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COST COMPARISON OF CONCRETE FRAMED STRUCTURE USING NATURAL AND ARTIFICIAL COARSE AGGREGATES

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Abstract: Due to increase in environmental issues, construction industry is continuously in search of materials that do not pose hazard to the environment. There is a need of cost effective and lightweight concrete mix that resolves these problems. This research provides solution to these problems alongside with significant compressive strength using naturally available lightweight structural aggregates concrete (LWSAC). Due to their low density they produce lightweight concrete, which also have better insulation property and brings down construction, operational and maintenance cost of the building. The aim of this study is to choose the best locally available material to produce lightweight concrete. Low density of these materials will lead to less dead load, hence reduced size of structural members which reduces overall construction cost. Low thermal conductivity leads to energy efficient housing. For this purpose, three samples will be taken. Low density means less dead load and hence reduced size of foundations, which reduces cost and concrete production. Low thermal conductivity leads to energy efficient housing. For this purpose, a sample was prepared using artificial (slate) aggregates from PCSIR Lab Peshawar as replacement for natural aggregates in concrete. Concrete samples were tested for strength, electrical conductivity, and thermal conductivity. 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. After that, these properties were used in design of multistory building to check any variation in the member sizes. It is noted that compressive strength of LWSAC is similar to normal concrete but this concrete has better insulation properties than that of normal concrete. Overall cost of structural members has also reduced when LWSAC was used instead of normal concrete.

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

INTRODUCTION

The most influential material in construction is concrete and many natural resources are utilized for its production [1]. It has three major components that are cement, water, and aggregates. Physical properties of concrete like grade, moisture absorption, thermal conductivity etc. are directly related with aggregate's characteristics, which is used in concrete [2]. Main problem confronted by construction industry is dense concrete production resulting in increased dead load, transportation/ handling cost which lead to low productivity and more manpower. The primary aim of this project is to provide an efficient strength to weight ratio by production of LWSAC that reduces dead load and hence member sizes. For sustainable construction, LWSAC has been 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 normal weight concrete (NWC) and LWSAC and also to choose the best locally available material to produce LWSAC which has required strength, lower cost, density, electrical resistivity, and thermal conductivity than NWC. Low density means less dead load and hence reduced size of foundations which reduces cost and concrete production. Low thermal conductivity leads to energy efficient housing energy efficient building thus causing money saving, longer life span of buildings and least maintenance and operation cost. Reducing this building energy consumption will prove significant in reducing environmental impact.

For this purpose, one sample was taken. This sample was made using artificial (slate) aggregates from PCSIR Lab Peshawar as replacement for natural aggregates in concrete. Concrete samples were tested for strength, thermal conductivity, and electrical resistivity. After that, these properties were used in design of multistory building to check any variation in the member sizes.

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. Since deterioration of environmental conditions in many parts of world, sustainable development has become a recognized goal for human society. Therefore, humanity has to pay more attention to the environment [3]. For several years, LWSAC 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 [4]. Some studies have shown that LWSAC with 43.8 MPa 90 days' compressive strength and dry density 1,860 kg/m³ can be produced by using basalt-pumice as coarse aggregates [5]. Many studies have been carried out on the different aspects of artificial lightweight aggregates such as manufacturing of LWSAC [6], properties of artificial lightweight aggregates [7], comparison between NWC and LWSAC in concrete mixture [8]. But this study is focusing on cost comparison of framed concrete commercial building using NWC and LWSAC.

Manufacture of lightweight structural aggregates concrete (LWSAC) involves using of variety of lightweight aggregates. Lightweight structural aggregates concrete (LWSAC) fulfills to the standard, defined in [9] "it should have a least compressive strength of 17 MPa nearly equal to 2500 Psi at 28 days and it should have a dry density value ranging between 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) [10]. LWA can exist naturally or can be made artificially using industrial processes [11]. The properties of the LWA like strength, thermal and acoustic insulation depend on type of aggregates used for its production, so consideration of aggregates properties is very important for manufacture of LWSAC. Most of countries now a days are manufacturing light weight expanded aggregates called light expandable clay aggregates (LECA), using some clay which can expand called bloated clay [12].

EFFECT OF LIGHTWEIGHT AGGREGATES ON PROPERTIES OF CONCRETE

High porosity is main property of LWSAC, which results into low specific gravity. Strength of LWA particles depends on source and type of aggregates. The strength of concrete is not depending upon strength of coarse aggregates since there is no exact relationship between aggregates strength and concrete strength [13]. Generally, compressive strength of concrete is related to content of cement at a given particular slump instead of water to cement ratio (w/c) [14]. In some cases, compressive strength can be increased by using good quality natural sand in place of fine light weight aggregates [15]. The NWC aggregate zone is stronger in conventional concrete as compared to the interfacial transition zone (ITZ) and cement matrix. Contrary to that, introduction of artificial lightweight aggregates in concrete mixture significantly affects the mechanical and elastic properties of lightweight concrete, since they are the weakest constituents [16]. Literature tells that strength of concrete is determined by its weakest component. Transformation of stress takes place through aggregates and mortar. If aggregates are weak, then transformation of stresses occurs through cement matrix, resulting into cracks propagation throughout LWA particles. This suggest that LWA itself is weaker than interfacial transition zone (ITZ) [17]. Therefore, density and volume of constituent LWA is very important to get results comparable with NWC [18].

LWSAC is subjected to more creep and shrinkage as compared to equivalent NWC cylinder. Such factors should be considered during design purposes [19]. 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 LWSAC by scanning electron microscopy (SEM) and back scattered electron imaging (BSEI), resulting in a better bond and much thinner interfacial zone than NWC [20]. Expandable LWA have better thermal resistivity and insulation as compared to NWC 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 [21]. The lower thermal conductivity causes exposed members to achieve a steady state temperature at a higher time, thus decreasing the internal temperature changes. This time difference lag moderate nightly cooling effect and solar buildup in buildings. Such property of thermal resistivity can be useful in tall buildings where exposed lightweight columns have no large volume and stresses variations due to lower coefficient of thermal expansion [22].

RESEARCH METHODOLOGY

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 building industry and consumes second highest amount of natural resources [23]. 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 LWA. The value of thermal conductivity of concrete is decreased by $0.13Wm^{-1}K^{-1}$ with the introduction of artificial lightweight aggregates in concrete and proven by the research work. Properties other than thermal conductivity were also studied and compared with NWC. After performing preliminary tests on NWC and LWSAC, properties of NWC and LWSAC has been used in design of commercial building. The cost analysis has performed for all the structures and hence cost comparison is carried out to find out the most economical structure out of these two.

CHOICE OF AGGREGATES

The choice of aggregates is very much related to a local supply chain. So, in this study we choose the best locally available aggregates to produce LWSAC 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 use of lightweight structures, reducing cost in handling and transportation, and enhancing labor productivity. Decrease in dimensions of structural members and good thermal and acoustic insulation can be achieved from its low density. Increased cost of LWSAC can be covered based on its ease in handling, less energy requirement in demolishing, less waste requirement and high durability due to 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 this research 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 was fine grained rock split into thin broad sheets with gray to black color. The slate is NWA but it is converted into a lightweight aggregate by expanding it. 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 [23]. LWA, expanded slate was yielded in PCSIR laboratory 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 MIX DESIGN

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

1. N100 (using 100% natural coarse aggregates)
2. N90 A10 (using 90% natural & 10% artificial coarse aggregates)
3. N80 A20 (using 80% natural & 20% artificial coarse aggregates)
4. N50 A50 (using 50% natural & 50% artificial coarse aggregates)
5. A100 (using 100% artificial coarse aggregates)

RESULTS AND DISCUSSIONS

COMPRESSIVE AND SPLITTING TENSILE STRENGTH OF CONCRETE

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. It is clear from figure that maximum compressive strength yielded by N100 having NWC altogether. But it is also interesting fact that all these samples have cleared the minimum threshold limit of compressive strength that is 2500 Psi. Which means that all these types of concrete can be used for construction purposes. It is also an interesting fact that compressive strength of concrete is decreasing with increase in percentage of LWA in concrete.

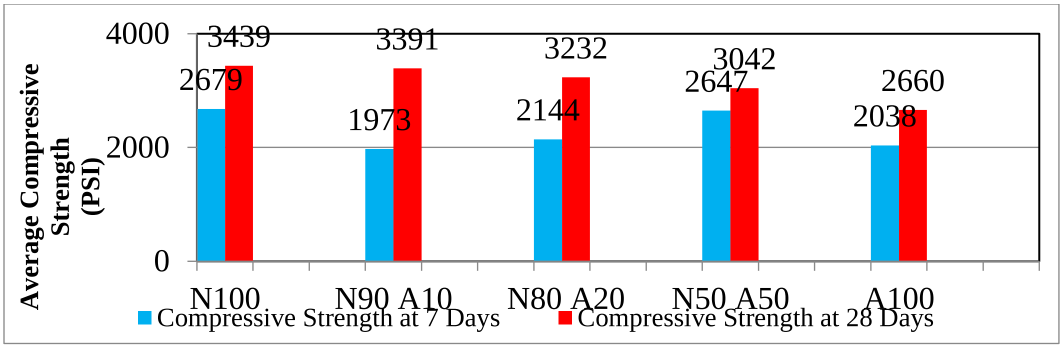

Figure 1: Compressive Strength at 7 & 28 days

Test results for splitting tensile strength are shown below in Fig-2. Almost similar tread has been noted here in split tensile strength. Where the strength of concrete is decreasing with increase in percentage of LWA in concrete. But all these samples have the strength more than the minimum threshold value. Hence all these types of concrete can be used in construction.

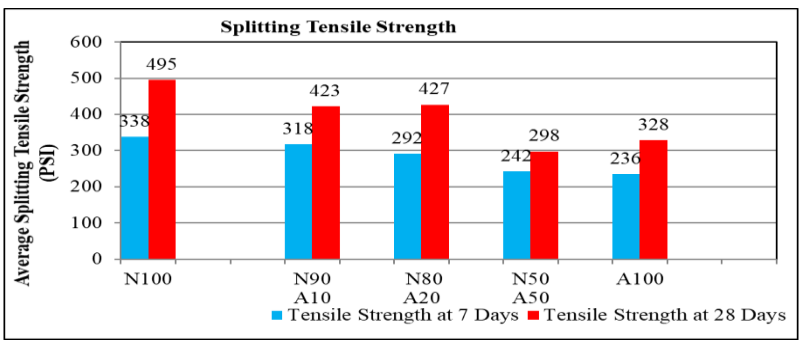

Figure 2: Splitting Tensile Strength at 7 & 28 Days

THERMAL CONDUCTIVITY AND ELECTRICAL CONDUCTIVITY

Tests results of thermal conductivity for NWC and LWSAC are shown in Fig-3 and Fig-4 respectively. NWC 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 [23]. 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.

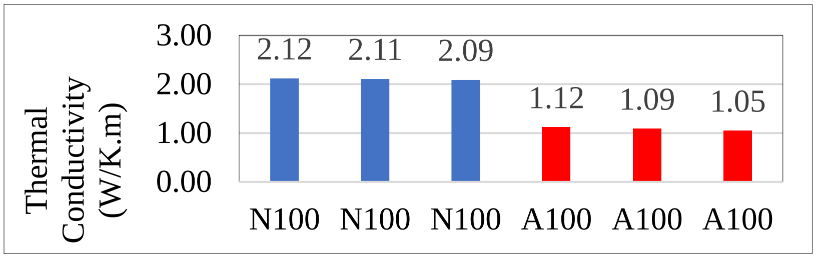

Figure.3: Thermal Conductivity

It is cleared that NWC has the highest Electrical Conductivity and Shale Karachi with 10% sawdust has the lowest 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.

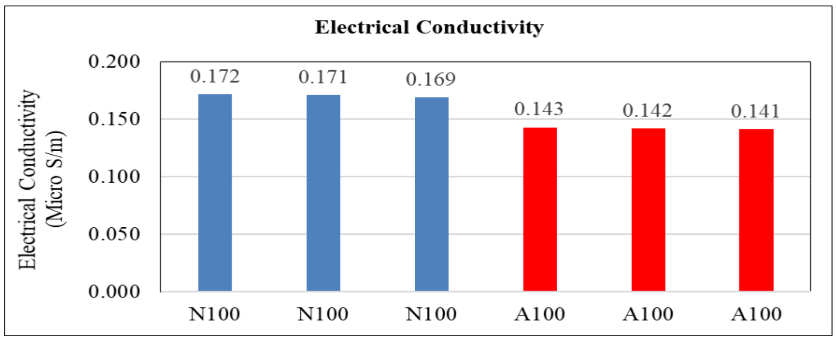

Figure 4: Electrical Conductivity

BUILDING DESIGN FOR COST COMPARISON

ETABS software was used to design triple stories buildings for all five formulations (N100, N90 A10, N80 A20, N50 A50 & A100) having plot size (150' x 60') according to the obtain results from our experimental work. Five buildings were design with different properties of concrete to investigate volumetric changes of members.

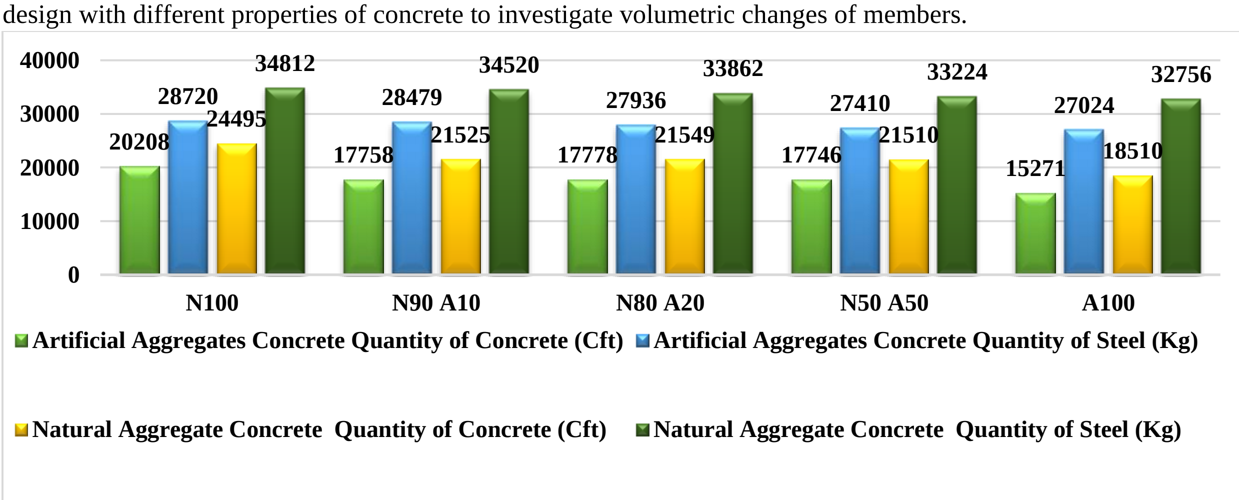

Figure 5: Cost Comparison of Building using Natural and Artificial Aggregates

The overall cost comparison of these buildings is given below in Fig-5. It is cleared from results that as LWA are increasing the member sizes are decreasing resulting in decrease in concrete quantity and hence cost of construction. Hence it can be concluded that even with the larger upfront cost of LWSAC due to more cost of LWA, even overall cost of building reduced with greater percentage which may balance upfront cost of LWSAC.

CONCLUSIONS AND RECOMMENDATIONS

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

1. Bulk density of LWA in loose state is only 70% of that of NWA and similarly the bulk density of LWA 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.
2. The specific gravity of LWA is only 1.88 which is 74% of that of NWA. This lesser specific gravity indicates lesser number of voids in concrete prepared with LWA as compare to concrete prepared with NWA.
3. Thermal conductivity of concrete prepared using LWA was coming out to be 1.030 which is around 49% of that of concrete prepared by using NWA. Lesser the thermal conductivity of material lesser will be heat transformation and moderate will be the room temperature. This moderate room temperature will reduce the energy demand of building and hence saves operational cost of building.
4. The electrical conductivity of concrete prepared by using LWA was 0.141 which around 16% lesser than the electrical conductivity of concrete prepared by using NWA. Lesser electrical conductivity of building better will be the comfort level of building.
5. The cost of LWA is very much higher than cost of NWA. It is because LWA are not producing in bulk amount that is why the manufacturing rate of small sample of LWA are larger than the cost of NWA. But though this higher cost of LWA will be compensated in energy saving and comfort level of building.

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 artificial lightweight aggregates that will help in reducing energy demand of building and also improve building comfort level.
2. Partial replacement (50%) gives better compressive strength without plasticizers than 100% replacement of artificial lightweight aggregates but we can also use 100% replacement of artificial lightweight aggregates after improving compressive strength using plasticizers.
3. 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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