023 doi:10.20944/preprints202310.1648.v1

Experimental preparation of GPB has been mentioned along with Raw Material composition as shown in Figure 1 and Table 2. Figure 1 shows ingredients of GPB. Sodium hydroxide NaOH is mixed with water and kept aside for 1 day. After 24 hours, sodium silicate Na_2SiO_3 has to be added to the above mixture in the bowl. After one-hour, Ground Granulated blast furnace and Fly ash mixed with coarse aggregate and fine aggregate sand has to be added in appropriate quantity to the bowl containing NaOH and Na_2SiO_3. The total mixture is shown in Figure 2. Figure 2 shows the status after mixing of all the ingredients of GPB. This is the Raw Material composition and process of making GPB. The prepared brick specimen is kept in electric oven and solar dryer as shown in Figure 3 and 4 respectively. The technique captures solar energy and converts it into heat energy inside the drying chamber. Convection and radiation are used to transfer energy. Convection is the major route of heat transport, while radiation is the passive mode. The 6 mm thick double layered UV coated polycarbonate sheet shown in Figure 4 allows solar energy to travel through the drying chamber but prevents it from leaving. The Black Cudappah stone Figure 4 is placed above the iron stand, which serves as the room's basement, and the sides and edges of the chamber are densely packed. The paraffin wax (PCM in the study) was placed on the Cudappah stone in an insulated stainless steel tray. Throughout the drying process, the charging and discharging phases of PCM occurred concurrently. An accurate balancing machine was used to determine the mass of the dried items. The trials were carried out in the chamber with PCM 400 g of paraffin wax and without PCM. The PCM Paraffin wax is in solid state which suffers phase change into liquid during curing of GPB. When there is reduction in temperature naturally PCM reverses its phase to solid nature. Of course when there all oscillations in surrounding ambience, phase change alters by itself to maintain a uniform curing nature inside the solar dryer. For measuring of mechanical properties, specimen is of standard geometry like cubic(10 cm * 10 cm * 10 cm) sample for compressive strength test, cylindrical (L = 20 cm and D = 10 cm) sample for tensile split strength test and rectangular (50 cm * 10 cm * 10 cm) prismatic sample for flexural strength test as shown in Figures 5 and 6 respectively. Number of samples for each test were two. For all the four methods of curing the following standards were used ASTM E9-19 Standard Test Method of Compression Testing of Metallic Materials at Room Temperature ASTM C496-96, Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimen ASTM D790-17 and Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.

Table 2. Raw Material Composition of GPB.

Materials	**Weight in kg/m³**
Fly ash	385
GGBS – Ground Granulated Blast furnace Slag	165
M sand	579.64
Coarse Aggregate 20mm	864.12
AAS Alkaline Activated solution	335.5
SSS sodium silicate solution Na_2SiO_3	239.64
NaOH	95.86
NaOH Molarity	12
Alkaline /binder ratio	0.61

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 October 2023 doi:10.20944/preprints202310.1648.v1

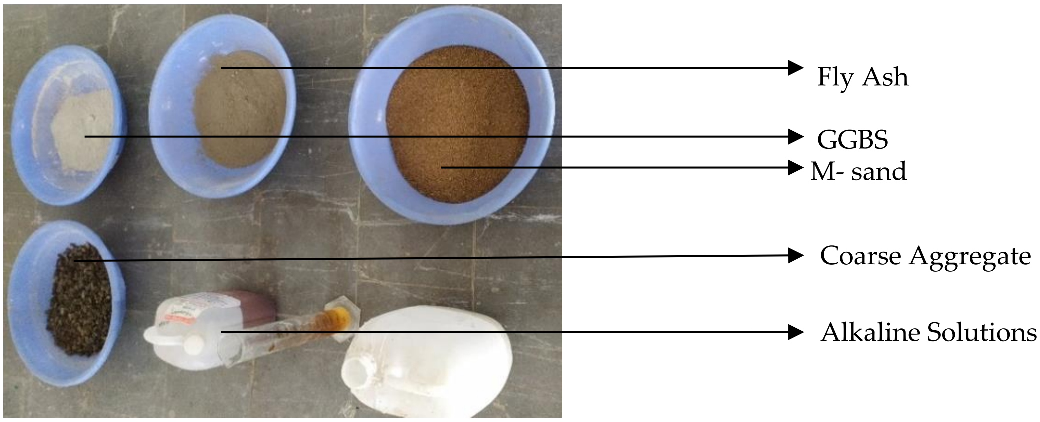

Figure 1. Mixture of ingredients of GPB.

Figure 2. Final mixture after mixing all ingredients

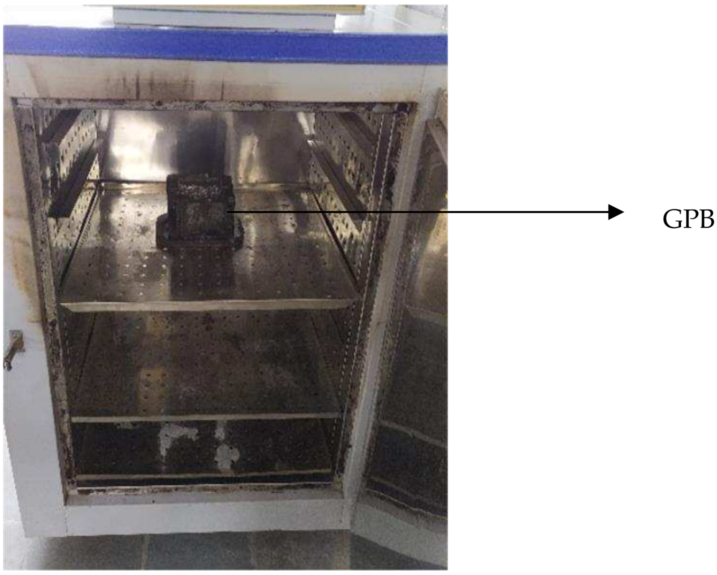

Figure 3. GPB kept in electrical oven.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 October 2023 doi:10.20944/preprints202310.1648.v1

Figure 4. GPB kept in solar dryer.

2.1. Electrical Oven Drying

LTMHOS-6 Electrical oven model with 3500 Watts with 220/230 V AC 50 Hz was used for curing of moisture content. GPB was kept in oven and it took 24 hours for curing moisture content. Here we use a simple rule of weighing in the GPB to have an idea of moisture content. In initial stages of curing the moisture content, GPB shows variations in weight and when the weight stabilizes it indicates that moisture content has got cured. This same rule is used for all the four mentioned curing methods. GPB was kept under ambient room temperature for 28 days for further curing in order to develop sufficient strength. After 28 days brick was taken for performing compression strength test, tensile split strength test and flexural strength test as shown in Figures 5 and 6. We use a cubic sample for measuring compression strength, cylindrical sample for measuring tensile split strength and rectangular prismatic sample for measuring flexural strength because proper clamping conditions should be ensured so that property values should not be affected.

2.2. Solar Drying without PCM

GPB was kept in solar dryer and it took 24 hours for curing of moisture content. Brick was kept under ambient room temperature for 28 days for further curing in order to develop sufficient strength. After 28 days brick was taken for performing compression (cubic sample) strength test, tensile (cylindrical sample) split strength test and flexural (rectangular prismatic sample) strength test as shown in Figures 5 and 6.

2.3. Solar Drying with PCM

GPB was kept in solar dryer and it took 22 hours for curing of moisture content. Brick was kept under ambient room temperature for 28 days for further curing in order to develop sufficient strength. After 28 days brick was taken for performing compression (cubic sample) strength test, tensile (cylindrical sample) split strength test and flexural (rectangular prismatic sample) strength test as shown in Figures 5 and 6.

2.4. Open Sun Drying

GPB was also kept in open sun for direct drying which consumed 24 hours for curing of moisture content. Brick was kept under ambient room temperature for 28 days for further curing in order to develop sufficient strength. After 28 days brick was taken for performing compression (cubic sample) strength test, tensile (cylindrical sample) split strength test and flexural (rectangular prismatic sample) strength test as shown in Figures 5 and 6.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 October 2023 doi:10.20944/preprints202310.1648.v1

Figure 5. GPB kept in compression and tension split test.

Figure 6. GPB kept in flexural test.

3. Results

This section interprets the results that have been obtained through this research study. The compressive, tensile split strength and flexural strength test results have been tabulated as shown Table 3. The following has been inferred from the test results. Electrical oven drying is more uniform in nature when compared to solar drying. Electrical oven drying temperature is around 65°C throughout the curing process. Solar drying operates around 60°C but fluctuations depend on the outer ambience. It is evident from Figure 7 that Solar drying with PCM consumes 2 hour less curing time when compared to all other methods.

Table 3. Mechanical properties of GPB obtained from 4 curing methods.

Drying Methods	Compressive Strength (MPa)	Tensile Split Strength (MPa)	Flexural Strength (MPa)
Electrical dryer	35.70	3.65	4.95
Solar dryer with PCM	38.50	4.90	6.20
Solar dryer without PCM	36.30	4.10	5.70
Open sun dryer	39.20	5.60	6.70

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 October 2023 doi:10.20944/preprints202310.1648.v1

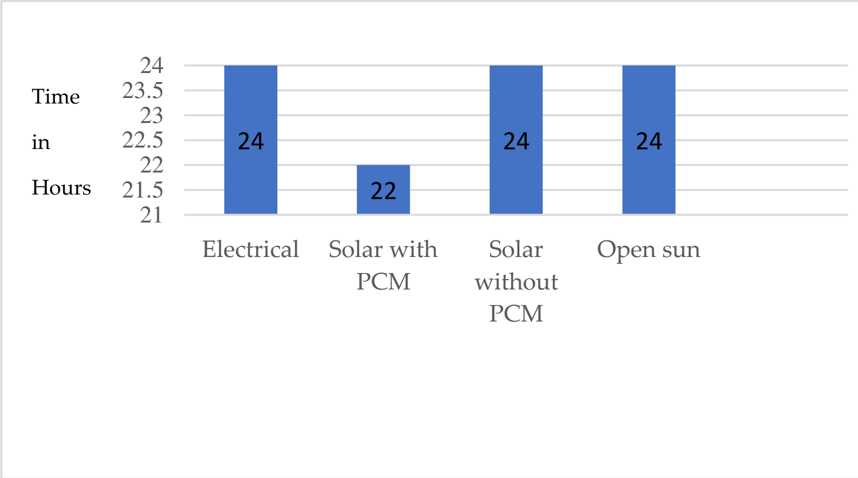

Figure 7. Curing Time Comparison of GPB of all four methods.

As per modified guidelines for Geo polymer concrete mix design using Indian standards, target compressive strength is around 30 MPa [2,3] but experimental results was obtained as 38.50 MPa in solar drying with PCM itself as shown in Figure 8 and Table 3. For geo polymers tensile split strength of 4.9 MPa was obtained in solar drying with PCM shown in Figure 9 and Table 3. Flexural strength of 6.2 MPa was obtained in solar drying with PCM shown in Figure 10 and Table 3.

Experimentally it is evident from Table 3 that solar dried brick with PCM and without PCM exhibits 7.84% and 1.7% higher compressive strength, 34.2% and 12.3 % higher tensile split strength, 25.25% and 15.15% higher flexural strength when compared to electrical oven dried brick respectively. Also Solar drying with PCM shows 6.1 % higher compressive strength, 19.5 % higher tensile split strength and 8.1 % higher flexural strength when compared to solar drying without PCM. At the same time open sun drying shows 1.8 %, 8 %, 9.8 %, higher compressive strength, 14.3 %, 36.5 %, 53.4 % higher tensile split strength and 8.1 %, 17.5 %, 35.35 % higher flexural strength properties when compared to solar drying with PCM, solar drying without PCM and electrical drying respectively.

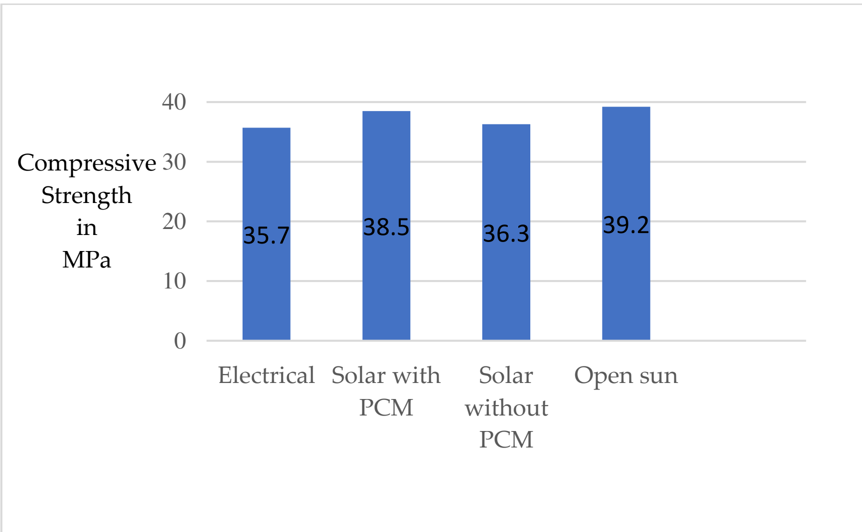

Figure 8. Compressive Strength Comparison of GPB of all four methods of curing. .

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 October 2023 doi:10.20944/preprints202310.1648.v1

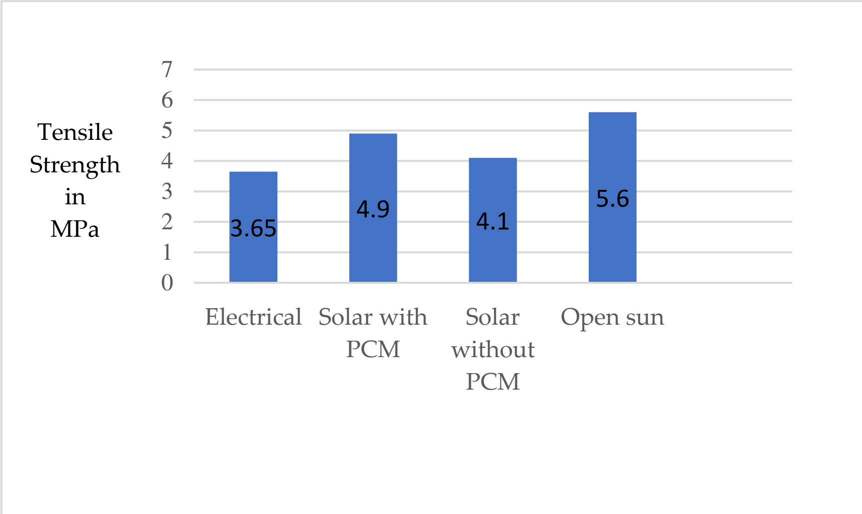

Figure 9. Tensile Split Strength Comparison of GPB of all four methods of curing.

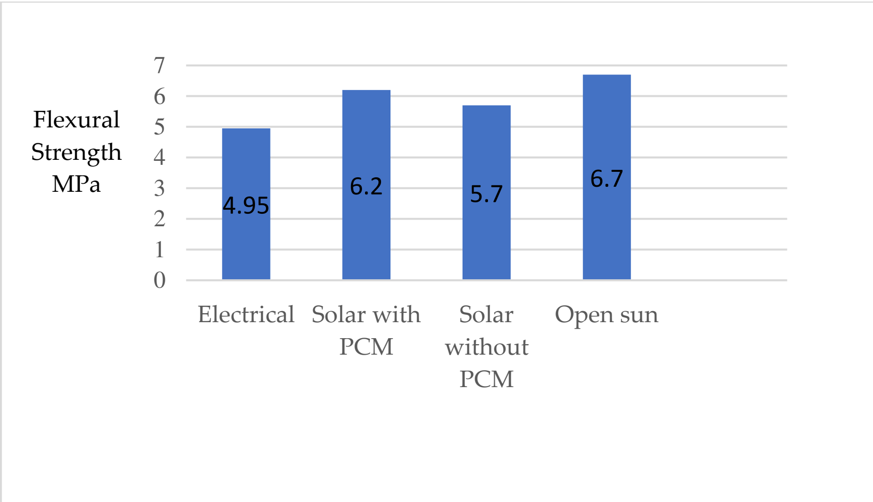

Figure 10. Flexural Strength Comparison of GPB of all four methods of curing.

In this work as solar energy is used which is free from fossil fuels for drying, economy is also met along with a safe climatic atmosphere so that the sustainability goals are met as shown in Table 4 below.

Table 4. Sustainability Development Goals (SDG).

Sustainability Development Goals	Description
SDG 7	Clean and affordable Energy – Usage of Solar energy
SDG 8	Economic Growth – Cheaper than Electric energy
SDG 13	Climate action and its impact –Free from fossil fuels and emissions

4. Discussion

Solar drying with PCM consumes 2 hour less curing time when compared to all other methods. which is in accordance with literature work [20]. This is due to the effect of PCM which captures more heat flux in the form of heat storage giving rise to hotter and uniform ambience inside the solar dryer when compared to the solar dryer without PCM. Experimentally it is evident from Table 3 that solar dried brick with PCM and without PCM exhibits higher compressive strength, tensile split strength, flexural strength when compared to electrical oven dried brick. This could be due to the effect of ambience which is hotter when compared to electric drying which occurs inside a room. This is also

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 October 2023 doi:10.20944/preprints202310.1648.v1

evident from literature work [20] which predicts that solar drying is more efficient and economic when compared to electric drying. Also Solar drying with PCM shows higher compressive strength, tensile split strength and flexural strength when compared to solar drying without PCM which is due to higher heat storage capacity by the PCM and changes in the atmospheric temperature are well absorbed by the PCM which gives rise to rough, tough and dry conditions in the brick. Open sun drying shows higher compressive strength, tensile split strength and flexural strength properties when compared to all other methods due to the brick surfaces exposed to very high sun temperatures in summer which gives rise to extreme rough, tough and dry conditions in the brick. Also waste management of products like fly ash from power plant is sustained by converting them into useful GPB which has proved it properties [2] as shown in Figures 8–10.

As solar drying is economical and shows better mechanical properties when compared to electrical drying, this study suggests that solar dryer as a potential candidate for curing of GPB for constructions applications. Also solar dryer is eco-friendly when compared to electrical dryer which satisfies the goal of SDG 7, 8 and 13. A simple Economic Analysis for 100 bricks for 4 modes of drying has been shown below in Figure 11. Electrical curing requires 3500 Watts of power consumption which results in usage of 0.4375 units of power supply. One unit in India cost Rs.8. therefore 0.4375 units cost Rs.3.5, whereas solar drying does not consume any electric power for curing. Assume 100 GPB per day are dried the total cost of electric curing would be 30*100*3.5 = Rs 10,500/- per month, where us solar drying does not need any electric power. Considering the cost of PCM Paraffin wax Rs 500 the Construction cost for solar dryer prototype is Rs 4000 without PCM and Rs 4500 with PCM. Solar dryer requires only initial cost and no running cost. Above all electrical energy is called as high grade energy because of its availability content when compared to thermal energy which has lesser availability when compared to electrical energy. Converting electrical energy into thermal energy in electrical oven curing to simply remove moisture content is not recommend from energy point of view. So on large scale basis like in construction industries curing of bricks by solar drying would be a better economic method when compared to electric oven drying.

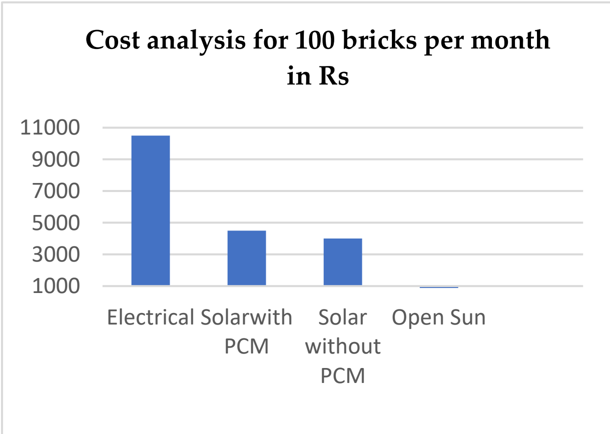

Figure 11. Economic Analysis for 4 drying modes.

5. Conclusion

- From Fly ash waste and other ingredients the constructed GPB undergoes full curing in all the four methods.
- Solar dryer with PCM consumes 2 hours less curing time when compared to all other methods.
- As per modified guidelines for Geo polymer concrete mix design using Indian standards, target compressive strength is around 30 MPa [2,3] but experimental results was obtained as 38.50 MPa in solar dried brick with PCM.
- Solar dried brick with PCM and without PCM exhibits 7.84% and 1.7% higher compressive strength, 34.2% and 12.3 % higher tensile split strength, 25.25% and 15.15% higher flexural strength when compared to electrical oven dried brick respectively.

- Also Solar drying with PCM shows 6.1 % higher compressive strength, 19.5 % higher tensile split strength and 8.1 % higher flexural strength when compared to solar drying without PCM.
- At the same time open sun drying shows 1.8 %, 8 %, 9.8 %, higher compressive strength, 14.3 %, 36.5 %, 53.4 % higher tensile split strength and 8.1 %, 17.5 %, 35.35 % higher flexural strength properties when compared to solar drying with PCM, solar drying without PCM and electrical drying respectively.
- But open sun drying may cause degradation of materials of GPB which may lead to extreme dry conditions inside GPB which may not be suitable from application point of view.
- Use of PCM like paraffin wax in solar dryer has pronounced effect on curing time and mechanical properties of GPB.
- When sustainability goals are concerned solar energy is a better performer when compared to electrical energy. From this research work we conclude that by using solar energy in drying applications we can save high grade electrical energy from energy and economy point of view.
- GPBs are finding their application in construction sectors as their properties are in accordance with concrete design standards.
- Newer PCMs (organic or inorganic) may be tested inside solar dryer for curing of GPB which forms the scope for future work. Along with, in what way PCMs can influence the mechanical properties of GPB can be studied. Also a thermal degradation study of PCMs is suggested as scope for future study to have an idea of entropy changes occurring inside PCMs so that the correlation between degradation and life of PCMs for solar dryer application can be established.

Author Contributions: Conceptualization, BJ.A. and S.M.; methodology, BJ.A. And S.M; software, R.S.P.; validation, B.J.A and S.M; formal analysis, R.V.I.S.; investigation, B.J.A.; resources, B.J.A.; data curation, B.J.A.; writing—original draft preparation, S.M.; writing—review and editing, R.S.P.; visualization, R.S and M.R.; supervision, S.M.; project administration, R.S.; funding acquisition, M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Any data related to this research study can be obtained from the corresponding authors upon request.

Acknowledgments: The authors are grateful for the support given by "Navajo Technical University, New Mexico, USA" to conduct the research and publication works.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. G.R. Gopinath, S. Muthuvel, M. Muthukannan, R. Sudhakarapandian, B. Praveen Kumar, Ch.Santhan Kumar, Sudhakar Babu Thanikanti. Design, development, and performance testing of thermal energy storage based solar dryer system for seeded grapes. Sustainable Energy Technologies and Assessments, Volume 51, June 2022, 101923. https://doi.org/10.1016/j.seta.2021.101923
2. IS 10262 (2009) Guidelines for Concrete Mix Design, Proportioning [CED2 Cement and Concrete], Bureau of Indian Standards.
3. Anuradha Ramachandran, R. Venkatasubramani, Srividya Venkataraman, B.V. Rangan. Modified guidelines for geopolymer concrete mix design using Indian standard Article in Asian Journal of Civil Engineering· January 2012. https://www.researchgate.net/publication/286998254
4. Zaineb Azaizia, Sami Kooli, Ilhem Hamdi, Wissem Elkhal, Amen Allah Guizani Experimental study of a new mixed mode solar green house drying system with and without thermal energy storage for pepper. Renewable Energy, Volume 145, January 2020, Pages 1972-1984. https://doi.org/10.1016/j.renene.2019.07.055
5. Santanu Malakar, Vinkel Kumar Arora. Development of phase change material assisted evacuated tube solar dryer: Investigation of thermal profile, drying characteristics and functional properties of pumpkin slices. https://doi.org/10.1016/j.ifset.2022.103109
6. Langov´a R, Jůzl M, Cwikov´a O, Kos. Effect of Different Method of Drying of Five Varieties Grapes (Vitisvinifera, L.) on the Bunch Stem on Physicochemical, Microbiological, and Sensory Quality. Foods 2020; 9(9):1183. https://doi.org/ 10.3390/foods9091183
7. Nicola De Simone, Vittorio Capozzi, Maria Lucia Valeria de Chiara, Maria Luisa Amodio, Samira Brahimi, Giancarlo Colelli, Djamel Drider, Giuseppe Spanoand Pasquale Russo. Screening of Lactic Acid Bacteria

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 October 2023 doi:10.20944/preprints202310.1648.v1

for the Bio-Control of Botrytis cinerea and the Potential of Lactic plant bacillus plantarum for Eco-Friendly Preservation of Fresh-Cut Kiwifruit. Journals/Microorganisms/Volume9/Issue4/10.3390/ microorganisms 9040773. https://doi.org/10.3390/microorganisms9040773
8. Bharani Priya A, Dinesh kumar M, Naveen Romi J, Vijay Nepolean A, Kirubakaran V. Solar Dryer Integrated with Thermal Energy Storage Systems for the Preparation of Dry Grapes in the Farmyard. Sustainable Rural Farming Approach. Research Journal of Chemistry and Environment. Vol.24 (Special Issue I), (2020).
9. Shiva Gorjian, Behnam Hosseing holilou , Laxmikant D. Jathar, Haniyeh Samadi, Samiran Samanta, Atul A. Sagade, Karunesh Kant and Ravi shankar Sathyamurthy. Recent Advancements in Technical Design and Thermal Performance Enhancement of Solar Green house Dryers. Journals/Sustainability/Volume13/Issue13/10.3390/su13137025. https://doi.org/10.3390/su13137025
10. Ankit Srivastava, Abhishek Anand, Amritanshu Shukla, Anil Kumar, D. Buddhi, Atul Sharma. A comprehensive overview on solar grapes drying: Modeling, energy, environmental and economic analysis. Sustainable Energy Technologies and Assessments. Volume 47, October 2021, 101513. https://doi.org/10.1016/j.seta.2021.101513
11. Edidiong Joseph EJ Bassey, JH Cheng, DW Sun. Novel non thermal and thermal pretreatments for enhancing drying performance and improving quality of fruits and vegetables- Trends in Food Science & Technology, 2021 – Elsevier. https://doi.org/10.1016/j.tifs.2021.03.045
12. K Sridhar, AL Charles. Mathematical Modeling to Describe Drying Behavior of Kyoho (Vitis labruscana) Skin Waste: Drying Kinetics and Quality Attributes. Processes, 2022 - mdpi.com. https://doi.org/10.3390/pr10102092
13. E Elavarasan,Y kumar, R Mouresh, Sendhil Kumar Nataraja. Experimental investigation of drying tomato in a double slope solar dryer under natural convection.. Advances in Mechanical and Materials Technology: Select Proceedings of EMSME 2020, 179- 190, 2022. https://DOI: 10.1007/978-981-16-2794-1_16
14. D Saikia, PK Nayak, KR Krishnan. Development of indirect type solar dryer and experiments for estimation of drying parameters of dhekia (Diplazium esculentum). Materials Today /proceedings. Volume 56, Part 2, 2022, Pages 774-780. https://doi.org/10.1016/j.matpr.2022.02.255
15. Ouassila Badaoui,Salah Hanini, Ahmed Djebli, Brahim Haddad, Amina Benhamou Experimental and modelling study of tomato pomace waste drying in a new solar greenhouse: Evaluation of new drying models. Renewable Energy, Volume 133,April 2019, Pages 144-155. https://doi.org/10.1016/j.renene.2018.10.020
16. Sukhmeet Singh, R.S.Gill, V.S.Hans, T.C.Mittal. Experimental performance and economic viability of evacuated tube solar collector assisted greenhouse dryer for sustainable development. Energy Volume 241, 15 February 2022, 122794, Elsevier. https://doi.org/10.1016/j.energy.2021.122794
17. Yanying Bai, Weichao Guo, Jianwei Wang, Zehua Xu, Shuai Wang, Qingxin Zhao, Jinman Zhou. Geo polymer bricks prepared by MSWI fly ash and other solid wastes: Moulding pressure and curing method optimization. Chemosphere, Volume 307, Part 3, 2022, 135987,ISSN0045-6535. https://doi.org/10.1016/j.chemosphere.2022.135987
18. Hao Shi, Hongwen Ma, Linan Tian, Jing Yang, Jiangyan Yuan. Effect of microwave curing on metakaolin-quartz-based geo polymer bricks, Construction and Building Materials. Volume 258, 2020,120354, ISSN 0950-0618. https://doi.org/10.1016/j.conbuildmat.2020.120354
19. Mohammed Rihan Maaze, Sandeep Shrivastava. Design development of sustainable brick-waste geo polymer brick using full factorial design methodology, Construction and Building Materials., Volume 370, 2023, 130655,ISSN 0950-0618. https://doi.org/10.1016/j.conbuildmat.2023.130655
20. Juan Pablo Capossio, María Paula Fabani, Andrés Reyes-Urrutia, Rodrigo Torres- Sciancalepore, Yimin Deng, Jan Baeyens, Rosa Rodriguez and Germán Mazz. Sustainable Solar Drying of Brewer's Spent Grains : A Comparison with Conventional Electric Convective Drying. Process_Design_Development/Journals/Processes/Volume 10/Issue 2/10.3390/pr10020339. https://doi.org/10.3390/pr10020339
21. A. Chithambar Ganesh, M. Muthukannan. Development of high performance sustainable optimized fibre reinforced geo polymer concrete and prediction of compressive strength. Journal of Cleaner Production, Volume 282, 2021, 124543, ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2020.124543
22. Vigneshwaran Shanmugam, Deepak Joel Johnson Rajendran, Karthik Babu, Sundarakannan Rajendran, Arumugaprabu Veerasimman, Uthayakumar Marimuthu, Sunpreet Singh, Oisik Das, Rasoul Esmaeely Neisiany, Mikael S. Hedenqvist, FilippoBerto, Seeram Ramakrishna. The mechanical testing and performance analysis of polymer-fibre composites prepared through the additive manufacturing, Polymer Testing, Vol93, 2021, 106925, ISSN0142-9418. https://doi.org/10.1016/j.polymertesting.2020.106925
23. Ammar Saliby, Béla Kovács. Minimization of annual energy consumption by incorporating phase change materials into building components: a comprehensive review, Volume 54, Issue 13, 2023, pp. 65-91, https://DOI: 10.1615/Heat Trans Res.2023047570

 doi:10.20944/preprints202310.1648.v1

24. Pranav Mehta, Nilesh Bhatt, Gurmitsingh Bassan, Abd Elnaby Kabeel. Performance improvement and advancement studies of mixed-mode solar thermal dryers: a review Environmental Science and Pollution Research 29 (42), 62822-62838, 2022. https://doi.org/10.1007/s11356-022-21736-3
25. Mall P, Singh D. Comparative study of performance of indirect mode with PCM and mixed mode solar dryer for coriander leaves. Int J Appl Eng Res 2018;13(8): 5909–19.
26. Mario Palacio, Camilo Ramírez, Mauricio Carmona, Cristóbal Cortés. Effect of phase change materials in the performance of a solar air heater Solar Energy 247, 385-396, 2022. https://doi.org/10.1016/j.solener.2022.10.046
27. Shanghai Huakeer Wang, Wei Lu, Zhigen Wu, Guanhua Zhang. Parametric analysis of applying PCM wallboards for energy saving in high-rise lightweight buildings Renewable Energy 145, 52-64, 2020. https://doi.org/10.1016/j.renene.2019.05.124
28. Hajar Essalhi, Mohammed Benchrifa, Rachid Tadili. Effect of Natural and Forced Ventilation on Drying of Kiwi in an Indirect Solar Dryer Sustainable Energy Development and Innovation: Selected Papers from the World Renewable Energy Congress (WREC) 2020, 177-180, 2022. https://doi.org/10.1007/978-3-030-76221-6_24
29. López-Vidaña Erick César, César-Munguía Ana Lilia, García-Valladares Octavio, Pilatowsky Figueroa Isaac, Brito Orosco Rogelio. Thermal performance of a passive, mixed-type solar dryer for tomato slices (Solanum lycopersicum) Renewable Energy 147, 845-855, 2020. https://doi.org/10.1016/j.renene.2019.09.018
30. Atalay H, Coban MT, Kıncay O. Modeling of the drying process of apple slices: Application with a solar dryer and the thermal energy storagesystem. Energy 2017; 134:382–91. https://doi.org/10.1016/j.energy.2017.06.030