Influence of elevated temperatures on compressive strength of concrete containing laterite aggregate

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Abstract. The present investigation looks into the effect of laterite aggregate as partial coarse aggregate replacement towards performance of concrete upon exposure to elevated temperature. Two mixes namely plain concrete with 100% granite aggregate and laterite concrete with 10% laterite stone as partial coarse aggregate replacement were prepared in form of cubes. All the specimens were water cured for 28 days before exposed to various level of high temperature. After that, it is left to cool down to room temperature by applying air cooling system. Behaviour of concrete upon exposure to high temperature has been evaluated through determination of mass loss and compressive strength reduction. The percentage of mass loss and compressive strength ratio pattern displayed by laterite concrete is similar to plain concrete. However, the variation in the percentage of mass loss and strength ratio of laterite concrete is governed by the different physical properties of laterite aggregate in comparison to granite aggregate. The temperature between 300 ^{o}C and 800 ^{o}C may be regarded as critical to the strength loss of laterite concrete.

Keywords: laterite aggregate, partial coarse aggregate replacement, concrete, elevated temperature, compressive strength

Introduction

The increasing demand for concrete to be used in the growing Malaysian construction industry has expanded the supply of granite from local quarries. Production of granite without plan to ensure its availability in the future would results in tremendous reduction in the number of unexplored granite sites thus contribute to unsustainable ecosystem. Quarrying activities that cause damage to biodiversity and habitat (Lameed and Ayodele, 2010) would create ecological imbalance and affect the healthy lifestyle of community surrounding due to granite extinction resulting from excessive production. However, the issues of aggregate depletion caused from the high demand on concrete (Al Shahwany, 2011) could be solved through incorporation of other materials that can function as partial coarse replacement in concrete that would be able to reduce the high dependency of industry on granite specifically.

The availability of laterite aggregate in Malaysia (Raju and Ramakrishnan, 1972) has inspired local researcher Sam (2007) on exploring the potential of this natural material for local concrete production. Laterite aggregate which formed as a result of weathering process possess the characteristic almost similar to granite aggregate. Early invesitigation by Caldeira and Caldeira (1999) discovered that this material is suitable to be integrated as partial coarse aggregate replacement in concrete making. Owing to its higher crushing value in comparison to granite, concrete with laterite aggregate tend to exhibit strength lower than plain concrete of 100% granite. However, Muthusamy and Kamaruzaman (2012) reported that incorporation of certain precentage of laterite stone as partial coarse aggregate replacement could produce concrete having the targeted strength. So far, information on the mechanical performance of laterite concrete is rather extensive, however behaviour of laterite concrete during fire outbreak is yet to be determined.

Therefore, this paper presents the result of investigation on the compressive strength performance of concrete containing laterite aggregate as partial coarse aggregate replacement when exposed to elevated temperature. The experimental tests has been conducted at laboratory of Faculty of Mechanical and Faculty Civil Engineering and Earth Resources, Universiti Malaysia Pahang.

Materials and Methods

Mix ingredients used to produce the specimens is ordinary Portland cement (OPC), river sand, crushed granite, laterite aggregate, superplasticizer and tap water. The laterite stone used as partial coarse aggregate replacement was collected from Felda Mempaga, Pahang, West Malaysia. Both laterite and granite aggregate used in this study complies to requirement in BS EN 12620 (2008). The size for laterite aggregate used same as the granite aggregate, which is, passing 20 mm sieve and retain at 5 mm sieve. The physical properties of granite aggregate and laterite aggregate is tabulated in Table 1.

Table 1 : Physical properties of granite and laterite aggregate

Physical Properties	**Granite Aggregate**	**Laterite Aggregate**
Water absorption (%)	0.92	1.070
Flakiness index	6.3	8.5
Elongation index	6.1	8.0
Specific gravity	2.69	2.54
Aggregate crushing value (%)	28.8	30.7
Ten percent fines (%)	8.4	10.2
Aggregate impact value (%)	26.2	28.7
Moisture content (%)	0.45	0.52

Two types of mixes, control specimen(PC) and laterite concrete (LC) of Grade 30 were used in this study. Control specimen consists 100% granite aggregate and laterite concrete were produced by adding 10% of laterite stone as partial coarse aggregate replacement. The mix proportion of both type of concrete is tabulated in Table 2. After placement, specimens (150x150x150mm) were covered with wet gunny sack and demoulded after 24h before immersed in water for further curing process. At the age of 28 days, cubes were taken out from the curing tank and left to dry for 24hr.

Table 2 : Mix proportion of plain concrete and laterite concrete

Material (kg/m^3)	**Plain Concrete (PC)**	**Laterite Concrete (LC)**
Cement	365	365
Granite	1170	1053
Laterite	-	117
Sand	660	660
Water	164	164
Superplasticizer	3.65	3.65

The procedure for the testing of elevated temperature is according to experimental method adopted by Ismail et al. (2011). Before the testing process, all specimens were weighed. A set of control specimens consisting PC and LC were tested without any heating process. Another set, were then subjected to heating at various temperature level using electric furnace. Temperature is controlled to the designated standard, which is 100°C, 300°C, 500°C and 800°C. The target temperature were maintained for 1 h in each case. Once the heating process is over, specimens were taken out and subjected to air cooling method whereby they were left to cool down to room temperature. Then, the weight of each specimens was taken to determined its mass loss before subjecting it to compressive strength test. The strength deterioration of the specimen was analysed using the approach of Vodak et al (2004) who considered the ratio of strength after cooling of specimen and its original value before subjected to heat in order to obtain the residual compressive strength ratio.

Results and Discussion

The result of residual mass loss of both types of concrete presented in Fig.1 shows that all specimens continuously losses its weight as the temperature become higher. Initially, between the room temperature and 100^{o}C, decrease in the mass of both type specimens is very slight due to drying of the available free water inside the hardened concrete. Beyond 100^{o}C, the specimens experienced rapid mass loss resulting from the dissapearance of capillary water and gel water that create empty voids within the hardened concrete internal structure. Previous researcher Hertz (2005) reported that free water dissapears when concrete is heated up and the chemically bound water begin to be released from the hydrated silicate gel above 150^{o}C up t0 270^{o}C. Basically, up to 300C the mass loss of concrete increases due to increment in the number of empty voids as a result of dissapearance of water inside the concrete. This fact has been stated by Janotka and Nurnbergerova (2005) who pointed out that loss in the mass of concrete is confirms the growth of air voids portion inside the hardened concrete. Both PC and LC undergoes drops in the mass value almost comparable until 500^{o}C. Beyond 500^{o}C, LC exhibit significant mass loss as compared to PC. Realizing that the concrete mass loss increases with the reduction in strength become higher during exposure to elevated temperature (Arioz, 2007), it can deduced that lower bond strength (cement-aggregate bond) in laterite concrete causes it to face larger strength reduction than plain concrete leading to higher mass loss.

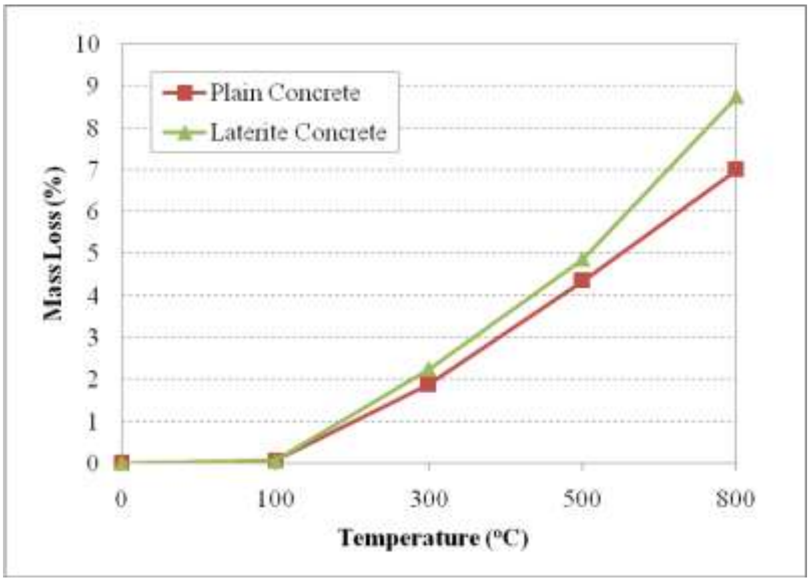

Fig.1 : Effect of elevated temperature on plain concrete and laterite concrete mass

Looking at the compressive strength reduction illustrated in Fig. 2, the compressive strength loss is insignificant for plain concrete and laterite concrete during the initial stage of testing. However, the strength loss for both type of concrete becomes noticeable at the temperature of 300^{o}C as a result of dehydration of concrete and aggregate expansion. Beyond that temperature, the loss of strength continues to be larger. One of the reasons is the internal stresses created by expansion of aggregate causing development of micro-cracks which definitely would disturb the structural integrity of concrete. According to Hertz (2005), concrete exposed to temperature higher beyond 300^{o}C would experience formation of microcracks penetrating through the material resulting in permanent strength loss.

The strength loss is significantly higher at the temperature of 500^{o}C and 800^{o}C due to decomposition of calcium hydroxide and calcium silica hydrate respectively. This has been highlighted by Hertz (2005) who stated that calcium hydroxide decompose into calcium oxide and water at 400 – 600^{o}C and then followed by decomposition of hydrated calcium silicate which occurs above 600^{o}C. Decomposition of C-S-H gel that plays important role in increasing concrete strength results significant alteration in microstructure that leads to higher deterioration of concrete that manifested in terms of strength loss. Variation in the performance of plain concrete and laterite concrete is due to properties of laterite stone used as partial coarse aggregate replacement in the latter mix. This fact has been highlighted by Gustaferro (1966) who stated that the properties of aggregate used influences concrete behaviour to high temperature. Conclusively, the temperature between 300 ^{o}C and 800 ^{o}C may be regarded as critical to the strength loss of laterite concrete.

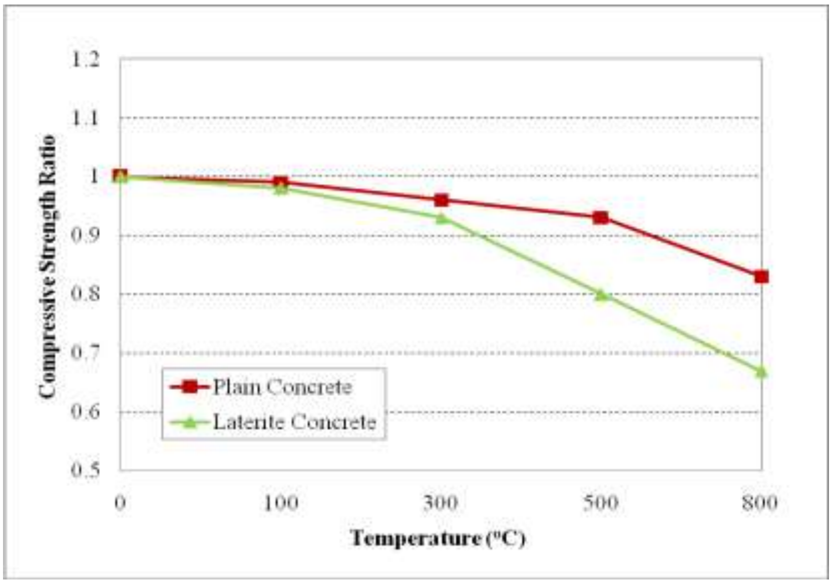

Fig. 2 : Effect of elevated temperature on compressive strength ratio of plain concrete and laterite concrete

Conclusion

Integration of laterite stone as partial coarse aggregate replacement influence the behaviour of the concrete upon exposure to elevated temperature. The physical properties of laterite aggregate which slightly varies in comparison to granite aggregate causes variation in the percentage of mass loss and strength ratio of laterite concrete. The results indicate the temperature between 300 ^{o}C and 800 ^{o}C may be regarded as critical to the strength loss of laterite concrete. Further investigation need to be undertaken to determine the suitable percentage of laterite aggregate to be integrated as partial coarse aggregate replacement to produce concrete behaving closely similar to plain concrete upon exposure to high temperature.

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