Analysis of Perlite Concrete's Response to High Temperatures

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Abstract:
There has been widespread waste of natural resources in the construction industry over the course of many decades. It is also crucial to increase the use of environmentally friendly supplies in the development of concrete structures in light of the fast environmental deterioration and consequent pollution. Because of its capacity to modify the concrete's behaviour after being subjected to high temperatures, perlite powder (PP) has recently been the focus of scientific attention as a naturally accessible sustainable additive. The goal of this study is to test the feasibility of using PP in high-temperature concrete. Following this line of thought, the author created not one but two novel concretes: a Perlite Binary Concrete (PBC) made from PP and cement, and a Ternary Blended Concrete (TBC) made from PP and Silica Fume (SF) in lieu of cement. In addition to the Controlled Concrete (CC) and the Portland Blained Concrete (PBC), we also created four TBC mixes by varying the percentage of PP used to replace the cement from 1% to 7% in 2% increments. Samples are air-dried after being heated to temperatures between 200 and 800 degrees Celsius at a rate of 200 degrees Celsius per hour for 7, 28, 56, and 90 days. Mechanical, durability, and microstructural tests, as well as an inspection of TBC and PBC samples, were conducted. These studies show that PBC with 5% PP substitution is the strongest and has the best thermal properties.

Keywords: Perlite Powder, Ternary Blended Concrete, Perlite Binary Concrete, Elevated Temperatures

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Introduction

Despite their abundance, the world's natural resources have not even been used to a rudimentary degree. Concrete is a versatile and commonly utilised construction material. Concrete is superior to steel and wood as a building material because of its greater resilience to high and low temperatures. In the case of an ignition or when exposed to high temperatures, concrete-made materials may melt readily. Spalling, cracking, the development of large pores, and a reduction in the strength of attachment between the stone particles and the cementations materials all result from exposures that last too long. Normal characteristics of the structural components, such as volume deformation, strength, structural integrity, and young's modulus of concrete, are greatly reduced when exposed to fire. Duration of exposure to high temperatures determines the extent of collapse of these structures. Damage to their durability characteristics would occur instantly and over time, potentially causing severe structural damage and ultimately collapse. In addition, the load-bearing capability of concrete after an accident is substantially more precarious.

Finally, extreme heat causes a profound shift in the physical structure and chemical composition of the construction materials. As a consequence, research into the effects of higher temperatures on concrete and the integration of cementitious materials into concrete is warranted. A literature search revealed that perlite powder is one of the cementitious materials that may provide extra strength and has the potential advantage of offering high resistance to heat. Perlite Powder (PP) was used to replace part of the cement in this study to generate a concrete composition that can tolerate high temperatures.

Introduction to perlite powder

Metakaolin, Sugarcan Bagasse Ash (SCBA), FlyAsh (FA), etc. are all examples of ashes that have been studied extensively as potential cement replacements in the past (Aldred et al., 2006; Abdul Kareem et al., 2014; Reddy and Meena, 2018; Fu and Chung, 1997), etc. Calcium hydrates these recovered materials often. The porosity of concrete may be decreased by using them as space-filling agents. In addition to this, the powdered form of perlite, which is mined from volcanic rocks, may be used as a cement substitute in concrete production (Celik et al., 2013). Figure 1 depicts the complex perlite beneficiation process.

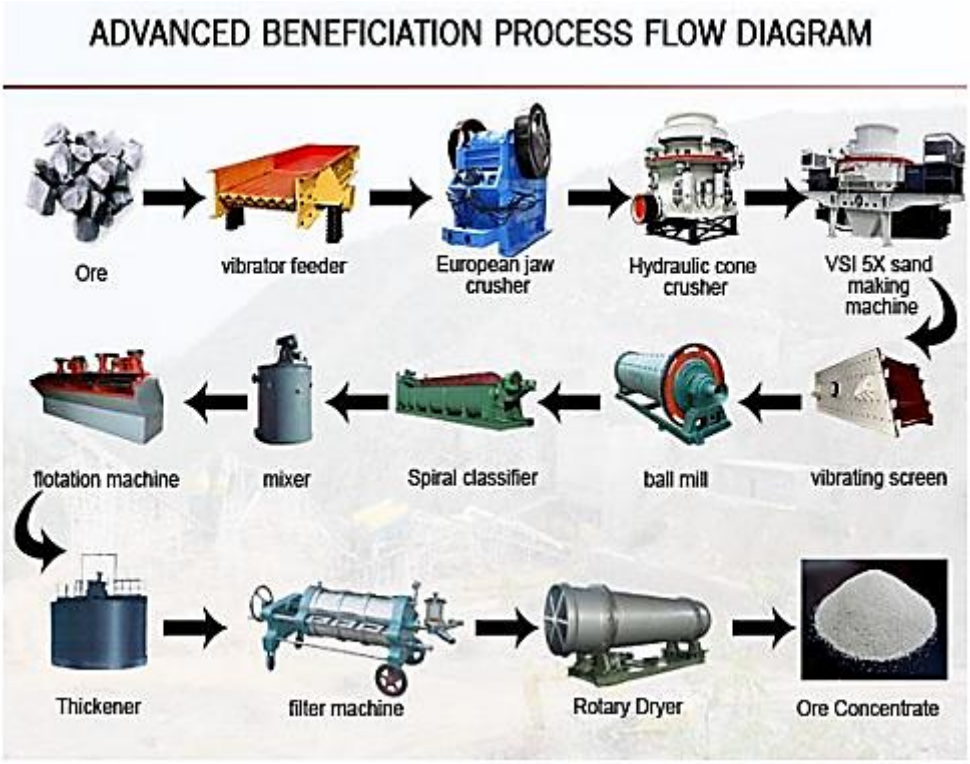


Figure.1 Perlite powder processing (Source: Internet)

The solidification of lava creates perlite, an example of volcanic glass with a high water content. The mineral is known by a number of other names, but it wasn't until 1822 that the word "perlite" was officially adopted. Although much research was conducted on perlite in 1929, it wasn't until the 1930s that significant progress was made. Also, in 1938, enlarged perlite was developed. Perlite's low bulk density is the result of the material's quick heating. In order for perlite to expand to 15-20 times its volume, the chemical water inside it must be boiled at a temperature of 1000oC (Yu et al., 2001; Topcu et al., 2008; Erdem et al., 2015), creating bubbles. Multiple businesses and fields make use of this extended perlite, including building and plumbing, insulation, gardening, and more. Natural PP may reduce cement use, boost workability, lessen permeability, increase strength and durability in concrete. Because of its superior pozzolanic characteristics, PP

may be used to partially replace cement. Seventy to seventy-three percent of its chemical makeup is silicon dioxide (SiO2), 12 to 15 percent is aluminium trioxide (Al2O3), and the rest is made up of illite, quartz, and feldspar in trace amounts (Yu et al., 2003; Erdem et al., 2007; Topçu and Işkda, 2008). Increased mechanical strength is a notable benefit of PP microspheres due to the presence of silicon aluminates. Expanded perlite is a lightweight mineral filler because of its advantageous microstructure, which includes low density, high porosity, and excellent insulating qualities. Metal curtain walls may also benefit from the fire resistance of perlite concrete.

Applications of perlite powder

Perlite Powder (PP) is a non-renewable resource obtained from the earth's crust. According to United States Geological Survey (USGS) Mineral Commodity Summaries 2011 (MCS 2011) records, 700 million tons of perlite is available in the world, among which Greece had been producing the highest amount of PP with 5 million tons, followed by the United States of America (USA) with 3.75 million tons and Turkey with 2.20 million tons. China is also one of the leading manufacturers of PP. The application of PP includes its uses in manufacturing insulation materials and as high heat resistant material. This property is an advantage for the manufacture of bricks, pipe insulations, and mortars. In USA almost one-half of perlite is used to produce products such as insulation pipes, fire-rated doors, ceiling tiles, to name a few. The light-weight property of perlite is beneficial in its usage in various applications across industries. As a result of various advantages, it holds, it is used as construction material, horticulture aggregate, and filler. The ensuing paragraphs discuss some of its major applications.

Because of its poor thermal conductivity, concrete helps to protect against heat-related damage to buildings (Dubé et al., 1992; Demirboa and Gül, 2003). Concrete's mechanical qualities deteriorate at high temperatures due to the development of pores & micro-cracks (Abdulkareem et al., 2014), which ultimately lead to the collapse of buildings. Earthquakes have triggered damage to the tall buildings because of the heavy concrete used in their construction. Lightweight PP concrete might be the answer to minimising damage caused by earthquakes. Though PP-containing mixed concretes may initially have lower strength than OPC, strength is improved with age due to pozzolanic processes. Extreme heat, such as that generated in a fire or by being near a reactor or furnace, may severely damage concrete. During these exposures, they undergo detrimental structural modifications and failures that compromise their defining features including volume stretching, modulus of elastic modulus, structural integrity, strength among the structural parts, etc. Therefore, research into the properties of concrete is essential. Due of its poor thermal conductivity, PP is able to withstand high temperatures. As a result, research into the properties of perlite concrete at high temperatures is in the works.

Temperature effect on concrete

One of the most dangerous accidents is a fire accident, which can happen at any place and at any point in time. It causes harm to occupants and also a loss of property. In India, on average, 25,000 human lives are lost every year due to fire-related causes. The awareness about the temperature effects in concrete is of much importance. The temperature effect in concrete is explained as follows. Initially, dehydration takes place where the chemically bonded water molecules escape from the C-S-H gel becomes noticeable at above 110 ºC temperature. From 300 ºC, dehydration continues, and the expansion of aggregate starts growing up due to heat, which increases the internal stresses and so micro-crack may take place through the concrete material. The most significant compound in cement paste is the $Ca(OH)_2$, and this will stop to react with surroundings at the temperature range of 530 ºC because it makes the concrete to shrink. The fire is put out by water (H_2O), and Calcium Oxide (CaO)

changes to calcium hydroxide cause crumbling and cracking of the concrete, which is detected in the way of spalling and surface cracking, and some color changes can also be visible during such exposures. The alterations in the composition are seen in the concrete material when the temperature exceeds 500 ºC. The transformation that takes place at this level is irreplaceable. Decomposition of calcium silicate hydrate gel, the strength producing compound expanded at further increases in temperature of 600 ºC and concrete reaches its crumbled stage at 800 ºC. At 1150 ºC, melting of feldspar takes place, and after that, all the minerals in the compounds transform from the cement phase into the glass phase. Finally, rigorous microstructural changes are provoked, and concrete materials lost their strength. This prompts the absolute breakdown and weakening of the structures. Thus, the strength and durability of the structure are highly affected and are more prone to the damages during such kind of exposures. Owing to the fire, the causes of the functional impairments and the aesthetic appearance of important buildings are lost. The aesthetic damage is somewhat eased to restore. However, the functional impairments are very intense and might require total or partial replacement, depends on its state and severity. Concrete comes under the composite material, which mainly comprises cement, fine and coarse aggregates, and water. The properties and type of aggregate play a vital role in concrete subjected to elevated temperature. The concrete having fire resistivity is appreciable, whether it is in a material form or structural form. Using concrete as a structural material helps to reduce the issues related to the elevated temperature. Incorporating of PP in the concrete makes the concrete inert to fire and safety of the structural design. The formation of bubbles, after vaporization, reduces the heat transfer mechanism, thereby increasing fire resistance to the concrete. By using perlite, the environmental and economic imperatives are assured to increases in the forthcoming years. The essential way to achieve these kinds of buildings is by enlightening the thermal insulation properties of concrete. The presence of higher porosity in lightweight concrete makes the material suitable for the thermal insulation of structures. Reduction in Portland cement utilization helps to diminish the CO_2 discharge and the cost. More than half of the electrical energy utilization is accompanied by concrete for granulating crude materials and clinker. Subsequently, this can be brought by the utilization of valuable cementitious materials.

Literature Review

Vosoughiet al. (2015)[26] have experimented by partially replacing cement with perlite powder. A couple of w/c ratios of 0.35 and 0.55 are adopted to find out the best mix. The result showed a positive effect on 0.35 w/c ratio with a 20% perlite replacement of cement for the curing period of 42 days.

Lee et al. (2016)[27] have driven the improved reactivity of fly ash slag geopolymer concrete by the addition of SF. The Geopolymer concrete is prepared based on fly ash and blast furnace slag by the addition of three different types of SF. To improve the reactivity of alkali activator, SF, and Aluminum (Al) were mixed in different proportions, which results in affecting the strength of geopolymer concrete. Microstructure analysis revealed that the addition of SF to fly ash changed the structure completely. The addition of SF to fly ash resulted in a decrease in reactivity of fly ash and those of the slag and Na. The strength improvement is due to the addition of SF, which acts as a micro-filler in geopolymer concrete."

Setayesh Gar, et al. (2017)[28] have performed experiments for the study of the behaviour of M30 and M35 grade of concrete under elevated temperatures. In this research, specimens were exposed to elevated temperatures by an open fire and in electric furnace. An open fire system was done in an open place that not only demonstrates the fire effects. This was done in an open place, and the running temperature was recorded

with an infrared thermometer. The results demonstrate that the specimens were completely turned to black colour after half an hour in an open fire, whereas it was not seen in specimens in the electric furnace. The number of cracks were also more with an increase in the duration of the open fire, which was less in the latter case

Ali et al. (2017)[3]investigated on Calcined Perlite Powder (CPP) as a cement replacement. Tests such as compressive strength test and Rapid Chloride Penetration Test (RCPT) are carried out. The test results show that CPP replacement of 30% in cement reduces the compressive strength of concrete, but the permeability shows improvement. Surface resistivity is considered as non-destructive test, and dependably it could find the migration co-efficient and rapid chloride permeability of the concrete

Research Methodology

The methodology for carrying out the current research work is illustrated through the flow chart in Figure 1.

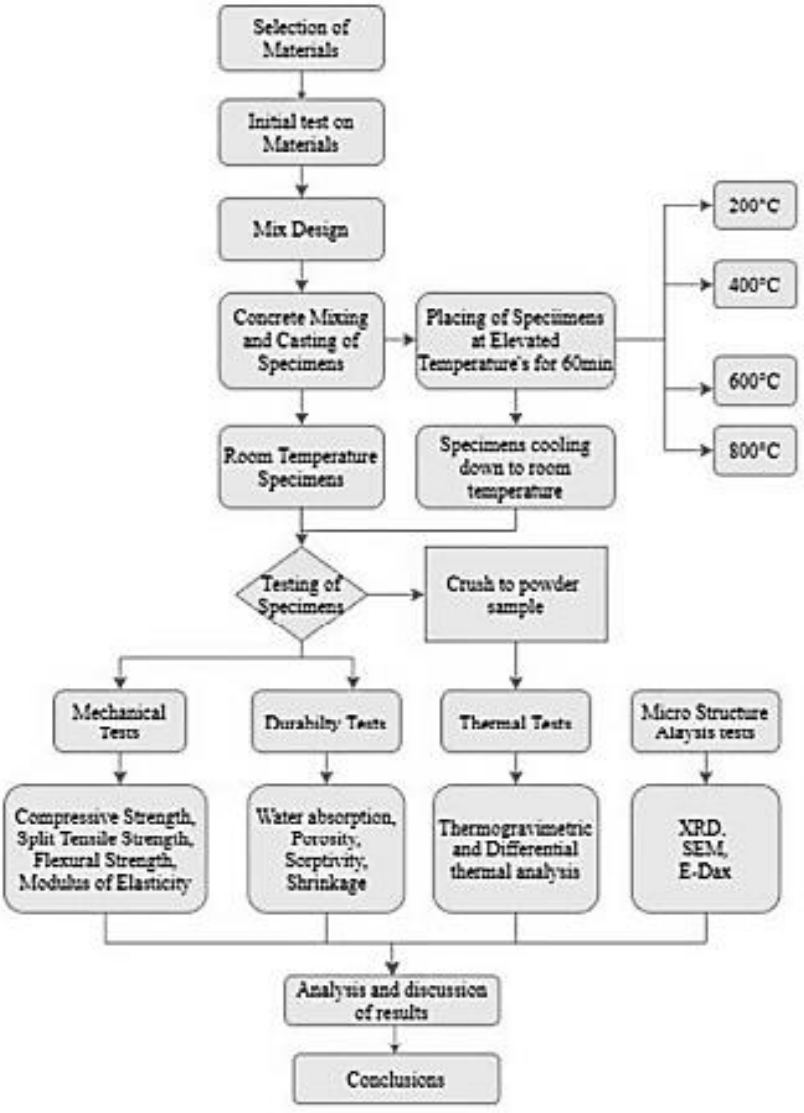


Figure 2 Research methodology

The process of proportioning concrete with suitable ingredients to attain good workability, strength and durability is known as mix design. Workability plays a key role in attaining the strength in concrete. Improper workability of the mix will not let it be placed and compacted properly and this leads to the reduction of concrete strength. Attaining the

required strength of concrete is subject to various factors, viz., quality of cement, types of aggregates, size of aggregates, quality of water, placing, mixing, compaction and water curing. The production cost of concrete is governed by its materials, labour and formwork. The cost of cement is very much higher than the other ingredients, and so it was planned to partially replace cement with other suitable admixtures. Adequate workability, maximum compressive strength and the selection of suitable w/c ratio are the key requirements for efficient mix design. The maximum cement content, maximum water content, type of exposure condition was selected as per IS:10262-2009. The choice of arriving at the proportions required for the mix design can be taken based on either weight or volume

Weight loss due to exposure to elevated temperature

The weight loss was recorded by taking the weights of the PBC specimens before and after placing them in a furnace, and the difference has been calculated. It was noticed that within an increase in the temperature shows an increase in a weight loss of specimen. The highest weight loss was recorded at 800º C, followed by 600 ºC, 400 ºC and 200 ºC respectively. The same trend could be observed for all the ages of concrete mixes. The results are graphically represented in Figure 3 to Figure 7

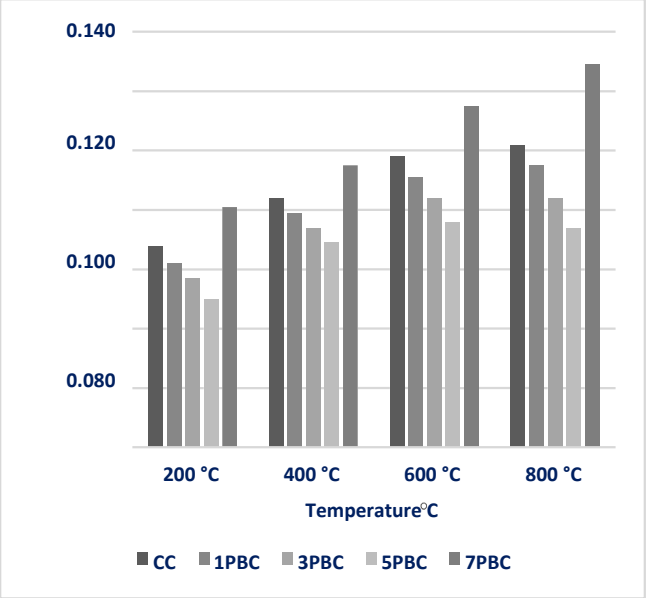


Figure3 . WeightlossofPBC after 7 days

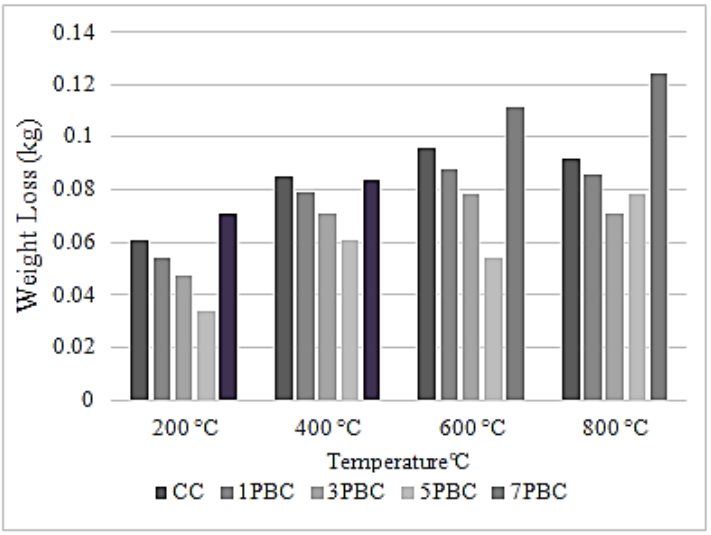


Fig. 4 Weight loss of PBC after 28 days

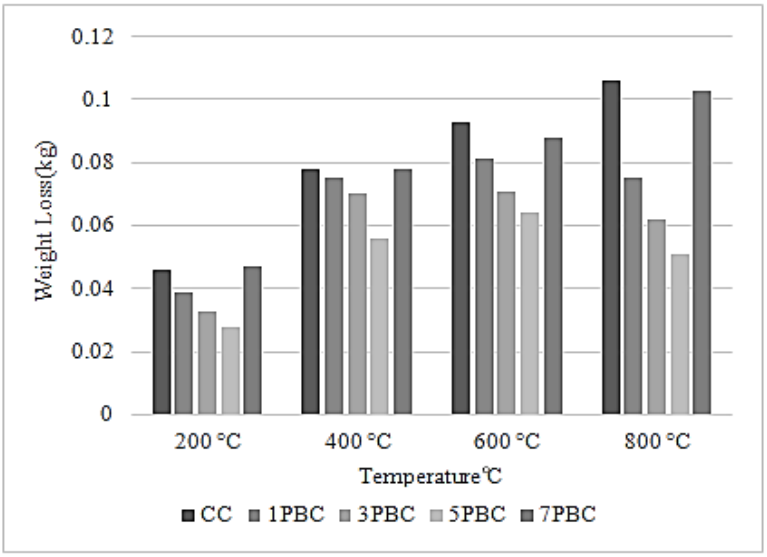


Fig. 5 Weight loss of PBC after 56 days

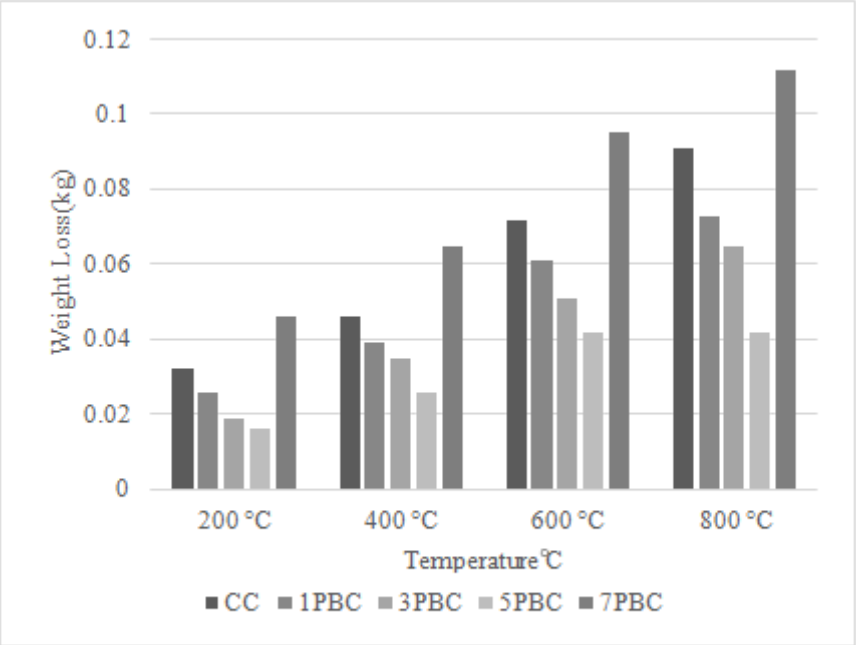


Fig. 6 Weight loss of PBC after 90 days

It could be observed that an increase in temperature had shown an increase in a weightloss of the specimens in all the mixes. Compared to CC, specimens made with partialreplacement of perlite had shown reduced weight loss up to the mix 5PBC. This is dueto the fact that there is less evaporation of water in C-S-H structure of perlite mixes.Lesser relative weight loss of the PBC may be due to lower heat conductivity of theperlite structure. The diffusion of heat into the PBC specimen core is less than the CCthat may also be the cause of lesser weight loss. The weight loss in 7PBC had shown ahigher weight loss compared to all the other mixes, the reason for this is the lack ofbonding between the cement paste and perlite, that leads to the weak concrete cubestructurewhichcaneasilytendtofail.Thiswa strueduringalltheagesofconcrete.

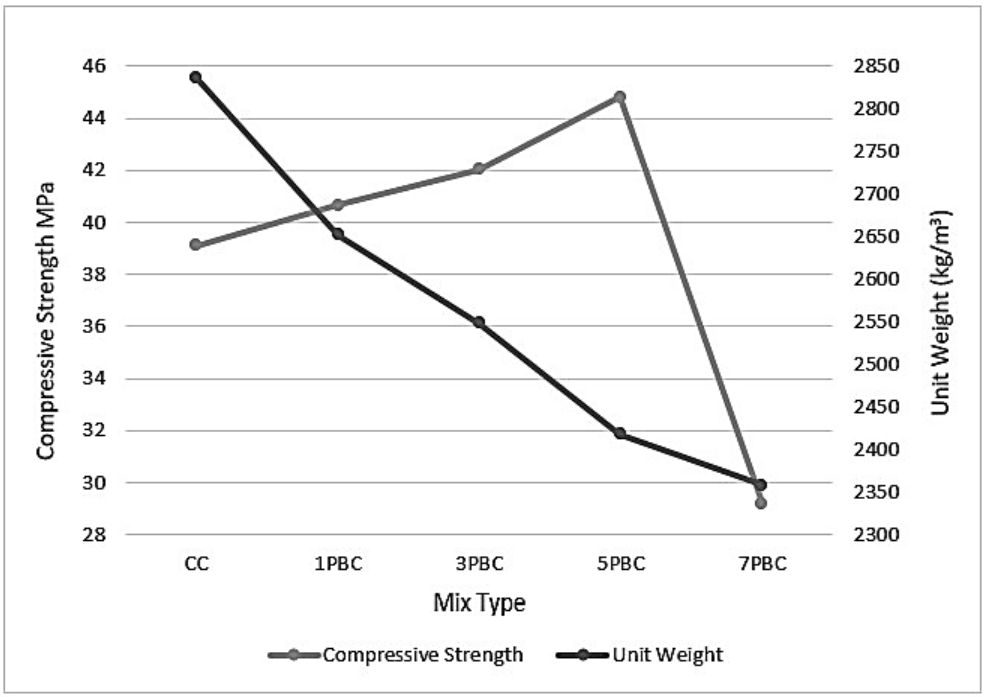
The reduction of weight loss in perlite-incorporated concrete is due to the thermalpropertyofperlitewhichcan resist heat.

Compressive strength vs unit weight

The compressive strength obtained for the PBC mix at the age of 28 days was compared with the unit weight of concrete for the same age to find out the relationship between them and the values were shown in the form of a graph in Figure 6. In this graph, the orange line indicates the compressive strength of PBC mixes, and the blue line indicates the unit weight of PBC specimens.

The unit weight of perlite-incorporated binary concrete was found to be less compared to CC. The values varied in the range of 2836 kg/m3 and 2358 kg/m3 for the specimens with 0% to 7% of perlite, with a reduction percentage of 21.3%. This can be attributed to the lightweight nature of PP that leads to a change in the internal pore structure of concrete

Figure. 6 Compressive strength vs Unit weight after 28 days



Conclusion

Perlite power, which has its source as volcanic rocks, can resist heat at high temperatures. Therefore, in this research, PP has been recommended as a partial replacement for cement and its optimal replacement level has been experimentally found to be 5%. The performance of perlite incorporated concrete under elevated temperatures has excellent thermal and mechanical properties and can withstand high temperatures. The beam element with ductile detailing has resulted in enhanced performance and hence PP incorporated concrete is recommended for structural applications like industrial buildings, where the structures are either subjected to high temperature or susceptible to high temperatures or both.

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