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Analysis and Optimization of Hybrid Soil Properties for Gel Based Roof Tiles

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Abstract: ***Our current 21st century has seen more drastic changes in terms of environmental conditions due to global warming, climate change and deforestation. This has shown a great rise in the global temperature throughout the world. Normally, the roof top of a building is provided with tiles to protect the structural components and to create a comfortable environment. The tiles can be made of materials like clay, concrete, fly ash, lime etc. Due to the prevailing environmental challenges, there is a need for the tiles to be made as with more energy efficient material that supports thermal insulation and cost effectiveness. Aerogel and hydrogel are the gel based product that are used in our current work to enhance the thermal insulation property of the tiles. Various tests such as water absorption test, wet and dry cycle test, bending strength test, thermal conductivity test, wear and tear test are carried out on the tile to quantify its characteristics. All the above shows better value than the normal commercial tile product.***

Keywords: Aerogel, Hydrogel, tiles, water absorption test, wet and dry cycle test, bending strength test, thermal conductivity test, wear and tear test

I. INTRODUCTION

Roof terrace is an open, external area located on the top of a building. They are exposed to various environmental conditions and constant sunlight. Due to the constant exposure to sunlight, the heat is also transmitted into the building and increases the temperature of the building. To solve this condition, tiles are laid on the terrace. Tile is a thin rectangular slab made of baked clay or other material. There are various types of tiles including porcelain and non porcelain tile. Porcelain tile is made of clay, sand and feldspar. Non Porcelain tile is made by adding along a ceramic material. The main function of the tile is to provide thermal insulation (i.e) not to let heat to pass through them. So that the indoor temperature of the building is minimum to an extent. As per research, Clay tile has the highest thermal insulation capacity and it is the most efficient and cost efficient material for the tile to be made.

Over the last 100 years we are witnessing more drastic changes in the environment because of global warming and climate change. As per research, the overall surface temperature of the earth has increased by 1° F in the last 100 years. Indoor room temperature also plays an important role in the health of the resident. When the indoor room temperature is higher than 26° C, it causes various health problems. Eight main health effects were described: respiratory, blood pressure, core temperature, blood glucose, mental health and cognition, heat-health symptoms, physical functioning and influenza transmission. To solve this problem there is a need for the tiles to be made with low thermal conductivity. This can be achieved by adding to the tile materials that have a low thermal conductivity. Aerogel and hydrogel are identified have a low thermal conductivity. By adding these materials in a selected proportion, the more will be the thermal insulation in the tile.

Aerogel is a synthetic porous ultralight material derived from a gel, in which the liquid component for the gel has been replaced with a gas without significant collapse of the gel structure. The result is a solid with extremely low density and extremely low thermal conductivity. Aerogel was first created by Samuel Stephens Kistler in 1931. The first aerogels were produced from silica gels. Kistler's later work involved aerogels based on alumina, chromia and tin dioxide. Carbon aerogels were first developed in the late 1980s.

A hydrogel is a network of cross-linked polymer chains that are hydrophilic, sometimes found as a colloidal gel in which water is the dispersion medium. A three-dimensional solid result from the hydrophilic polymer chains being held together by cross-links. Hydrogels are highly absorbent (they can contain over 90% water) natural or synthetic polymeric networks. The thermal conductivity of hydrogel is 0.57 W/mK. The hydrogel is mainly utilized in the field of agriculture and pharmaceutical industry and its applications are yet to be explored in the construction industry. Most significant factor about making the hybrid tile is the proportioning. The materials that which are to be added to the tile mix has to have the right proportion. So that they react well and produce the results they are intended to provide or else they may show adverse effects and even weaken the tile. The proportions can be determined by trial and error method or by referring to journals that gives information on these characteristics. Tiles must also have a high durability, because they are expected to last for at least 20 years. So while making an hybrid tile, durability must also be ensured. The strength of the tile must also be considered. Though strength is not an important factor in the tile, they should at least have a least amount of strength to withstand load at certain conditions.

OBJECTIVES

- To study the thermal behaviour of terracing roof tile using gel based admixture to reduce the thermal effect in residential buildings.

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- To develop cost effective heat resistant tile with adequate strength and durability.
- To produce eco-friendly cost effective terracing roof tile using hybrid soil materials.

II. LITERATURE REVIEW

The study also examines granular added type insulation with 20, 40 and 60% volume fractions of plastic in powder form as well as same volume of fractions separately but with Polyurethane foam by introducing them into tile made mixture. These tiles are tested unsteadily (at different local hour times) in real domestic room during day and night hours. The results show a clear difference in thermal insulation ability according to tile composition, addition type and thickness. This study designs and makes an ideal tile, collects improved thermal insulation, strength, lightweight, moist proof, wear resist as well as low cost. The results show a good agreement between the experimental and theoretical analysis. The heat savings reach 40% of the room floor share from total room heat loss for rubber added type as upper limit and 5% for plastic-powder (20% volume fraction) added type as lower limit with a gradual percentage for other types between limits (1). The developed cool roof solution is characterized by the same visual appearance of traditional "natural brick" colour tiles, while the solar reflectance is higher than natural terracotta tile by 13%. Therefore its thermal performance is optimized in order to reduce the roof overheating and the consequent energy requirement for cooling. Results of dynamic simulation of the case study building show how the proposed tile is able to decrease the number of hours when the indoor operative temperature of the attic is higher than 26°C by 18%, while the same effect in lowering the indoor temperature below 20°C in winter is less than 1%. Therefore, the proposed solution could be considered as an interesting strategy for new buildings or for traditional roof retrofitting, without producing any significant architectural impact, even in traditional or historic buildings, where more invasive solutions are too difficult to be implemented (2).

This Paper studies the shape of high-thermal insulating concrete tiles used for roof tiling. The theoretical part consists of a comparison between this invented tiles and ordinary terrazzo tiles. The analysis depends on the values of thermal conductivity of the material used. The results showed that when these tiles are used for roof tiling, the temperature difference between the outside of roof surface and the inside room can be reduced about six times compared with the use of ordinary terrazzo tiles. In addition, these specimens were fabricated and tested for rupture and absorption tests. The test results showed that, they had a good resistance to the applied test loads, and high resistance to water absorption. The authors believe that, the results are remarkable, highly applicable and should be taken into consideration in building constructions (3). In Indian buildings concrete roof tiles are mostly used. Commonly in traditional rural residential buildings. The cooling roof tile technology provides less heat absorbs and sunlight reflecting comparing to standard roof tile. Just providing light color can reduce the heat gain in hot climate, same principal is used in cooling roof tile material. Considering the essential function of roofing features in building energy efficiency and interior thermal quality conditions, novel approaches to enhance the thermal energy output of this diffused roofing feature have become a main development issue. In this opinion, cool roofing technologies are an important approach to this goal. The current research deals with the Review of revolutionary materials or coatings for conventional roof tiles, with the goal of growing their cooling capacity (4). The Urban Heat Island (UHI) is a phenomenon that affects millions of people worldwide. The higher temperatures are experienced in urban areas compared to the surrounding countryside and have enormous impacts on the health and wellbeing of people living in cities. The increased use of manmade building materials and increased anthropogenic heat production are the main causes of the UHI. This has led to the perceptive that increased urbanization is the most important cause of the urban heat island. The UHI impact additionally results in expanded energy demands that further add to the heating of our urban landscape, and the related environmental and public health issues. Pavements and roofs dominate the urban surface exposed to solar irradiation. This article summarizes the contribution that roofs make to the UHI effect and analyses localized mitigation strategies against the UHI. In this study, the thermal properties of the widely used roofs are investigated to estimate the potential for mitigating the UHI effect. The ability of roofs to regulate indoor thermal comfort was also analyzed (5). Earthenware is proof of our way of life improvement in an archaeological manner. Ceramics is intricate of water, soil, and mud compound utilized as home vessels of old periods. Ceramics making has become a preservationist industry in numerous pieces of the world. This industry is called ceramics in Tamil, and stoneware is classified "Potter." Pot has fundamentally in mud porcelain or (Kaolinite), mud normally contains 40% aluminium oxide, 46% silicon oxide, and 14% water may be all things considered insinuated as having utilization is a lot of medical advantages. Earthenware is organized using a variety of strategies like carefully assembled and potter's wheel strategy. In old Tamilians was fabricated numerous sorts of pots are utilized different purposes and satisfied their needs (6). In this work, the gels used in the tile are aerogel and hydrogel which have a very low thermal conductivity and also provide strength and high resistance to deformations. Thus high thermal insulation in the tile can be achieved without compromising the strength and other important characteristics.

III. MATERIALS AND ITS PROPERTIES

Silica Aerogel

Aerogel is a synthetic porous ultralight material derived from a gel in which the liquid component of the gel has been replaced with a gas. The result is a solid with extremely porous, low density and low thermal conductivity. Sol-gel is the most used method of preparation. Aerogel melts at 1200ºC and the thermal conductivity is almost 0. Is a solid material with the smallest density because contains about 99.8% air. Aerogel insulation is a good choice because it nearly neutralizes all three methods of heat transfer: convection, conduction and radiation. The resistance to thermal transfer by conduction is given by the majority of gaseous components. Therefore, the most used aerogel for thermal insulation is the silica aerogel with carbon as nanostructured material. The high price makes it currently inaccessible and less used material.

Figure 1.Silica Aerogel

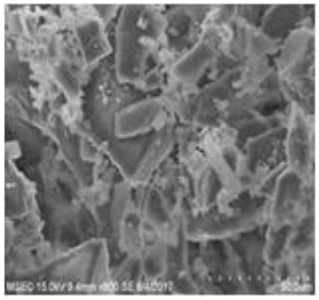

Figure 2. SEM image

In this project we are adopting silica aerogel for purpose of achieving low thermal conductivity in roof terrace tile. Silica aerogel is the most common type of aerogel, and the most extensively studied and used. Silicon aerogel is a nanostructured material with high specific surface area, high porosity, low density, low dielectric constant, and excellent heat insulating properties. The silica solids, three-dimensional, intertwined clusters that comprise only 3% of the volume. Conduction through the solid is therefore very low. The remaining 97% of the volume is composed of air in extremely small nanopores. The air has little room to move, inhibiting both convection and gas-phase conduction. Figure 1 and 2 represents Silica Aerogel and SEM image of Silica Aerogel respectively.

Hydrogel

Hydrogels are three-dimensional, hydrophilic, polymeric networks proficient in absorbing a great amount ofwater or biological fluids. Owing to their high water content, porosity and soft consistency, they intently simulate natural living tissue, more so than any other category of synthetic biomaterials. Hydrogels can either be chemically durable or they may eventually disintegrate and dissolve.

Figure 3. Hydrogel

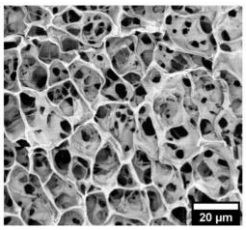

Figure 4. SEM image

Hydrogels are also known as 'reversible' or 'physical' gels if molecular entanglements and/or secondary forces such as ionic, hydrogen bonding or hydrophobic forces play the principal role in forming the linkage. Hydrogels can be manufactured practically from any watersoluble polymer, including a wide range of chemical compositions and bulk physical properties. Additionally, hydrogels can also beformulated in a number of physical forms such as slabs, microparticles, nanoparticles, coatings or films. Accordingly, hydrogels are universally being employed in clinical practices and investigational medicine for a wide variety of applications. Figure 3, 4, 5 and 6 represents Main components of hydrogel, Classification of hydrogel, hydrogel and SEM image of hydrogel respectively. It shows the properties of hydrogel.

Alluvial Soil

Alluvium is loose soil or sediments that is eroded and carried in suspension by flood or river water before being deposited. The material of alluvium is may be unconsolidated, i.e. not formed together into solid rock, and can by picked up or eroded and carried away by moving water before being deposited elsewhere when the water flow slows down. Where the loose alluvial material is consolidated into a stone-like material, this is known as lithification. The fine-grained fertile soil that is deposited by water that flows over flood plains or river beds is known as alluvial soil. Alluvial soils are most fertile, occupying over 43% of the total soil area of the country. These soils are formed through the process of deposition of sediments (sand, silt, clay, etc.) in layers. Alluvial soils are classified into newer alluvium (Khadar), and the older alluvium (Bhangar). The Bhangar lands are generally above the flood levels. The Bhangar lands are however, characterised with Bhurs (winds – deposits), and usar soils. Figure 5 represents alluvial soil.

Figure 5. Alluvial Soil

Red Soil

Red soil, Any of a group of soils that develop in a warm, temperate, moist climate under deciduous or mixed forests and that have thin organic and organic-mineral layers overlying a yellowish-brown leached layer resting on an alluvial red layer. Red soils generally form from iron-rich sedimentary rock. They are usually poor growing soils, low in nutrients and humus and difficult to cultivate. Red soils develop over the old crystalline and metamorphic rocks. They occupy over 18% of the total soil area of the country. These are found in the hot and humid regions.

The colour of the soils is generally red due to high iron content. Red soils cover a large part of Tamilnadu, Karnataka, Andhra Pradesh, Chattisgarh, Jharkhand, Madhya Pradesh and Odisha. These soils are poor in phosphorous, nitrogen and lime content. Figure 6 represents red soil. enhancement.

Figure 6. Red Soil

Earthenware Clay

Earthenware is glazed or unglazed non-vitreous pottery which has normally been fired below 1200°C. Porcelain, bone china and stoneware, all fired at high enough temperatures to vitrify, are the main other important types of pottery. Earthenware bodies exhibit higher plasticity than most whiteware bodies and hence are easier to shape by RAM press, roller-head or potter's wheel than bone china or porcelain.

Due to its porosity, earthenware, with a water absorption of 5-8%, must be glazed to be watertight. Earthenware has lower mechanical strength than bone china, porcelain or stoneware, and consequently articles are commonly made in thicker cross-section, although they are still more easily chipped. There are several types of earthenware : Terracotta, Redware, Victorian majolica, Lusterware with special iridescent glazes, Raku, Ironstone China, Yellowware. Figure 7 represents earthenware clay.

Figure 7. Earthenware Clay

Hybrid Soil

The different types of soils are mixed in various proportions and the optimum proportion is achieved. According to the optimum proportion the properties of the hybrid soil is tested. The optimum moisture content that is determined by Proctor compaction method and the liquid limit value are shown in the figures 8 and 9.

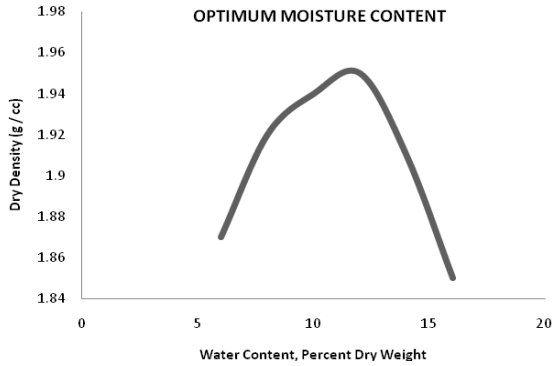

Figure 9. Moisture-Density Relationship

IV. MANUFACTURING PROCESS

Preparation of clay

Preparation of clay for roof tile manufacturing is done in six steps: Unsoiling of clay we need pure clay for the preparation of roof tile. The top layer of soil may contains impurities, so the clay in top layer of soil about 200mm depth is thrown away. This is called unsoiling. Digging After the removal of top layer, the clay is dug out from the ground and spread on the plain ground. Cleaning In this stage, the clay is cleaned of stones, vegetable matter etc. if large quantity of particulate matter is present, and then the clay is washed and screened. The lumps of clay are converted into powder with earth crushing rollers. Weathering the cleaned clay is exposed to atmosphere for softening. The period of weathering may be 3 to 4 weeks or a full rainy season. Generally, the clay is dug out just before the rainy season for larger projects. Blending if we want to add any ingredient to the clay, it is to be added in this stage by making the clay loose and spread the ingredient over it. Then take small portion of clay into the hands and tuning it up and down in vertical direction. This process is called blending of clay. Tempering In this stage, water is added to clay and pressed or mixed. The pressing will be done by cattle or with feet of men for small scale projects, pug mill is used as grinder for large scale projects. So, the clay obtains the plastic nature and now it is suitable for moulding. In this project we have selected three types of clay: Earthenware clay, Alluvial soil, Red soil and two types gels: Aerogel and Hydrogel.

Drying

After moulding process the tiles contain some amount of moisture in it. So, drying is to be done otherwise they may cracked while burning. The drying of raw clay tile is done by natural process. The period of drying may be 3 to 10 days. It also depends upon the weather conditions. The drying yards are also prepared on higher level than the normal ground for the prevention of roof tiles from rain water. In Some situations artificial drying is adopted under special dryers or hot gases. In this project the tiles are dried for a period of 10 days using natural process. Figure 11 represents drying of raw tiles in direct sunlight.

Figure 11. Drying of raw tiles in direct sunlight

Burning

In the process of burning, the dried tiles are burned either in clamps (small scale) or kilns (large scale) up to certain degree temperature. In this stage, the clay tile will gain hardness and strength so it is important stage in manufacturing of tiles. The temperature required for burning is about 800^{O}C. If they burnt under this limit, they will not gain full strength and there is a chance to absorb moisture from the atmosphere. Hence burning should be done properly to meet the requirements of good tile. In this project the tiles were heated in the clamp for a period of 3 days in the brick chamber. Figure 12 represents clamp burning of tiles, bentonite clay, fly ash based tile, conventional clay roof tile, gel based clay roof tile respectively.

Figure 12. Clamp Burning of tiles

V. EXPERIMENTAL TESTING

Bending Strength Test

It allows the determination of the breaking load, the breaking strength and the rupture modulus of a tile by applying a bending force at the centre of the tile at a specified rate, the point of application being in contact with the tile's leveled surface. Figure13 and 14 shows the tile flexural strength testing machine with specimen before loading and after loading. The bending resistance (σ) N/mm^2 is determined by using the following formula.

$$\text{Bending resistance } (\sigma) = 3FL/2bh^2$$

Figure 13.Before Loading **Figure 14.After Loading**

Water Absorption Test

Water absorption is the measure of the amount of pore in the hardened sample that is filled by saturated specimen with water. After curing in the oven, the dry weight of the sample is taken and weighted as W, and the sample is then soaked in the water for 24 hours. The sample is taken out after 24 hours and washed with the clean rag, and the weight (W_0) is measured. As shown in the Figure 15, the tile specimens are tested for water absorption in accordance with ASTM C64206

$$\text{Water absorption } (\%) = (W_0 - W) / W$$

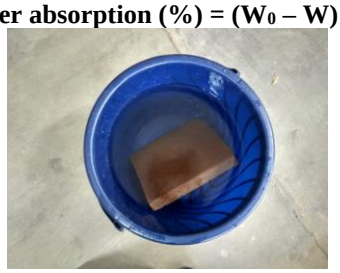

Figure 15. Water Absorption Test

Abrasion Test

The main objective of abrasion test is tofind the durability of the tile. In this test, a test specimen is placed in the apparatus so that it is tangential against the rotating disc and ensure that the feed of abrasive material into the grinding zone is uniform at a rate of atleast 100g / 100 revolutions. Rotate the steel disc for 220 revolutions. Remove the test specimen from the apparatus and measure the chord length of the groove by means of the measuring gauge to the nearest 0.5 mm. Test each speciman in at least two places at right angles in its proper surface. Figure 16 represents tile abrasion test machine.

$$T = 10 (W_1 – W_2) V_1 / W_1A$$

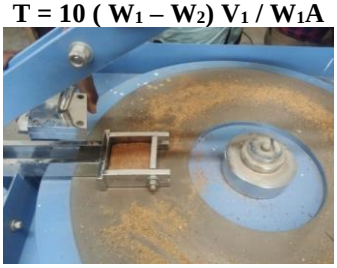

Figure 16. Tile Abrasion Test

Thermal Conductivity Test

In this project, Guarded hot plate method is used to measure the thermal conductivity of clay tile. A solid sample of materials is placed between two plates, one plate is heated and other is cooled or heated to lesser extent. Temperature of the plate is monitered until they are constant. The steady state temperature, the thickness of the sample and the heat input to the hot plate are used to calculate thermal conductivity. Figure 17 represents tile placed in guarded hot plate apparatus.

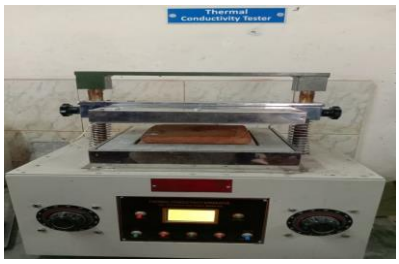

Figure 17. Tile in Guarded Hot Plate

Wet and Dry Cycle Test

The freezing and thawing test is done to determine the resistance of tile to the weathering conditions. A tile is divided into 8 equal parts and are weighed.

Figure 18. Hot Air Oven **Figure 19. Tile in Water**

In a simultaneous time, 4 tile pieces are kept in oven for heating and 4 tile pieces are immersed in water. After 1 hour they are taken out an are weighed. In the next trial the tiles which are first immersed in water are heated and vice versa. After 1 hour they are taken out and weighed. This continues for 6 trials. Figure 18 and 19 shows the wetting and drying process of tile.

VI. RESULTS AND DISCUSSION

Bending Strength Test

The graphical image represents the bending strength of the tile obtained by adding aerogel and hydrogel to the tile. The tile which is incorporated with aerogel and hydrogel has a lower value than the conventional tile. Pores created by the hydrogel slightly lower the strength. Figure 20.

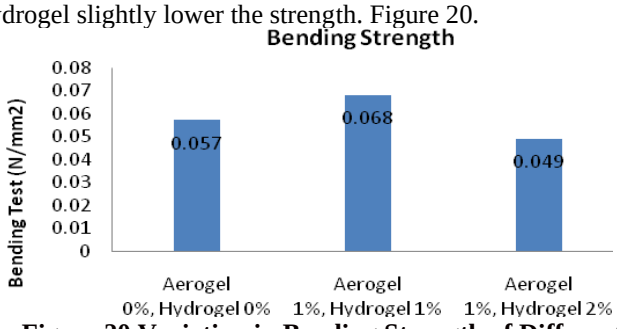

Figure 20 Variation in Bending Strength of Different Gel Based Tiles

From the graph it is inferred that when 1% of aerogel and hydrogel is added to the tile the strength increases compared to the conventional tile but when the addition of hydrogel content is higher, strength decreases. So the tile with 1% of aerogel and hydrogel is found to be more efficient in terms of bending strength.

Water Absorption Test

The specimens are further tested for water absorption. The water absorption of the tile added with aerogel and hydrogel have higher water absorption than the conventional tile. This is because the hydrogel has a higher swelling capacity and can absorb more water. The tile with 1% hydrogel has water absorption and the tile with 2% hydrogel has a water absorption given in Figure 21. As per IS 2690 (Part 2): 1992 Burnt Clay Flat Terracing Tiles-Specification: Part 2 Hand made the water absorption shall not exceed 20%. In this case all the three types of tiles have water absorption less than 20%.

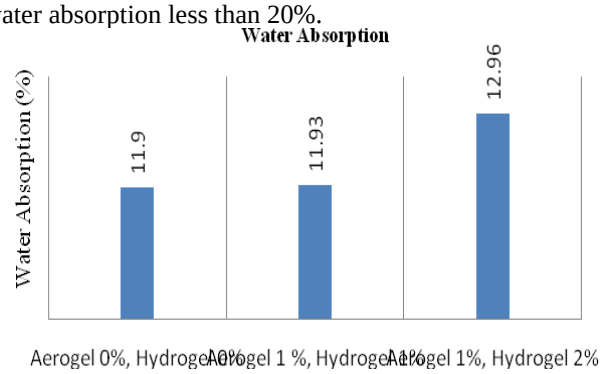

Figure 21 Variation in Water Absorption of Different Gel Based Tiles

Abrasion Test

The abrasion test is done by using tile abrasion testing machine for 220 turns. The value obtained for the convention tile and the abrasion value of the added with hydrogel and aerogel he abrasion value of the tile with hydrogel and aerogel is higher than the normal tile.

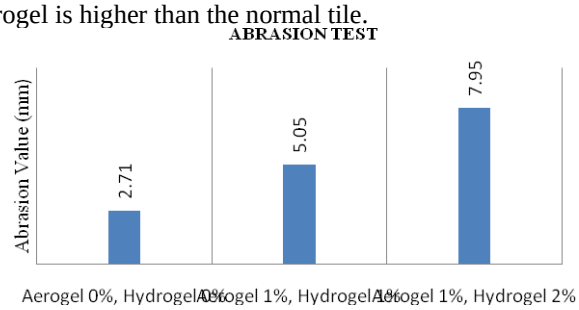

Figure 22 Variation in Abrasive Behaviour of Different Gel Based Tiles

From the Figure 22, it is known that when the amount of hydrogel increases the abrasion of the tile also increases. This proves that when hydrogel is added in higher quantity it affects toughness of the tile.

Thermal Conductivity Test

The thermal conductivity of the tile is done by using guarded hot plate method. The value obtained for the conventional tile and the value obtained for the tile with aerogel and hydrogel. The tile with aerogel and hydrogel has a lower conductivity than the conventional tile. The thermal conductivity value of conventional clay tile and Gel based tile is shown in table 9 and figure 23.

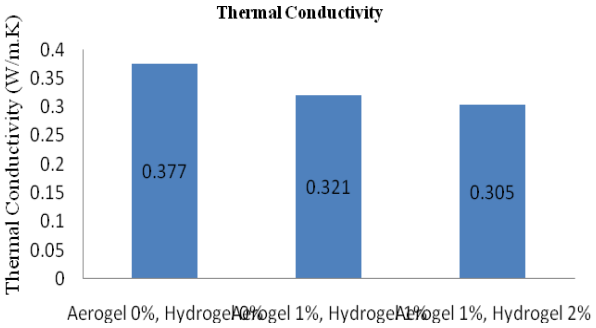

Figure 23 Variation in Thermal Conductivity of Different Gel Based Tiles

From the figure 23,it is found that when aerogel and hydrogel which have low thermal conductivity are added to the tile, the thermal insulation of the tile is higher. The trials were stopped when hydrogel was added at 2% because beyond that limit, the strength of the tile was drastically reduced.

Wet and Dry Cycle Test

The wet and dry cycle test is done for 6 trials with the time period of every 1 hour. In the wet and dry cycle test figure 24, when 6 trials are completed, No cracks and deformations were found in both type of tiles. The average weight loss of 'P' tiles was 22 g while in 'I' tile the average weight loss was 22.75 g. Since the average weight loss in 'P' tile is slightly lower, 'P' tile has more durability than 'I' tile.

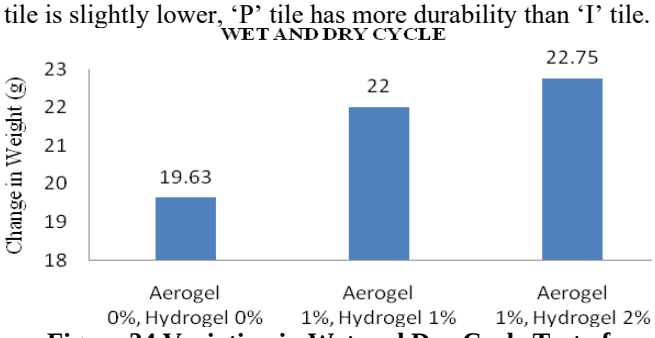

Figure 24 Variation in Wet and Dry Cycle Test of Different Gel Based Tiles

VII. CONCLUSION

The clay tile in addition with aerogel and hydrogel had a higher insulation than the conventional clay tile.

- With 1% aerogel and 1% hydrogel, the Gel Based tile has a bending strength of 19.3% greater than conventional tile . Hence it provides more flexural strength than the conventional tiles.
- With 1% of aerogel and 1% hydrogel, the tile has the water absorption is 11.93% which is within the prescribed limit of 20% which is nearly equal to the water absorption of conventional tile whose value is 11.90%
- With 1% aerogel and 1% hydrogel, the tile has an abrasion value of 5.05 mm which is lower than the conventional tile which has a value of 2.71 mm but higher than tile with 1% aerogel and 2% hydrogel of value 7.95 mm. Durability of tile with 1% aerogel and 1% hydrogel is greater than the durability of tile with 1% aerogel and 2% hydrogel.

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- With 1% aerogel and 1% hydrogel the tile has a thermal conductivity is 0.321 W/m.Kwhich is 14% lower than the conventional tile which is 0.377 W/m.K and 5% more than tile with 1% aerogel and 2% hydrogel, hence thermal insulation is achieved

Considering all the factors, the tile with 1% aerogel and 1% hydrogel is more efficient than conventional tile and tile with 1% aerogel and 2% hydrogel.

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