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Mechanical properties of cold bonded quarry dust aggregate concrete subjected to elevated temperature

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HIGHLIGHTS

- Quarry dust aggregate concrete (QDAC), a new alternate material for concrete is suggested.
- The effect of high temperature on the mechanical properties of QDAC is discussed.
- The exposure temperature is the most significant factor affecting the mechanical properties of cold bonded aggregate concrete.

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ABSTRACT

The use of waste materials such as fly ash and quarry dust in the building construction process is explored in this paper. The coarse aggregate prepared using quarry dust and fly ash by cold bonding process is used for the making of concrete. The mechanical properties of the concrete, namely, compressive strength, splitting tensile strength and modulus of elasticity are determined. The variables considered are aggregate ratio, water binder ratio, temperature ratio and type of aggregate. For cold bonded aggregate concrete, it is found that the strength of the concrete is completely lost when exposed to certain limiting temperature. The limiting temperature is different for fly ash aggregate and quarry dust aggregate concrete. The limiting temperature of fly ash aggregate concrete is 300 °C and that of quarry dust aggregate concrete is 400 °C. This is due to the variation in the agglomeration process of fly ash and quarry dust in cold bonding process. The scanning electron microgram of spit aggregate on the cracked face of the specimen shows the evidences of formation and expansion of cavities due to the exposure to high temperature. The multiple regression models for the prediction of mechanical properties are developed. The present study gives an insight to the end users regarding the scope of the utilization of cold bonded aggregates in construction exposed to temperature.

1. Introduction

Concrete is the most popular construction material. Seventy five percent of the volume of concrete is filled by aggregates. The high rate of consumption of aggregates lead to the depletion of natural resources, which is initiated many environmental issues. For the future infrastructure development, it is very necessary to find alternative materials for the production of concrete. In this context, identification and manufacture of artificial aggregate materials from waste and other environment friendly materials are very important for the future growth of the industry. Most of the studies on conventional concrete showed that the properties of aggregates influence the quality of concrete. The characteristics of concrete when subjected to elevated temperature are correlated to the type of aggregate used in the concrete. The literatures on the temperature effect on artificial aggregate concrete are limited and present study addresses this lacuna.

The performance of temperature influence on building material is one of the significant areas of researchers in the safety aspect of the buildings against high temperature. Chi et al. [1] determined strength properties of concrete using three types of cold bonded fly ash aggregates. It is suggested that water binder ratio and properties of light weight aggregate influence the compressive strength of concrete significantly. Karakoc [2] used expanded perlite and pumice as fine and coarse aggregate in concrete. The hardened concrete is exposed to 700 °C and cooled by three methods, namely, natural, water and furnace cooling. A significant loss of strength is observed at temperature 700 °C in all methods of cooling. The concrete exposed to water-cooling is found to have higher

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strength than natural cooling. Jonaitis and Papinigis [3] found that the decrease in compressive strength of the concrete is about 20–30% when exposed to a temperature of 90 °C. Netinger et al. [4] used dolomite as fine aggregate and steel slag as coarse aggregate. The concrete is subjected to temperatures of 100, 200, 400, 600 and 800 °C and tested. The specimens are exposed at high temperature for 60 min and the fire is applied gradually at a rate of 1 °C per minute. The reduction in the compressive strength is found to be 30% when subjected to 800 °C. Arioz [5] used crushed limestone and river gravel in the production of concrete. The concrete is exposed to temperature ranging from 200 to 1200 °C for 2 h at a rate of 20 °C/min. The effect of temperature on strength at elevated temperature is found to be more pronounced for siliceous river gravel aggregate concrete when compared to argileous lime stone aggregate concrete. Henry et al. [6] reported that the heating of concrete results in expansion of gas inside the void space and the formation of cracks connecting these voids. More cracks form in the mortar aggregate interfaces, which act as to weak zones of failure when subjected to compressive loads. Noumowe et al. [7] found that the reduction in compressive strength of limestone aggregate concrete is 15 and 60% at 200 and 600 °C respectively. The change in microstructure of concrete is found to be little when subjected to the temperature of 120 °C. Andic-Cakir and Hizal [8] used three types lightweight aggregate, namely, limestone and pumice from different sources for the production of the concrete. It is reported that the cement paste penetrating into the surface pores of the pumice aggregate forms stronger bond at the inter-transition zone. The detrimental effects due to internal bleeding near the aggregate surface are found to be low in porous aggregate concrete. Netinger et al. [9] used crushed brick and tiles as coarse aggregate in concrete. It is found that the reduction in compressive strength at 200 °C is found to be 15% when compared to its residual strength. The strength of alternate aggregate concrete is decreased to 60% when exposed a temperature of 600 °C. Husem [10] prepared high performance micro concrete (HPMC) using lime stone coarse aggregate. The concrete is exposed to temperatures of 200, 400, 600, 800 and 1000 °C for one hour. The reduction in compressive strength of concrete is only 20% when exposed to 200 °C. The compressive strength is found to be very little at 800 °C. Colangelo et al. [11] prepared fly ash artificial aggregate having density between 1000 to 1600 kg/m^3 by double step cold bonding pelletization technique. Güneyisi et al. [12] stated the increase in compressive strength is limited when steel fibers are added to the concrete made up of cold bonded light weight aggregate. Gomathi and Sivakumar [13] reported that the sintered fly ash aggregates can be used for the production of concrete having a compressive strength up to 39.9 MPa. Gesoğlu et al. [14] found that compressive strength of self compacting light weight concrete with full replacement by the cold bonded light weight coarse aggregate is 43 MPa at 28 days. Gesoğlu et al. [15] stated that with increasing volume of cold bonded light weight coarse aggregate, the hardened strength properties reduced regardless of testing age. Güneyisi et al. [16] showed that incorporating the mineral admixtures enhanced significantly compressive strength of the self compacting light weight concrete containing cold bonded aggregates. Vasugi and Ramamurthy [17] reported that the lignite pond ash cold bonded aggregates exhibits higher water absorption and can be utilized for internal curing. Terzić et al. [18] found out that the mechanical activation by increasing the fineness of the fly ash can improve the property of the sintered fly ash aggregate and thereby it improves the concrete strength properties.

In this work, two types of artificial aggregates are manufactured and used for the production of concrete. The fly ash and quarry dust are used in the manufacture coarse aggregate. The artificial cold bonded aggregates are used for the concrete production. The concrete is exposed to various temperatures and tested to determine the variation in the compressive strength. Multiple regression analysis is used for the development of strength prediction model. The influence of three factors namely fine aggregate to total aggregate ratio, water to binder ratio and exposure temperature on compressive strength of artificial aggregate concrete is determined.

2. Testing of concrete

Ordinary Portland cement [19] is used in the production of concrete and also as a binder in aggregate manufacturing process. The artificial aggregate is prepared using Class F Fly ash [20] and quarry dust aggregate. Quarry dust, otherwise a waste material, is collected from granite stone quarry is also used in aggregate production. The chemical constituents in cement, quarry dust and fly ash are given in Table 1. Quarry dust contains silica SiO_2 about 62%. The quarry dust is an inert material. Class F fly ash of low reactive oxides is used. The CaO content is low in fly ash when compared to cement. The specific gravity of the quarry dust and fly ash aggregate is found to be 2.12 and 1.98 respectively.

The two types of artificial coarse aggregates, namely, quarry dust aggregate (QDA) and fly ash aggregate (FAA) are prepared to use in concrete. The binder used for the production of aggregate is cement. Artificial coarse aggregates are prepared in a rotating drum type pelletizer. The powdered raw materials to binder ratio of 80:20 are charged initially for dry mixing. The water is sprayed into the rotating drum to facilitate the formation of aggregate balls. Ball shape aggregates of 12–20 mm size are collected by sieving and cured for 14 days. The aggregate balls are shown in Fig. 1.

2.1. Details of concrete mix

The strength in compression and tension and modulus of elasticity of concrete were determined. The variables considered in this study are coarse aggregate ratio and water binder ratio. Three numbers of cubes of 150 mm and cylinders of 150 mm Ø and 300 mm height were cast in each batch. The specimens were prepared cured for 28 days immersing in water. The specimens are then subjected to elevated temperature in a muffle furnace. The weight of the constituents and designation of concrete mix is shown in the Table 2. Designation represents the type of coarse aggregate, coarse to total aggregate and water to binder ratio. For example, in Q65/35, Q denotes quarry dust aggregate, 65 represents coarse aggregate to total aggregate ratio of 0.65 and 35 represents the water to binder ratio of 0.35. The weight of constituents of the concrete was prepared based on absolute volume method [21]. In the trial, when the specimens are subjected high temperature, it is found that the quarry dust aggregate concrete (QDAC) explodes inside the furnace at temperature above 400 °C and fly ash aggregate concrete (FAAC) explodes above 300 °C. The cold bonded aggregate act as internal curing agents by retaining water in it. Heating of concrete might have resulted in the emission of excess steam through the available pores, which is caused the exploding of the specimens. Hence, the exposure temperature in

Table 1
Chemical contents in quarry dust, fly ash and cement.

Chemical constituents	Weight by percent in materials		
	Quarry dust	Fly ash	Cement
LOI	0.5	3.5	1.2
SiO_2	62.5	57.1	21.4
Al_2O_3	18.7	24.7	5.1
Fe_2O_3	6.5	10.5	2.9
CaO	4.8	2.5	64.0
MgO	2.5	1.4	1.6
SO_3	1.0	0.9	2.0