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ACHIEVING THE SUSTAINABILITY IN CONSTRUCTION BY USING ARTIFICIAL AGGREGATES IN CONCRETE

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Abstract: Environmental issues compel construction experts to search materials that do not pose hazard to environment. Reduction of natural resources and higher density of natural aggregates results in production of dense concrete that increase dead load, and hence overall building cost. Therefore, cost effective and lightweight concrete mix can resolve these problems. The aim of this research is to choose the best locally available material to produce cost effective lightweight concrete which has required strength, lesser density, electrical conductivity, and thermal conductivity as compare to normal weight concrete (NWC). For this purpose, three types of sample were taken to evaluate compressive strength, thermal conductivity, and electrical conductivity. First sample was made by using bloated Shale from Islamabad, Lahore, and Peshawar, second one by using bloated Shale from Karachi and third one by using bloated Slate from Peshawar and these samples were used as replacement of natural aggregate in concrete. Concrete samples were tested for strength, electrical conductivity, and thermal conductivity. The strength and other properties were used to design the multistory building to check variation in member sizes and hence cost. These tests showed that, the particle size of artificial lightweight aggregates is larger than particle size of natural aggregates that will helpful in improving strength of concrete. Bulk density of artificial lightweight aggregates in loose state is only 70% of that of natural aggregates and similarly bulk density of artificial lightweight aggregates in compact state is around 68% of that of natural aggregates. Thermal conductivity of artificial lightweight aggregates concrete is 1.030 which is around 49% of that of normal concrete. The electrical conductivity of artificial lightweight aggregates is 0.141 which around 16% lesser than electrical conductivity of normal concrete. Normal weight concrete has the highest strength and shale Karachi with 10% sawdust has the lowest strength. On basis of pairwise comparison putting their relative scores in the software and result extracted from the software shows that NWC is best alternative with respect to compressive strength. The artificial light weight aggregate concrete has lesser energy demand, better comfort level and lesser structural cost compare to normal weight concrete. As artificial light weight produced in lesser amount therefore, manufacturing cost of these aggregate is higher than normal aggregate.

Keywords: Energy Performance, Normal Concrete, Lightweight Concrete, Natural Aggregates, Artificial lightweight aggregates, Human Comfort.

INTRODUCTION

The intense climate change in the last decade has led to increased problems for society and environment. Due to increase in environmental issues, construction industry is continuously in searching for materials which reduce both the energy and carbon emission in buildings. Energy consumption from buildings is heavily affecting environment, as 90% of impact is causing by energy consume by building [1]. According to U.S. Green Building Council "About 40% of world's energy is consumed by buildings and this value is way more than that of energy consumption by transportation and other construction sectors. In next 25 years, amount of CO_2 emission is going to be increase from building sector as compared to any other sector, with an average increase in 1.8% per year from commercial sector in USA". Reducing this building energy consumption will prove significant in reducing environmental impact [2]. Therefore, structures must be designed in such a way that they have a least environmental impact over their lifetime, while fulfilling normal level of comfort and durability for inhabitants. Sustainable development of buildings reduces use of energy, land, water, raw materials, and many resources. It also decreases greenhouse gases emission, thus reducing the impact of pollution in environment and thus safeguarding people's health. By increasing the efficiency of buildings with the help of sustainable construction will result into energy efficient building thus causing money saving, longer life span of buildings and least maintenance and operation cost [3].

Main problem confronted by construction industry is dense concrete production resulting in increased dead load, and problem in transportation/ handling. There is a need of cost effective and lightweight concrete mix that resolves these problems. This research provides solution to these problems along with significant compressive strength using naturally available artificial lightweight aggregates. The primary aim of this project is to provide an efficient strength to weight ratio by production of structural lightweight concrete that reduces dead load and design size of concrete. Therefore, for sustainable construction, artificial lightweight aggregates are chosen for production of lightweight concrete with 10%, 20%, 50% and 100% replacement with natural aggregates.

The aim of this study is cost comparison of concrete framed commercial building using natural and artificial coarse aggregates and also to choose the best locally available material to produce lightweight concrete which has required strength, lower cost, density, electrical resistivity, and thermal conductivity than normal concrete. Low density means less dead load and hence reduced size of members which reduces overall cost. Low thermal conductivity leads to energy efficient housing thus causing money saving, longer life span of buildings. Reducing this building energy consumption will prove significant in reducing environmental impact [4].

For this purpose, three types of sample were taken to evaluate compressive strength, thermal conductivity, and electrical conductivity. First sample was made by using bloated Shale from Islamabad, Lahore, and Peshawar, second one by using bloated Shale from Karachi and third one by using bloated Slate from Peshawar and these samples were used as replacement of natural aggregate in concrete. Concrete samples were tested for strength, electrical conductivity, and thermal conductivity.

LITERATURE REVIEW

The future of this planet is a matter of concern. Environmental issues and how human communities affect ecosystem concerns have been part of human society from the beginning. Because of deterioration of environmental conditions in many parts of the world, sustainable development has become a recognized goal for human society. Therefore, humanity has to pay more attention to the environment [5].

For several years, lightweight high strength concrete has been used productively for structural objectives. The research has presented that it can be possible to make lightweight concrete by using Lightweight Expanded Clay Aggregates (LECA) with 10 % silica fume which achieved 70.5 MPa compressive strength having 1,860 kg/m³ density [6]. Some studies have shown that lightweight concrete with 43.8 MPa 90 day's compressive strength and dry density 1,860 kg/m³ can be produced by using basalt-pumice as coarse aggregates [7].

Many studies have been carried out on different aspects of artificial lightweight aggregates such as manufacturing of artificial lightweight aggregates [8], properties of artificial lightweight aggregates [9], comparison between natural and artificial coarse aggregates in concrete mixture [10] and so on. But this study is focusing on comparison of framed concrete commercial building using natural and artificial lightweight aggregates.

LIGHTWEIGHT CONCRETE AND ITS PROPERTIES

Manufacture of lightweight structural aggregates concrete (LWSAC) involves using of variety of lightweight aggregates. Lightweight structural aggregates concrete (LWSAC) fulfills to the standard "it should have a least compressive strength of 17.5 MPa nearly equal to 2500 Psi at 28 days and it should have a dry density value ranging 1120–1920 kg/m³". Those aggregates whose particle density is not greater than 2000 kg/m³ or loose bulk density is not greater than 1200 kg/m³ are termed as lightweight aggregates (LWA) [11].

Lightweight aggregates can exist naturally or can be made artificially using industrial processes [12]. The properties of lightweight concrete like strength, thermal and acoustic insulation depend on type of aggregates used for its production. Therefore, consideration of properties of aggregates is very important for manufacture of lightweight concrete. Most of countries are manufacturing light weight expanded aggregates called light expandable clay aggregates (LECA), using some clay which can expand called bloated clay. This clay is heated in a horizontal rotary kiln at about 1200 degree Celsius, using wet process. In this process paste of water and clay is made which is then fed into the kiln where it is broken into smaller granules, resulting into formation of porous structure [13].

High porosity is the main property of artificial lightweight aggregates, which results into low specific gravity. Strength of artificial lightweight aggregates particles depends on source and type of aggregates. The strength of concrete is not dependent on the strength of coarse aggregates since there is no exact relationship between aggregates strength and concrete strength. Generally, compressive strength of concrete is related to content of cement at a given particular slump instead of water to cement ratio (w/c). In some cases, compressive strength can be increased by using good quality natural sand in place of fine light weight aggregates. The normal weight aggregates zone is stronger in conventional concrete as compared to interfacial transition zone (ITZ) and cement matrix. Contrary to that, introduction of artificial lightweight aggregates in concrete mixture significantly affects mechanical and elastic properties of lightweight concrete, since they are the weakest constituents [14].

Literature tells that strength of concrete is determined by its weakest component. Stress transfer takes place through aggregates and mortar, when aggregates are rigid constituent. If aggregates are weak, then transfer of stresses occurs through cement matrix, resulting into cracks propagation throughout artificial lightweight aggregates particles. This suggest that artificial lightweight aggregates itself is weaker than interfacial transition zone (ITZ) [15]. Therefore, density and volume of constituent artificial lightweight aggregates is very important to get results comparable with normal weight concrete [16].

Lightweight concrete is subjected to more creep and shrinkage as compared to equivalent normal concrete cylinder. Such factors should be considered during the design process [17]. The significance of using light expandable clay aggregates (LECA) in concrete mix is better bond formation between mix constituents. The "Wall Effect" which is related to particle packing does not exist on surface of expanded clay aggregates in lightweight concrete by scanning electron microscopy (SEM) and back scattered electron imaging (BSEI), resulting in a better bond and much thinner interfacial zone than normal concrete [18].

Expandable light weight aggregates have better thermal resistivity and insulation as compared to normal concrete because of lower coefficient of thermal expansion, lower thermal conductivity, and fire stability since they are made by heating at very high temperatures of 2000^0F. Lower thermal conductivity causes exposed members to achieve a steady state temperature at a higher time, thus decreasing internal temperature changes. This time difference lag moderate nightly cooling effect and solar buildup in buildings. Such property can be useful in tall buildings where exposed lightweight columns have no large volume and stresses variations due to lower coefficient of thermal expansion [19].

RESEARCH METHODOLOGY

One of the main reasons of environmental problems is energy consumed by the construction industry. Therefore, a detailed literature review was carried out to identify different solutions. One of the main challenges in sustainable design of buildings is to improve the energy efficiency of the building during its lifetime along with reducing the environmental impact of the design. Concrete is the most widely used construction material in the building industry and consumes the second highest amount of natural resources [20]. In order to make concrete more environmentally sustainable, it should be energy efficient. Thermal conductivity is the most influencing factor in energy efficiency of concrete. Thermal conductivity of concrete is dependent on type of aggregates used in the concrete mixture. Some published construction properties databases associate thermal conductivity to concrete density. Therefore, it is possible to make concrete more energy efficient by replacing natural aggregates with low density artificial lightweight aggregates. The value of thermal conductivity of concrete is decreased by 0.13Wm-1K-1 with the introduction of artificial lightweight aggregates in concrete and proven by the research work. Properties other than thermal conductivity were also studied.

CHOICE OF AGGREGATES

The choice of aggregates is very much related to a local supply chain. So, in this study the best locally available aggregates to produce lightweight concrete which has required strength, minimum cost, low density, thermal conductivity and electrical resistivity. As the most important property, is its lightweight, which will result into decrease in dead load, thus enabling the use of lightweight foundations, reducing cost in handling and transportation, and enhancing the time of construction. Decrease in dimensions of structural members and good thermal and acoustic insulation can be achieved from its low density. Increased cost of artificial lightweight aggregates can be covered based on its ease in handling, less energy requirement in demolishing, less waste requirement and high durability due to the strong bond of aggregates. After identification of properties, availability of artificial lightweight aggregates was located. Artificial lightweight aggregates were chosen for further research.

Slate for was extracted from Manki Formation (95 km from Peshawar city). Manki Formation is characterized by metamorphic rocks from Precambrian age e.g. slate, quartzite and phyllite. Raw slate used in this research was fine grained rock split into thin broad sheets with gray to black color. The slate is a normal weight aggregates but it is converted into a lightweight aggregate by expanding it.

In carrying out the process, slate was prepared by reducing it to a finely divided state, mixing it with the bloating agent, and with suitable amounts of water to impart sufficient plasticity, and shaping it into individual particles as by extrusion and division into desired lengths. Exact pre shaping of the particles is, however, unnecessary and it is sufficient to break up the slate into particle sizes correspondingly smaller than the desired bloated size. The size of the particles will therefore vary considerably but generally it is preferred that they have a size distribution such that when bloated will yield artificial lightweight aggregates conforming to the prevailing specifications in the industry. In the preparation of slate's, it is necessary only to roughly size the slate. Those slate's, which do not naturally bloat, must be reduced to a fine powder, and mixed with a bloating agent before shaping. Slate may be prepared similarly to a non-bloating slate by reducing it to a fine powder, mixing it with a bloating agent and shaping [21].
Artificial lightweight aggregates, expanded slate was yielded in PCSIR (Pakistan Council of Scientific and Industrial Research) Peshawar through processing of natural aggregates in rotary kiln method. The chemical composition of shale Karachi is, 37-60% weight of $Si0_2$, 15-26% weight of $A1_2O_3$ + $Ti0_2$, 3-13% weight of Fe_20_3, 11-16% weight of alkaline earths (CaO+MgO) and alkalies (Na_20+K_20) and loss on ignition 3.94%. The chemical composition of shale Peshawar is, 59.07% weight of $Si0_2$, 0.57% weight of $A1_2O_3$ + $Ti0_2$, 15.85% weight of Fe_20_3, 10.25% weight of alkaline earths (CaO+MgO) and alkalies (Na_20+K_20) and loss on ignition 3.87%.

FORMULATION OF CONCRETE MIX DESIGN

Five formulations were designed. Following were the quantities for the respective mixes:

1. N100 (using 100% natural coarse aggregates) (Normal Weight Concrete)
2. Shale Karachi with 10% Sawdust
3. Shale Karachi
4. Shale Peshawar
5. Slate

RESULTS AND DISCUSSIONS

COMPRESSIVE STRENGTH TEST

Six cylindrical samples (6"x12") for each artificial (10%, 20%, 50% & 100%) and natural (100%) aggregates were casted and tested at 07 and 28 days for compressive strength. In this method, cylinders were subjected under axial compressive load for some time until the sample fails. The maximum load, which was attained by sample before its failure, was divided by the sample cross section area to get compressive strength of sample. (ASTM C 39). Six cylindrical samples (6"x12") for each artificial (10%, 20%, 50% & 100%) and natural (100%) aggregates were casted and these samples were casted and tested at 07 and 28 days splitting tensile strength. Basically, in this method we were calculated indirect tensile strength of the concrete. (ASTM C 496/C 496M).
Test results for compressive strength are shown below in Fig-1. Normal weight concrete has the highest strength and shale Karachi with 10% sawdust has the lowest strength. On basis of pairwise comparison putting their relative scores in the software and result extracted from the software shows that NWC is best alternative with respect to compressive strength.

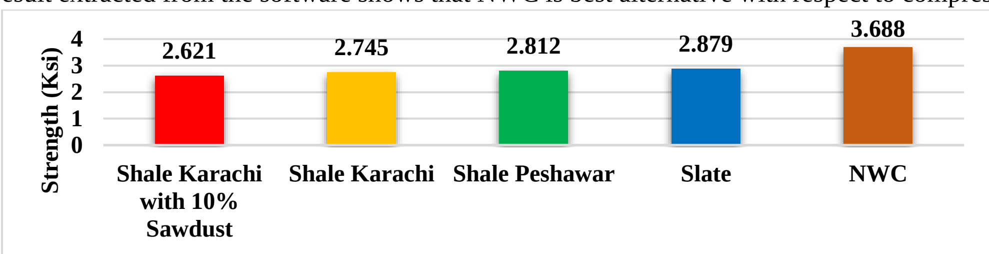

Figure 1: Compressive strength test results

THERMAL CONDUCTIVITY

Six samples (2"x2"x2") in cube for each N100 and A100 of concrete were casted. The samples were further cut down to a size of (2"x2"x1") in as it is the requirement of the apparatus. The samples were sent to NED University Karachi for testing of thermal conductivity. The thermal conductivity test was done by using guarded heat flow meter.

In this test a sample and a heat flux sensor, which is a transducer (HFT), is placed between two plates, having controlled different temperature, which causes heat flow. To ensure the proper contact resistance between sample and surface of the plate, test application is subjected to some load through some pneumatic mean. To minimize the heat losses, a guard is used around the plates, which is maintained at the mean temperature of plates. The difference in temperature between the surfaces is measured with the help of the sensors, which are placed in plates along with the heat flux transducer electrical output. This electrical output voltage is directly proportional to the heat flow through the specimen. Before taking any measurement, calibration of the instrument is done with the help of the sample of known value of thermal resistance to obtain the proportionality. (ASTM E1530 – 11).
Results for thermal conductivity are shown below in Fig-2. Normal weight concrete has the highest thermal conductivity and Slate has the lowest Thermal Conductivity. Lesser the thermal conductivity lesser will be heat passed through building hence results in reduction in energy consumed by building [22]. On basis of pairwise comparison putting their relative scores in software and graph extracted shows that Slate is the best alternative with respect to thermal conductivity.

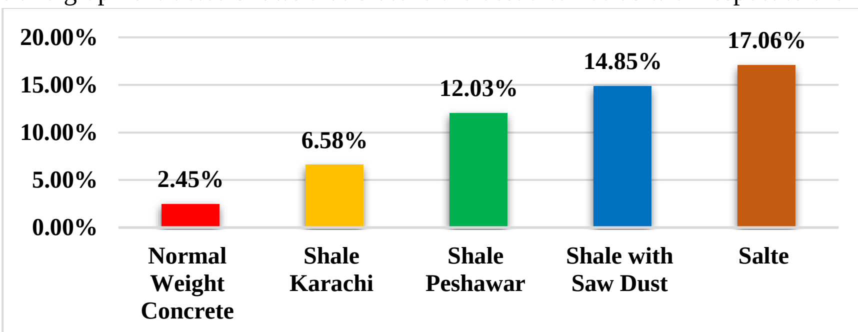

Figure 2: Comparison of samples on the basis of Thermal Conductivity

ELECTRICAL CONDUCTIVITY

Six samples (2"x2"x2") in cube for each N100 and A100 of concrete were casted. The samples were further cut down to a size of (2"x2"x1") in as it is the requirement of the apparatus. The samples were sent to NED University Karachi for testing of electrical conductivity. The electrical conductivity test was done by using two electrode soil box method.
In this method, a sample is placed between two opposite faces of a box. A voltage is applied between two opposite faces of box, which act as electrode. Current start flowing between the electrodes, causing a voltage drop, which is measured. This voltage drop is proportional to the voltage by Ohms law. (ASTM G187 – 12a).
Resistivity (electrical conductivity) is measured with the help of the formula:

$$\mathbf{r = (a \times R)/D}$$

where:
a = Area of cross section in cm^2
R = Sample resistance in ohms
D= Distance between electrodes in cm.
Electrical Conductivity test results are shown in Fig-3. It is cleared that normal weight concrete has the highest Electrical Conductivity and Shale Karachi with 10% sawdust has the lowest electrical conductivity.

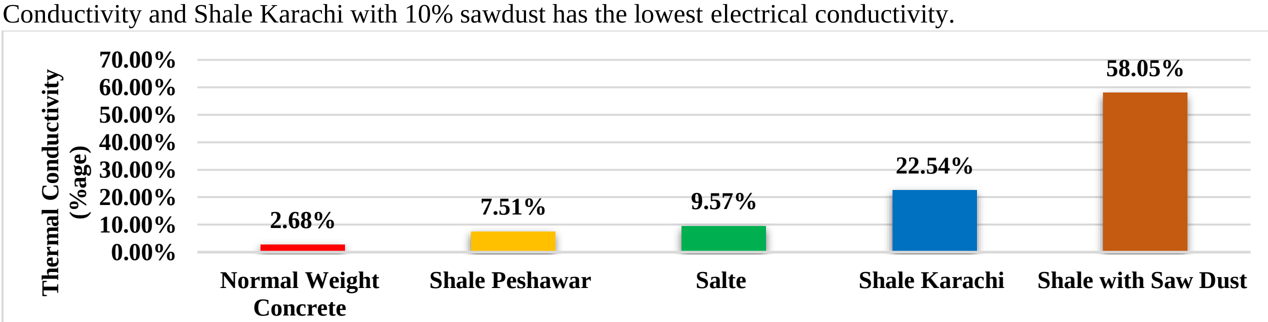

Figure 3: Comparison of samples on the basis of Electrical Conductivity

On the basis of pairwise comparison putting their relative scores in the software and results obtained shows that Shale Karachi with 10% sawdust is best alternative with respect to Electrical Conductivity.

CONCLUSIONS AND RECOMMENDATIONS

In order to find out effect of ALWA on building performance and building demand, an attempt is made to evaluate effect of ALWA on thermal and electrical performance and hence on building demands. Following are major findings of this project.

1. From sieve analysis results it is clear that the particle size of ALWA is larger than particle size of NWA that will helpful in improving strength of concrete.
2. Bulk density of ALWA in loose state is only 70% of that of NWA and similarly bulk density of ALWA in compact state is around 68% of that of NWA. This lesser density will reduce the self-weight of concrete and also self-weight of overall building. This reduction in self-weight of concrete and overall building will reduce the members' size and hence reduce the overall cost of building.
3. The specific gravity of ALWA is only 1.88 which is 74% of that of NWA. This lesser specific gravity indicates lesser number of voids in concrete prepared with ALWA as compare to concrete prepared with NWA.
4. Thermal conductivity of ALWC concrete is 1.030 which is around 49% of that of NWC. Lesser the thermal conductivity of material lesser will be heat transformation and moderate will be the room temperature.
5. The electrical conductivity of ALWC is 0.141 which around 16% lesser than electrical conductivity of NWC. Lesser electrical conductivity of building better will be the comfort level of building.
6. The most influential factor is cost, cost of ALWA is very much higher than cost of NWA. It is because ALWA are not producing in bulk amount and hence manufacturing rate of small sample of ALWA are larger than the cost of natural aggregates.

After the comprehensive test results and suitable findings following conclusions are made for the stake holders as well as for the future research.

1. Pakistan is suffering from energy crises that is why building should be constructed using ALWA that will help in reducing energy demand of building and also improve building comfort level.
2. Awareness in stakeholders will increase demand of ALWA which helps in reducing production cost of ALWA.
3. Partial replacement (50%) gives better compressive strength without plasticizers than 100% replacement of ALWA but we can also use 100% replacement of ALWA after improving compressive strength using plasticizers.
4. Future research should be carried out but designing a particular building by using natural and ALWA and check how much cost will it save by conducting detail bill of quantities.
5. Life cycle costing and life cycle cost analysis should be carried out in future to find out variation in different phases and components of buildings.

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