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Fresh and hardened properties of concrete containing cold bonded aggregates

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Abstract. The properties of fresh and hardened concrete made using three types of artificial cold bonded aggregates are determined. The properties, namely, slump, water absorption, compressive strength and splitting tensile strength of concrete containing artificial aggregate are reported. The variables considered are aggregate type and water-to-cement ratio. Three types of cold bonded aggregates are prepared using fly ash and quarry dust. The water-to-cement ratio of 0.35, 0.45, 0.55 and 0.65 is used. The test result indicates that artificial aggregates can be recommended for making the concrete up to a strength grade of 38 MPa. The use of quarry dust in the production of artificial aggregate mitigates environmental concerns on disposal problems of the dust. Hence, the alternate material proposed in this study is a green technology in concrete production.

Keywords: concrete; artificial aggregate; fly ash; properties; cold bonded

1. Introduction

Concrete is the largest consumed material by the construction industry. The construction industry is witnessing a strong growth in the last decade. The consumption of various raw materials, quarry products such as quarry sand and coarse aggregates is very high. The scientists have developed methods to evaluate the year left or limit to growth for quarry products. In this situation, it is important to consider alternate solutions for these constituent materials in concrete. Artificial coarse aggregate is one of the solutions to mitigate the scarcity of aggregate for the production of concrete in future.

The dust part of quarry sand is a waste material from the quarry. At present, quarry dust is used for land filling only and not being utilized for any commercial application. The disposal of this fine dust particle for land filling causes high levels of suspended particulate matter in ambient air. In most part of world, the disposal of quarry dust is a major issue as the quantity of the dust production is huge and proportional to the construction activities in the locality. In this context, identification of the methods to add value to quarry waste material is of national and international importance. In this study, the quarry dust is used for the production of cold bonded aggregates. It is expected that the outcome of the proposed study helps to mitigate the problems of disposal of

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quarry dust.

Fly ash is another waste product from coal-fired boilers. The fly ash contains cementitious compounds and can be used as binding material. Though the fly ash is used to replace cement in concrete, the waste material is not fully utilized. In this study, fly ash is used as a binding material in the preparation of cold bonded aggregates. In addition to fly ash, a small amount of cement is also used to facilitate the sufficient strength in the hardened stage.

Cold bonding is a process in which least energy is consumed and results in low carbon emission. In this process, the aggregates are pelletized using mechanical method and no sintering is employed. Cold bonded artificial aggregates using fly ash and quarry dust, which are otherwise waste materials, are prepared in this study. The proposed study promotes green technology and sustainable development in construction industry.

In this study, properties of concrete made using the artificial cold bonded aggregates are studied. The concrete mixture is prepared by varying the aggregate type and water-to-cement ratio. The properties of the concrete both in fresh and hardened stage are determined and results are presented in this paper.

2. Background information

Chi *et al*. (2003) used three types of cold bonded cement based fly ash aggregates for the production of concrete. The study indicates that type of lightweight aggregate and water to binder ratio are the significant factors influencing strength of concrete. Gesoglu *et al*. (2004) prepared concrete using cold bonded fly ash aggregate made with Portland Type 1 cement as binder. The variables of this study are water-to-cement ratio cement content and coarse aggregate ratio. The artificial aggregates are used after soaking for a period of 30 minutes in water. The compressive strength of concrete is found to be between 20 and 47 MPa. Test results indicate that compressive strength decreases with coarse aggregate to total aggregate ratio. Jo *et al*. (2007) produced geo-polymer concrete of strength grade of 33 MPa using cement based fly ash artificial aggregates. Joseph and Ramamurthy (2008) determined the fresh and hardened properties of concrete made using cold bonded fly ash aggregate. The cement content of 250 and 450 kg/m^3 is used for the preparation of concrete. The variables of the study by Joseph and Ramamurthy (2008) are cement content, water-to-cement ratio and aggregate ratio. It is found that the compacted density of concrete reduces with increase in volume fraction of cold bonded fly ash aggregate. The results of the study indicated that the cold bonded aggregate content influence the workability of the concrete. The strength of the concrete is found to increase with increase in cement content. The failure of concrete is found to be controlled by aggregate fracture. Joseph and Ramamurthy (2009) studied the influence of high volume of fly ash in concrete containing cold bonded fly ash aggregate. The fly ash replacement ratio of 10, 30 and 50 percent by weight of cement and the coarse aggregate ratio of 50 and 65 percent are used. The fresh density of concrete is found to reduce with increase in fly ash replacement ratio and cold bonded aggregate ratio. The workability of concrete is found to increase with increase in fly ash content. Joseph and Ramamurthy (2009) studied the workability and strength properties of concrete made using cold bonded fly ash aggregate. It is reported that workability of concrete is influenced by volume fraction of cold bonded fly ash aggregate. The failure of concrete is explained by the failure of mortar phase or aggregate phase. The test results indicated that cement content in concrete influences the failure of mortar phase. The strength of concrete decreases with increase in volume fraction of cold bonded aggregate. Joseph and Ramamurthy (2011) studied the influence three different types of curing methods, such as mist, sealed, air curing on strength of artificial aggregate concrete. The influence of moisture movement from aggregate to the paste in the matrix is determined at different ages. The test results indicate that the strength and hydration of matrix are insensitive to the type of curing. This indicates that the cold bonded fly ash aggregates act as internal curing agents in concrete. Gesoglu *et al*. (2012) prepared concrete of strength grade 51 MPa using artificial aggregate. The ground granulated blast furnace slag and fly ash were adopted to prepare cold bonded aggregates. Fly ash of class F and C was used. The ordinary Portland cement is used as the binder. The test results indicated that aggregates prepared using class F fly ash without Portland cement is not suitable for concrete production. It is found that the crushing strength of aggregates would influence the compressive strength of concrete. Gesoglu *et al*. (2012b) prepared self-compacting concrete using cold bonded lime cement based fly ash aggregates. The test results indicated that the ball shaped aggregates particles enhanced the workability of the cold bonded aggregate concrete. Bui *et al*. (2012) studied the strength of concrete produced using artificial aggregates made from ground granulated blast furnace slag (GGBS), rice husk ash and class F fly ash. The binder used in preparation of artificial aggregate is alkaline activator solution containing sodium silicate and sodium hydroxide. The geo-polymer artificial aggregate concrete of compressive strength between 14.8 and 38.1 MPa was prepared. It is found from the literature that studies of the properties of cold bonded quarry dust aggregate concrete is limited. This paper addresses the lacuna. The properties of concrete prepared using cold bonded quarry dust aggregate is being studied and reported.

3. Materials and methods

The constituent materials are cement, fly ash, quarry dust and fine aggregate.

3.1 Cement

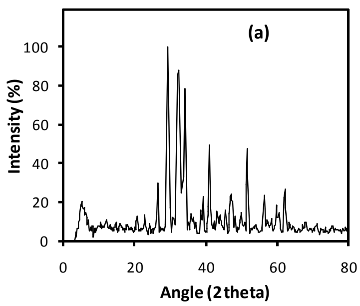
Ordinary Portland cement of grade 43 conforming to IS:8112 (1989) and with a specific gravity of 3.12 is used. The initial setting time and final setting time is found to be 90 and 150 minutes respectively. The chemical analysis reported in Table 1. The calcium oxide, which responsible for hydration and strength development, is found to be 64 percent. The XRD of cement is given in Fig 1(a). Cement is used in the production of concrete and as binder in aggregate manufacturing process.

3.2 Fly ash

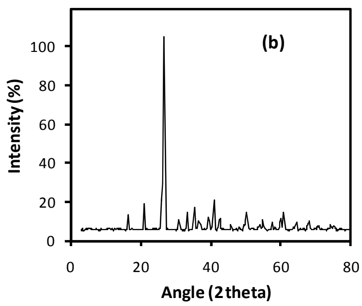
Fly ash collected from thermal power plant is used. The combustion of powdered coal in thermal power plants produces the fly ash. The high temperature of burning the coal turns the clay minerals present in the coal powder into fine particles having cementing properties. The fines in fly ash comprise of aluminium oxide and silicate. The chemical analysis result of fly ash is given in Table 1. The calcium oxide content in fly ash is 2.5 percent. Based on the chemical analysis results, it is concluded that the fly ash belongs to class F type. The alumina content in fly ash is higher than that in cement. It is expected that presence of higher alumina content will enhance the

Table1 Chemical constituents in cement, fly ash and quarry dust

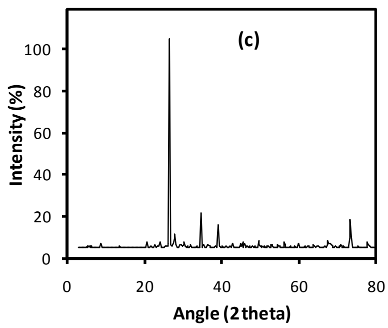
Chemicals	Percentage weight of chemicals		
	Cement	Fly ash	Quarry dust
SiO_2	21.4	57.1	62.5
Al_2O_3	5.1	24.7	18.7
Fe_2O_3	2.9	10.5	6.5
CaO	64.0	2.5	4.8
MgO	1.6	1.4	2.5
SO_3	2.0	0.9	1.0



(a) Cement



(b) fly ash



(c) quarry dust

Fig. 1 XRD pattern of cement, fly ash and quarry dust

sulphate resistance of the cementitous compound. The XRD pattern of fly ash is given in Fig 1(b). Fly ash is used for the production of cold bonded artificial aggregates.

3.3 Quarry dust

The dust collected from granite quarry is used for preparation of artificial aggregates. The specific gravity of quarry dust is found to be 2.69 and contains 15 percent of fines of size smaller than 90 micron. The chemical composition of quarry dust is shown in Table1. The silica in quarry dust is 62.5 percent. The XRD pattern of quarry dust powder is given in Fig 1(c). The particle size distribution of the quarry dust is given in Fig 2. The size of the particles in the quarry dust is compared with the quarry sand in Fig 2. The size of quarry dust is very much smaller than the quarry sand.

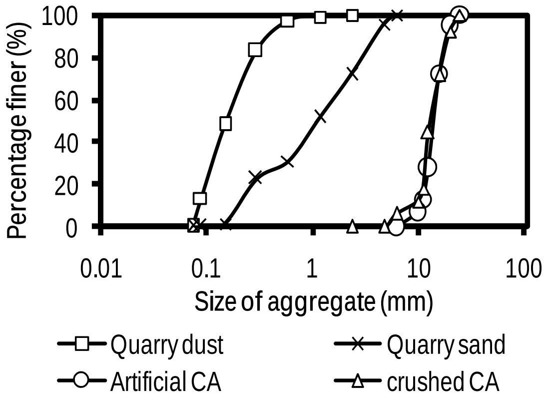


Fig. 2 Particle size distribution of dust and aggregates

3.3 Quarry dust

The quarry sand is the coarser fraction raw quarry powder separated by water washing. The quarry dust along with the water is collected in a pit. The quarry sand consists of particles of size between 1.00 mm and 4.75 mm. The particle size distribution of quarry sand is given in Fig 2. The quarry sand conforms to zone III of IS 383 (1970). The specific gravity of quarry sand is found to be 2.70. The quarry sand is used as the fine aggregate in concrete.

3.4 Artificial aggregate

Artificial aggregates are manufactured by cold bonding process. The quarry dust, fly ash and cement are dry mixed in a pelletizer. The angle of rotation of the drum of the pelletizer is set as 25 degrees and speed of revolution is 26 rpm to get the highest efficiency of production, which is determined based on the preliminary study. The water is sprayed to the dry mixed materials in the rotating drum. The water content of 50 percent by weight of mixture is used for the aggregate production. The particles of the dry mix bonded together in presence of water during the rotation of the drum. The aggregate balls thus formed are discharged from the drum and sieved.

The artificial aggregates are dried in air for 24 hours and cured for another 28 days by immersing in water. Three types of artificial aggregate are prepared and designated by A, B and C. The proportion and constituents of different types of artificial aggregates are given in Table 2. The test of specific gravity, water absorption and loose bulk density of the aggregates are carried out as given by IS 2316 (1997). The results of physical test on aggregates are given in Table 2. The specific gravity of Type B aggregates is found to be lower than Type A and C. The fly ash is relatively lightweight and hence the specific gravity of the artificial aggregate decreases with increase in fly ash content. The water absorption in quarry dust artificial aggregates designated by ‘A’ is found higher than Type B and C aggregates. The bonding is found to be better when fly ash is used for aggregate production and this might have resulted in lower the pores in the fly ash aggregate balls. In addition, the pores in the fly ash aggregate balls are partially filled due to the pozzolanic reaction.

Fig. 3 Image of artificial aggregate type B

Table 2 Proportion of constituent materials in artificial aggregate

Artificial aggregates type	Percent by weight of constituent materials			Properties of cured artificial aggregates			
	Cement	Quarry dust	Fly ash	Specific gravity	Water absorption (%)	Loose bulk density (kg/m^3)	12 mm diameter ball crushing strength (N)
A	20	80	-	2.43	20.1	1238	1510
B	20	-	80	1.85	17.3	998	2820
C	20	40	40	2.18	18.7	1112	2210

The shape of the cold bonded aggregate is found to be spherical and is shown in Fig 3. The shape is found to be almost similar in A, B and C type aggregates. The loose bulk density of the aggregates is found to be proportional to the specific gravity of the aggregate. The crushing strength of aggregate balls of nominal diameter 12 mm is determined as per BS 812 part 110 (1990). The ball crushing strength of fly ash aggregate is found to be higher than quarry dust aggregate. The alumina content in fly ash is more than that in quarry dust (Table 1). It is expected that the pozzolanic reaction of fly ash helped to improve the strength of aggregates.

4. Experimental study

Three types of cold bonded artificial aggregates were adopted to prepare concrete. The proportion of concrete mix is arrived at based on absolute volume method given by IS 10262 (2009). The designation of concrete mix and the weight of constituent materials are given in Table 3. The variables considered are type of aggregate and water-to-cement ratio. The water content is recommended by IS 10262 (2009) by 20 mm coarse aggregates is considered and is equal to 186 kg per cubic meter of concrete. The cement content corresponding to water-to-cement ratio and water content is determined. The ratio of coarse aggregate to total aggregate is taken as 0.65. The weight of fine and coarse aggregates is determined based on absolute volume method. The cold bonded artificial coarse aggregates are pre-soaked for 24 hours to compensate the water absorption.

The cement and fine aggregate are mixed dry in a rotating drum mixer. The water content is compensated for the surface moisture present in the pre-soaked coarse aggregate. The seventy five percent of the adjusted water content is added drum and mixed. The pre-soaked coarse aggregates are discharged into the drum and mixing operation is continued. The balance 25 percent of the adjusted water content is added at the end of mixing process.

The quantity required for casting the specimens and initial workability test is discharged from the drum. The drum is continued to rotate to simulate the continuous mixing process similar to that in the transit mixer. At every 15 minutes, the required quantity of fresh concrete for the workability test is discharged and mixing operation is continued.

The slump test is carried out to determine the workability of fresh concrete as per IS 1199 (1950). The slump at a given time interval is measured and the slump loss in concrete containing artificial aggregates is determined.

Three standard cubes of size 150 mm × 150 mm × 150 mm and three standard cylinder of 150 mm diameter and 300 mm height are cast. The cube and cylinder specimens are demoulded after 24 hours and cured using moist burlap. The cubes and cylinder specimens are tested at an age of 28 days. Water absorption of concrete is determined using standard cubes of size of 150 mm × 150 mm × 150 mm as per ASTM C642-06 (2006). The compressive test is carried out using standard cube specimens as per IS:516 (1959). The splitting tensile strength is carried out using standard cylinder specimen as per IS:5816 (1999).

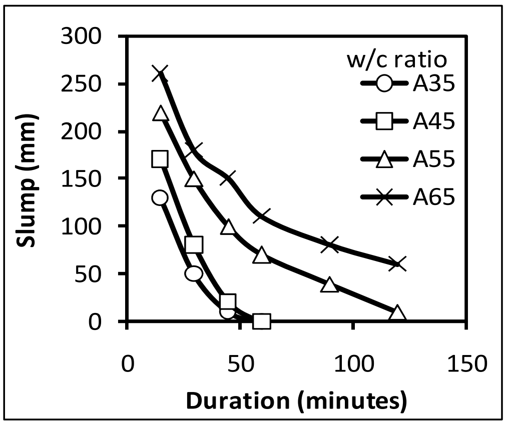
5. Results and discussion

The properties of the concrete containing cold bonded artificial aggregate are determined. The workability of the fresh concrete is determined using slump test. The slump is also determined at every 15 minutes for a period of 120 minutes. The water absorption of concrete is determined and reported in this paper. The compressive strength and split tensile strength of the concrete are determined.

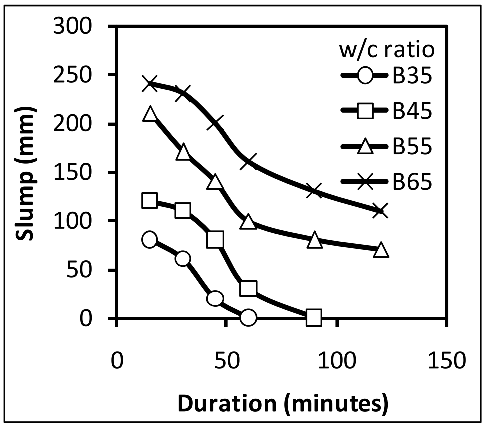
5.1 Slump

Slump is the popular method of testing workability of concrete. The settlement flow-ability of fresh concrete mass is estimated using the slump. The initial slump is measured at 15 minutes of adding water to concrete and is given in Fig 4. The slump of concrete with water-to-cement ratio of 0.65 is found to be high when compared to the mix with water-to-cement ratio 0.55, 0.45 and 0.35. The variation in slump in concrete is complex phenomena and influenced by both internal and external factors. Internal factors are water-to-cement ratio, friction between the aggregates and shape of aggregate. The amount of water covering the surface of constituent particles increases with increase in water-to-cement ratio and will act as lubricating agents in the wet continuum. The smooth surface of round fly ash aggregate facilitates easy movement in fresh mass, similar to balls in a bearing system. The mechanism of slump loss is influenced by the absorption and moisture content in artificial aggregates (Ghafoori and Diawara 2010). The exposure surface area of the fresh concrete, ambient temperature and humidity are the external factors affecting the variation in slump.

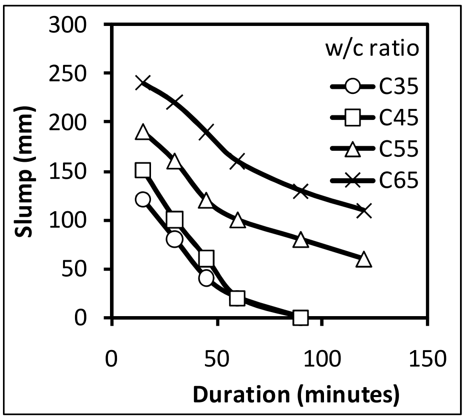
The variation of slump with time is given in Fig 4. The reduction of slump in concrete



(a) type A aggregate concrete



(b) type C aggregate concrete



(c) type C aggregate concrete

Fig. 4 Variation of slump with time in concrete containing cold bonded artificial aggregate

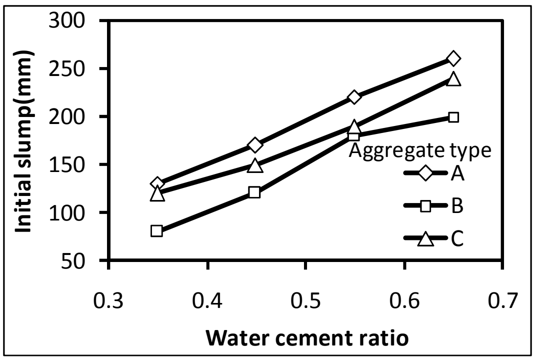


Fig. 5 Initial slump in concrete containing artificial aggregate

containing A-type artificial aggregate is found to be high when compared to the concrete with B and C-type artificial aggregate. The stiffening properties of the cementitious compound are influenced by presence of high alumina content in the fly ash. The variation in slump loss in artificial aggregate concrete is attributed to the variation in the moisture transfer rate between the aggregate and cement paste. The test results of this study corroborate with the test results reported by Poon *et al*. (2007).

The initial slump of concrete containing A, B or C type artificial aggregates are compared and are given in Fig 5. The initial slump of B type aggregate concrete is found to be greater than concrete C and type A type aggregate concrete. The initial slump mainly depends on the friction between the aggregate surface and the cement paste. The fly ash is a fine powder and surface of the fly ash aggregate is smooth when compared to the quarry dust aggregate. The friction between the fly ash aggregates and paste is low. This may be reason for the higher magnitude of slump in fly ash aggregate concrete.

5.2 Water absorption

The water absorption of the hardened concrete is estimated using cube specimen. The absorption of the water in concrete by capillary suction provides useful information relating to its pore structure, permeation characteristics and durability (Parrott 1992). The part of the total porosity, which is connected to the boundaries or surface points are only important for the transport of liquid or gases in concrete (Nguyen 2011). The water absorption in saturated condition is explained by permeability mechanism (Emerson 1990). The water penetration through permeability mechanism is influenced by pore radius, porosity, pressure difference and penetration time.

Water absorption is a measure of connected surface open pores in the concrete. The durability of the concrete is directly proportional to the water absorption. The water absorption of the concrete is found to be significantly lower than the water absorption in the aggregate given in Table 3. This may be due to the fact that the mortar surrounded by the aggregate in the composite prevents the seepage of water towards the relatively porous aggregate. The influence of the water-to-cement ratio on the water absorption of concrete is given in Fig. 6.

The water absorption of B type aggregate concrete is found to be lower than A and C type aggregate concrete. The aggregates on the surface or near to the surface of the cube specimens

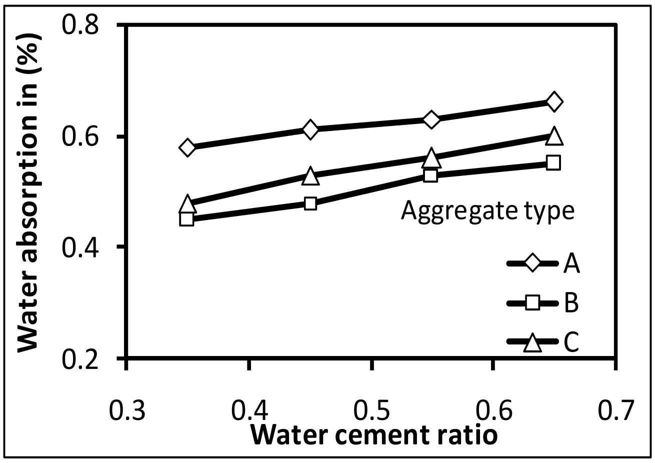


Fig. 6 Water absorption of the concrete containing artificial aggregate

absorb water. The amount of water absorbed by the concrete is found to be proportional to the pores in the matrix phase and the aggregate exposed to cube boundary. The water absorption in fly ash aggregate concrete is found to be low when compared to the quarry dust aggregate concrete. The pores in the matrix phase increases with the quantity of water added to the concrete. This may be reason for the increase in water absorption of concrete with the increase in the water-to-cement ratio.

5.3 Compressive strength

The compressive strength of the concrete containing artificial aggregates is determined using standard cube specimens and given in Fig 7.

The strength of concrete depends on the strength of the matrix and aggregate phase. The strength of matrix depends on the water cement ratio. The strength of the concrete containing B type artificial aggregate is found greater than A and C type aggregate concrete. This may be attributed to the fact that the ball crushing strength of fly ash aggregate is greater when compared to the quarry dust aggregate. The strength of the matrix phase decreases with increase in pore, which is directly proportional to the water-to-cement ratio. This may be the reason for the decrease in the compressive strength with increase in water-to-cement ratio.

The crack in cube specimen of A45 mix is given in Fig 8. The mechanism of failure of the laboratory cube specimens indicates that there are three zones exist in the test piece varying the stress conditions (Yu *et al*. 2008). The top and bottom conical portions are in triaxial state of stress. These conical portions are subjected to both the axial stress and confining pressure mobilized by friction between the steel platen of the machine and specimen surface. The central area at mid height is the most severe compression area in the specimen. The third zone is the wedge portion, which is later peeled off from the sides due to lateral bulging of the specimen and frictional failure controlled by Mohr-Coulomb criterion. Shear conical failure is observed in all specimens. Partial splitting of aggregates is also found on the crack surface of the cube specimens. The rich mix used corresponding to the water cement ratio of 0.35 and 0.45. Thus, the matrix phase is relatively strong in these concrete mixes. The splitting of aggregate is found to be more significant in strong matrix weak aggregate system.

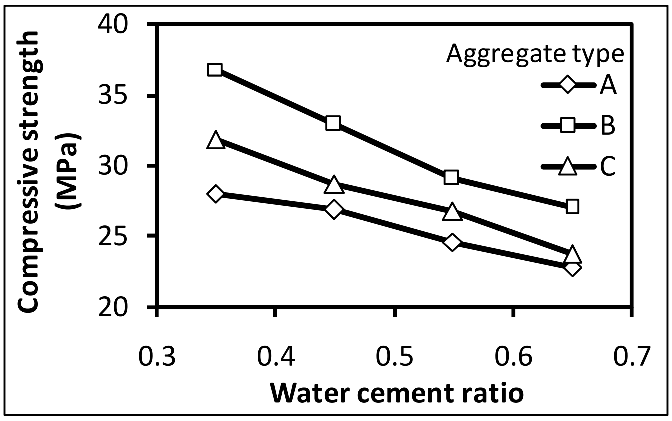


Fig. 7 Compressive strength of concrete strength of concrete containing artificial aggregates

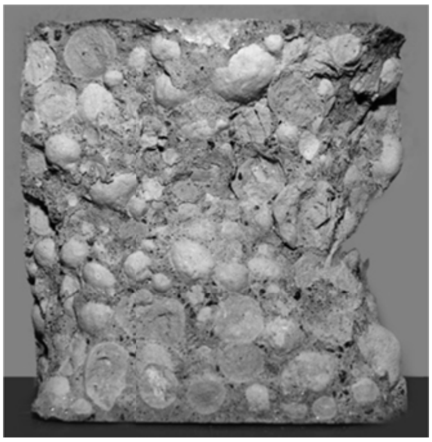


Fig. 8 Crack pattern in A45 concrete cube specimen

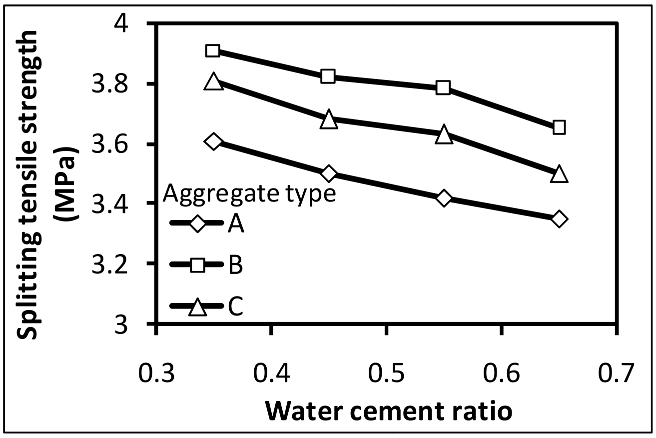


Fig. 9 Splitting tensile strength of concrete strength of concrete containing artificial aggregates

Joseph and Ramamurthy (2008), Priyadharshini *et al.* (2011), Chi *et al.* (2003) and Gesoglu *et al.* (2004) reported that the compressive strength fly ash aggregate concrete with water-to-cement ratio of 0.45 is between 35 to 45 MPa. In this study, the compressive strength of concrete containing fly ash aggregate with water-to-cement ratio of 0.45 is found 34 MPa. The variation in strength may be attributed to the difference in variation in strength of aggregate and testing conditions.

5.4 Splitting tensile strength

The splitting tensile strength of the concrete is determined and is given in Fig 9. The splitting failure is due to the lateral bulging of the specimen. The failure is due to the development of a macro-crack, which is initiated from the tip of the inherent micro-cracks. The propagation of the crack is largely influenced by the bonding between the aggregate and the mortar matrix (Malárics and Müller 2010). The crack propagates through the aggregates when the strength of the ball is low. The crack propagates by failing the aggregate-matrix interface when the bond is weak. Hence, the tensile strength of the concrete specimen is the cumulative strength of the components in the tortuous crack path.

The variation of the split tensile strength is found to be similar to that of the compressive strength. The failure of the cylinder specimens depends on the splitting of matrix and aggregate phase. The strength of the B-type aggregates is greater than that of A or C-type aggregates. Hence the splitting tensile strength of B-type concrete artificial aggregates is found to be greater than that of A or C type aggregate concrete.

Joseph and Ramamurthy (2008) reported that the spit tensile strength of concrete containing fly ash artificial aggregate with water-to-cement ratio is 3.5 MPa, the corresponding strength obtained in the present study is 3.6 MPa. The split tensile strength reported in this study corroborates with the test data of Joseph and Ramamurthy (2008).

6. Conclusions

Based on the experimental study of concrete containing cold bonded artificial aggregates following conclusions are arrived at.

- The fly ash aggregate concrete exhibited high workability when compared to the quarry dust aggregate. Smoothness of the aggregate surface enhances the workability of the concrete.
- The rate of loss of slump in concrete containing artificial aggregates is significant in the first 60 minutes. Hence, the test result on slump loss of artificial aggregates concrete given in this paper is useful for the mix designer to evaluate the slump at delayed placing at worksite.
- The water absorption of concrete is directly proportional to the pores in the aggregate phase. The water absorption of the quarry dust aggregate concrete is found to be slightly greater than the fly ash aggregate concrete.
- The compressive strength of the concrete depends on the aggregate strength. The fly ash aggregate concrete is found to have higher strength when compared to quarry dust aggregate concrete.

The compressive strength of quarry dust aggregate concrete is found to be about 75 percent of the strength of corresponding mix with fly ash aggregate. Hence, it may be concluded that, cold bond quarry dust aggregates can be used for the production of concrete with appropriate modification in the mix design procedure. The quarry dust aggregate is an alternate potential constituent in concrete and a sustainable solution for disposal problems.

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