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Utilization of clay burnt brick aggregate for making high strength concrete

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Abstract

A study has been conducted to understand the possibility of utilization of clay burnt brick coarse aggregate for making high strength concrete in Bangladesh. For investigation, good quality brick aggregate was collected from a local market. Compressive strength of mortar portion of concrete was found significantly higher than the compressive strength of concrete made with brick aggregate irrespective of the investigated cases. Although higher strength of mortar led to higher compressive strength of concrete, but the rate of increase of compressive strength of concrete is reduced at higher level of mortar strength. It is found that with the utilization of mineral admixtures (fly ash, slag, and silica fume) and keeping W/C at a lower level (0.35), it is possible to produce high strength concrete by using good quality brick aggregate. Specimens with lower water to binder ratio, higher binder content and lower maximum aggregate size showed higher compressive strength. Relationships between compressive strength of concrete and splitting tensile strength and modulus of elasticity are proposed. Relationship between compressive strengths of concrete obtained from destructive and non-destructive test (by Schmidt's hammer) is also proposed.

Keywords: High strength concrete, brick aggregate, blended cement, water to binder ratio, silica fume.

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1. Introduction

In the course of achieving the status of a middle-income country by 2021 and a developed country by 2041, government of Bangladesh has undertaken several megaprojects like Metro Rail Project, Paira Port Project, Dhaka Elevated Expressway Project, Matarbari Deep Sea Project, and Karnofuli Tunnel Project, and so forth. Also, due to the scarcity of land as well as high population growth, it is necessary to make high-rise buildings in major cities of Bangladesh. For making these buildings and associated infrastructures, utilization of high strength concrete is indispensable. Also, from the viewpoint of sustainability of construction materials, it is necessary to utilize high strength concrete in Bangladesh as it is closely related to durability of concrete. The service life of a structure can be increased significantly by utilizing high strength concrete in construction. It will eventually help toward sustainability of construction materials as it will reduce the demand of construction materials. However, we need to overcome the challenges for making high strength concrete in Bangladesh.

High strength concrete is defined as a concrete having compressive strength more than 6000 psi (41 Mpa) or more but it is also recognized that the definition of HSC varies on a geographical basis (ACI Committee 363, 1992). High strength concrete is not a new material as it has been in use since 1980. A lot of studies were conducted globally on mix design, production and utilization as well as properties of high strength concrete (Aitcin & Mehta, 1990; Chen & Liu, 2008; Hassan et al., 2000; Memon et al., 2002). These studies concluded that for making high strength concrete, it is indispensable to utilize mineral and chemical admixtures. Bangladesh is a land of delta. Due to scarcity of the source of stone aggregate, clay burnt brick coarse aggregate is widely used for construction. Stone aggregates are also imported from several countries for utilization in concrete. Possibility of utilization of Maddhapara hard rock for utilization in concrete for making high strength has been studied and results showed that by utilizing this aggregate in concrete, it is possible to produce high strength concrete having compressive strength more than 10,000 psi (Mohammed et al., 2019). Some research works were also conducted to explore the possibility of utilization of locally available aggregates for making high strength concrete (Sarwar et al., 2012; Rashid & Mansur, 2009). Further detailed research is still necessary to understand the strength of concrete that we can achieve by using locally available good quality brick aggregate. With this background, two series of concrete specimens were made by varying water to binder ratio, cement content, sand to aggregate volume ratio, maximum size of coarse aggregate, and types of cement. The results are summarized in this article and will be useful to understand the possibility of utilization of brick aggregate for making high strength concrete.

2. Experimental method

2.1 Materials

Good quality clay burnt brick chips were collected from a local market and then washed thoroughly to remove impurities and tested for specific gravity, absorption capacity, and abrasion value as per ASTM C127, ASTM C127, and ASTM C131, respectively. The maximum size of coarse aggregate was 20 mm (Series A and Series B) and 15 mm (Series B only). For making a compact grading of coarse aggregate, twenty-one different aggregate grading were investigated for unit weight and void content in aggregate. It was found that the best compact grading (minimum void and maximum unit weight determined as per ASTM C29) is produced for a mixture of aggregate prepared with 40% of aggregate from 20 mm to 15 mm, 30% of aggregate from 15 mm to 10 mm, and 30% of aggregate from 10 mm to 5 mm for the maximum size of aggregate of 20 mm. The same was found as 70% of aggregate from 15 mm to 10 mm plus 30% of aggregate from 10 mm to 5 mm for the maximum size of 15 mm (Anis et al., 2011). The specific gravity, absorption capacity, and abrasion value of brick aggregate were 2.35, 19.6%, and 36.17%. The fineness modulus (FM) of the graded coarse aggregate was 6.7 for 20 mm and 15 mm downgraded aggregate. The FM of the 15 mm downgraded aggregate is not reduced as the cumulative percentage retained on 3/8-inch sieve was same as the same for 20 mm downgraded aggregate. The grading curve of the coarse aggregate is shown in Figure 1 along with the requirements of ASTM C33. The grading curve of coarse aggregate satisfies the requirement of ASTM C33. Two types of sand such as coarse sand and fine sand were collected from a local market and washed carefully to remove dust and other organic impurities. The aggregates were tested for absorption and specific gravity. The coarse sand was divided into two sizes, such as 5 mm to 2.38 mm and 2.38 mm to 1.19 mm whereas the fine sand was sieved for 1.19 mm to 0.15 mm size. Then both coarse and fine sand samples were mixed for 14 different proportions to find a compact grading. The compact grading was found for a mixture of sand with 30% from 5 mm to 2.38 mm, 30% from 2.38 mm to 1.19 mm, and 40% from 1.19 mm to 0.15 mm as this mixture of fine aggregate produced the maximum unit weight and minimum void. The specific gravities were 2.6 and 2.49 for coarse and fine sand, respectively.

Ordinary portland cement (defined as CEM I as per BDS EN 197) was used for Series A. For Series B, a customized blended cement was prepared with 50% CEM Type I cement, 20% fly ash (fineness 3180 cm2/g), 20% slag (fineness 4728 cm2/g), and 10% silica fume. Sulfonated naphthalene-formaldehyde condensates (SNF) superplasticizer was used as 1.2% of weight of cement to increase workability of concrete made for the mixtures with low W/Bs. Tap water was used for mixing concrete. The FM of the graded sand was 3.35 which was higher than the FM of normal strength concrete. For the production of high strength concrete, it is required to use a coarse graded sand (ACI Committee 211, 1993). The grading curve of fine aggregate is shown in Figure 2 along with the requirements of ASTM C33. The grading curve of fine aggregate satisfies ASTM C33.

2.2 Mixture proportions

Concrete mixes were designed for two series of specimens (Series A and Series B) by varying the types of binder. For Series A, the binder was ordinary Portland cement (CEM Type I as per BDS EN 197). For Series B, the binder was blended cement with silica fume as discussed in the previous section. For Series A, 15 mixture proportions were prepared by varying W/B as 0.35, 0.40, 0.45, 0.50, and 0.55 and cement content as 350 kg/m^3, 400 kg/m^3 and 450 kg/m^3. Sand to total aggregate (s/a) volume ratio was kept fixed at 0.38 and maximum size of aggregate was 20 mm. The investigated mixture proportions are summarized in Table 1. As summarized in Table 1, the Case No. A1-BC 350 WB 35 SA 38 M 20 indicates the first case of Series A made with binder content 350 kg/m^3, W/B = 0.35, sand to aggregate volume ratio = 0.38, and maximum size of coarse aggregate = 20 mm. For Series B, four mixture proportions were prepared by varying sand to total aggregate volume ratio as 0.34, 0.36, and 0.38 and maximum aggregate size as 20 mm and 15 mm. The mixture proportions of Series B are summarized in Table 2. As summarized in Table 2, the Case No. B1-BC 450 WB 35 SA 34 M 15 indicates the first case of Series B made with binder content = 450 kg/m^3, W/B = 0.35, sand to total aggregate volume ratio = 0.34, and maximum size of brick aggregate = 15 mm. High range water reducer (Sulfonated naphthalene formaldehyde) was used for low W/B to improve workability. Air content was assumed to be 2% as no air entraining admixtures was used.

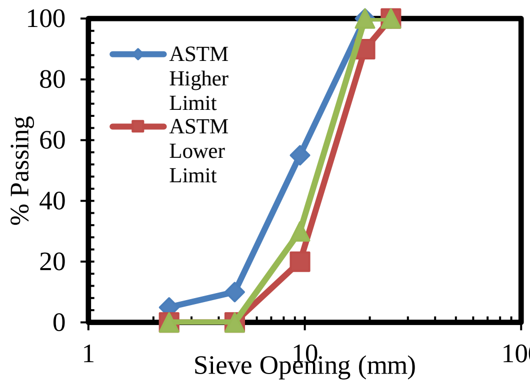

Fig. 1. Grading curve - coarse aggregate

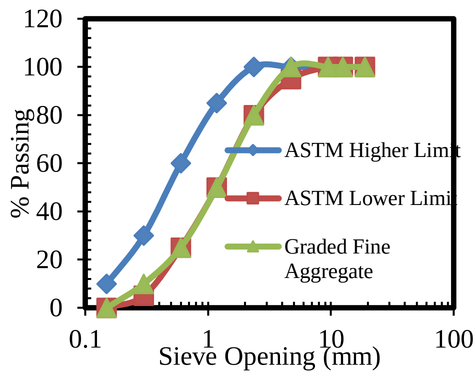

Fig. 2. Grading curve - fine aggregate

Table 1
Mixture proportions of concrete - Series A

Case No.	W/B	s/a	Max. Aggregate Size (mm)	Unit Content (kg/m^3)								
				W	Binder				CA	S	HRWRA
					OPC	FA	Slag	SF			
A1-BC 350 WB 35 SA 38 M 20	0.35	0.38	20	118.3	350	0	0	0	1085	723	4.2
A2-BC 350 WB 40 SA 38 M 20	0.40			136.5	350	0	0	0	1059	706	3.5
A3-BC 350 WB 45 SA 38 M 20	0.45			154.7	350	0	0	0	1034	689	2.8
A4-BC 350 WB 50 SA 38 M 20	0.50			175	350	0	0	0	1008	672	---
A5- BC 350 WB 55 SA 38 M 20	0.55			192.5	350	0	0	0	983	655	---
A6-BC 400 WB 35 SA 38 M 20	0.35			135.2	400	0	0	0	1036	691	4.8
A7-BC 400 WB 40 SA 38 M 20	0.40			156	400	0	0	0	1007	671	4
A8-BC 400 WB 45 SA 38 M 20	0.45			180	400	0	0	0	978	652	---
A9-BC 400 WB 50 SA 38 M 20	0.50			200	400	0	0	0	949	632	---
A10-BC 400 WB 55 SA 38 M 20	0.55			220	400	0	0	0	919	613	---
A11- BC 450 WB 35 SA 38 M 20	0.35			152.1	450	0	0	0	987	658	5.4
A12-BC 450 WB 40 SA 38 M 20	0.40			175.5	450	0	0	0	954	636	4.5
A13- BC 450 WB 45 SA 38 M 20	0.45			202.5	450	0	0	0	921	614	---
A14- BC 450 WB 40 SA 38 M 20	0.50			225	450	0	0	0	889	592	---
A15- BC 450 WB 40 SA 38 M 20	0.55			247.5	450	0	0	0	856	571	---

Note: W/B, s/a, W, OPC, FA, SF, CA, S and HRWRA refer to water-to-binder ratio, sand-to-total aggregate volume ratio, water, ordinary portland cement, fly ash, silica fume, coarse aggregate, sand and high range water reducing admixture respectively.

Table 2
Mixture proportions of concrete - Series B

Case No.	W/B	s/a	Max. aggregate size (mm)	Unit Content (kg/m^3)							
				W	Binder				CA	S	HRWRA
					OPC	FA	Slag	SF			
B1-BC 450 WB 35 SA 34 M 15	0.35	0.34	15	157.5	225	90	90	45	1051	589	54
B2- BC 450 WB 35 SA 36 M 15		0.36		157.5	225	90	90	45	1019	623	54
B3- BC 450 WB 35 SA 38 M 15		0.38		157.5	225	90	90	45	987	658	54
B4- BC 450 WB 35 SA 34 M 20		0.34	20	157.5	225	90	90	45	1051	589	54

Note: W/B, s/a, W, OPC, FA, SF, CA, S and HRWRA refer to water-to-binder ratio, sand-to-total aggregate volume ratio, water, ordinary portland cement, fly ash, silica fume, coarse aggregate, sand and high range water reducing admixture respectively.

2.3 *Casting, curing and testing*

A 200-liter capacity concrete mixer was used for mixing concrete. Both coarse and fine aggregates were kept in saturated surface dry (SSD) condition. Immediately after mixing concrete, workability of concrete was measured by slump cone test as per ASTM C143. Cylindrical concrete specimens of diameter 100 mm and height 200 mm were made. Also, 50 mm mortar cube specimens were made by screening each mixture of concrete through #4 (4.75 mm) sieve. The specimens were demolded after one day and kept under wet condition for curing. The specimens were tested with a universal testing machine (UTM). During compression test, two dial gauges were attached at a gauge length of 100 mm to measure strain over the specimens under applied load. The modulus of elasticity of concrete was determined from the stress-strain curves. The stress of concrete at strain level 0.0005 was used to determine the modulus of elasticity. Tensile strength of the specimens was measured by splitting tensile test. The concrete specimens of Series B were tested at 28 days, 56 days and 90 days. The specimens of mix Series A were tested at 28 days only. The compressive strength and splitting tensile strength were determined as per ASTM C39 and ASTM C496 respectively. The specimens were also tested by a Schmidt's hammer as per ASTM C805 before crushing them for compressive strength test.

3. Results and discussion

3.1 *Workability*

The slump values of fresh concrete are shown in Figure 3. Irrespective of binder content, type of binder, sand to aggregate volume ratio, and maximum size of coarse aggregate it is found that workability of concrete is increased significantly for concrete mixes with low W/Bs due to the utilization of water reducing chemical admixture (1.2% and 12% of weight of cement for Series A and Series B, respectively). Higher dosage of superplasticizer was required for Series B due to the presence of 10% silica fume (particle size about 1/100th of cement particle). Similar results were also observed by other researchers (Nagataki, 2002). It is clearly understood that by varying the dosage of sulfonated naphthalene formaldehyde condensates based high range water reducing chemical admixture, it is possible to increase workability of concrete made with brick aggregate. This study was conducted with a particular type of chemical admixture. Therefore, the scope of this study can be extended to a new generation powerful super plasticizer, such as poly carboxylate-based superplasticizer.

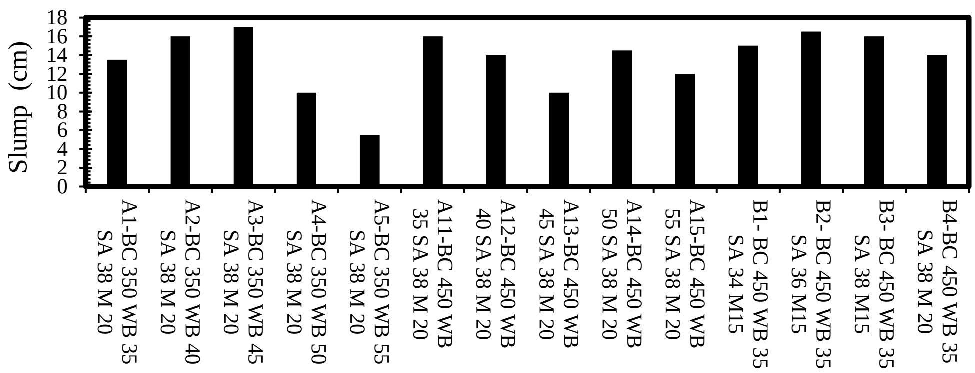

Fig. 3. Slump of fresh concrete.

3.2 *Compressive strength*

The compressive strength of both mortar and concrete specimens at 28 days, 56 days and 90 days are shown in Figure 4, Figure 5 and Figure 6 respectively. Compressive strength tests at

56 days and 90 days were only carried out for Series B specimens made with customized blended cement (50% CEM Type I + 20% fly ash + 20% slag + 10% silica fume) considering the slower rate of hydration for mineral admixtures.

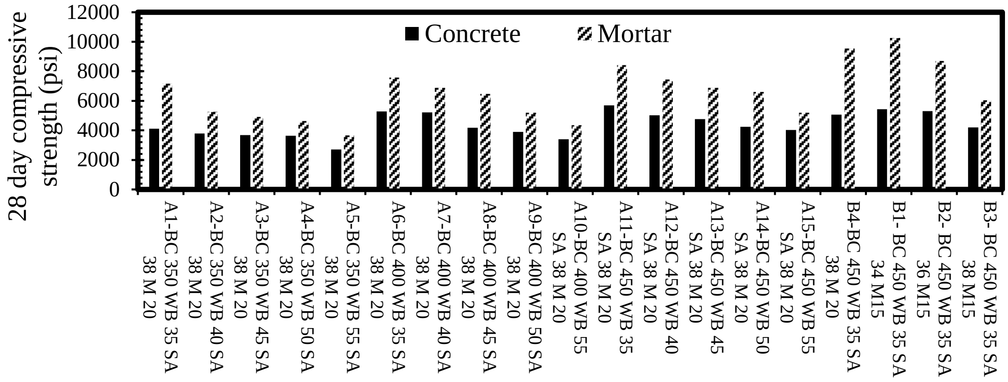

Fig. 4. Compressive strength of concrete at 28-day.

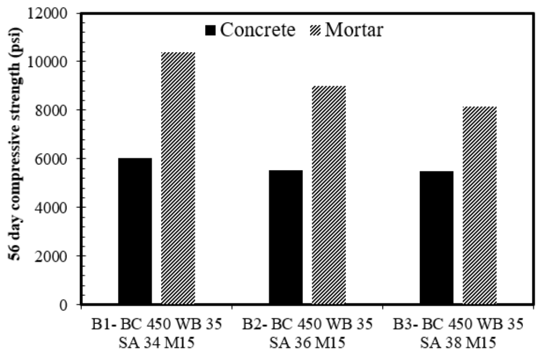

Fig. 5. Compressive strength of concrete at 56-day.

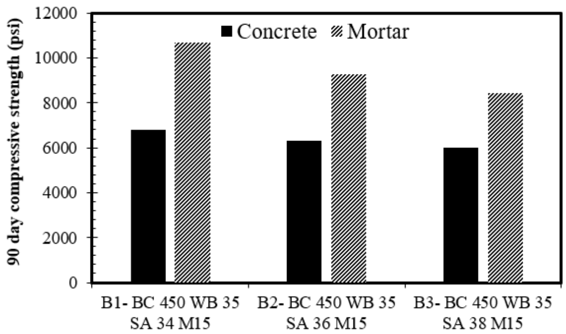

Fig. 6. Compressive strength of concrete at 90-day.

The variation of compressive strength with time for Series B specimens is shown in Figure 7. For all cases, the mortar strength of concrete (prepared by screening fresh concrete through #4 sieve) is higher than the compressive strength of concrete. It is because of inclusion of softer brick aggregate (higher abrasion value) in concrete. The difference between the mortar strength and the strength of concrete is increased for Series B specimens. With the addition of silica fume and other mineral admixtures, the strength of concrete is not increased as increased for mortar specimens. From the results, it is also found that higher compressive strength of concrete as well as mortar was obtained for a lower W/B irrespective of the other variables investigated in this study. Specimens of the both series with the highest binder content of 450 kg/m^3 and the lowest W/B of 0.35 showed the highest compressive strength. At 28 days, these specimens exceeded compressive strength of 5000 psi but failed to reach the target strength of 6000 psi, the minimum strength requirement for high-strength concrete (ACI Committee 363, 1992). The highest compressive strengths at 28 days were 5687 psi and 5425 psi for Series A (made with OPC) and Series B (made with blended cement), respectively. The specimens of Series B showed lower compressive strength compared to the similar specimens of Series A due to slower rate of hydration of binder used for Series B. At 56 days, compressive strength of concrete of several cases of Series B (B1- BC 450 WB 35 SA 34 M15) exceeded 6000 psi. However, the compressive strength of concrete for all cases of Series B made with maximum size of coarse aggregate of 15 mm exceeded 6000 psi at 90 days. It is understood that for making high strength concrete, it is necessary to reduce the size of coarse aggregate. The interfacial transition zone (ITZ) around a smaller size of coarse aggregate is stronger than a larger size of coarse aggregate (Mohammed et al., 2017). It helps to achieve more compressive strength of concrete. Further research on the effect of compressive strength of concrete made with different size of coarse aggregates, such as 10 mm, 15 mm, 20 mm, 35 mm, 50 mm, 63 mm, and 75 mm was conducted and similar observations were found (Sakib et al., 2018). It was also found that (for Series B) with increase of sand to aggregate volume ratio of concrete, the strength of concrete is reduced. Therefore, for making high strength concrete, sand to aggregate volume ratio is to be set at a lower level compared to the normal strength concrete.

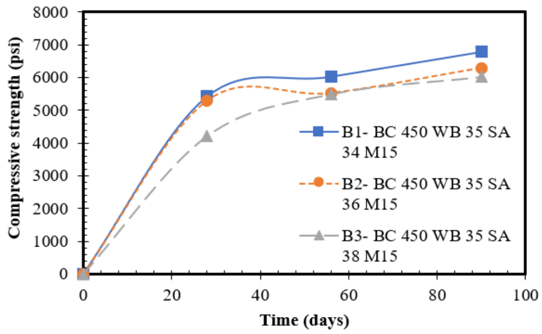

Fig. 7. Compressive strength vs time.

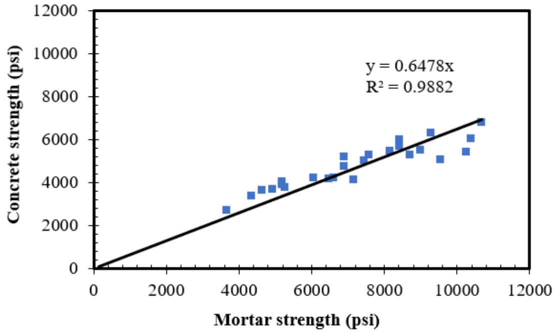

Fig. 8. Concrete strength vs mortar strength.

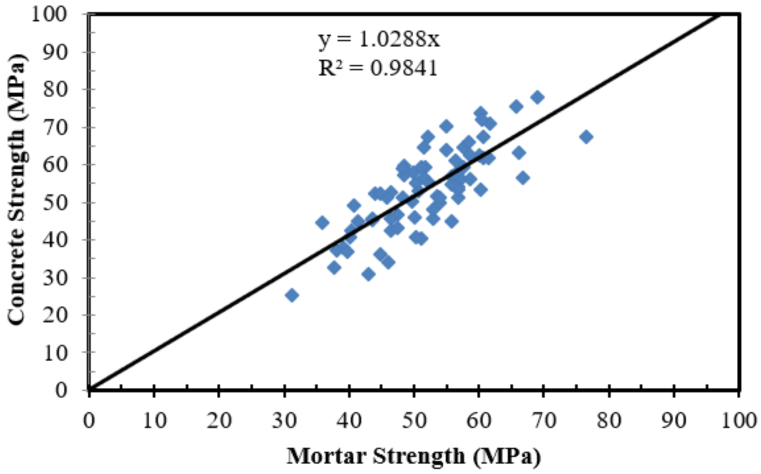

Fig. 9. Mortar strength versus concrete strength made – Hard Rock, Dinajpur.

The variation of mortar strength and concrete strength for all specimens is shown in Figure 8. It is found that the compressive strength of concrete is much lower than the compressive strength of mortar. The difference is increased with the increase of mortar strength of concrete. The results indicate that by further increasing cement content (500 to 550 kg/m^3), it will be possible to increase the strength of mortar but the increase in strength of concrete may not be significant. A separate study was conducted on utilization of hard rock aggregate of Dinajpur for making high strength concrete.

The variation of mortar strength of concrete made with hard rock and the strength of concrete made with the same aggregate is shown in Figure 9. It is seen that there is no significant difference between mortar strength and strength of concrete. The strength of concrete for the case of hard rock is controlled by the strength of mortar of concrete. However, in the case of brick aggregate, the strength of concrete is controlled by the strength of brick aggregate itself. The fractured surfaces of concrete are shown in Figure 10. It is clearly found that the fractured surfaces are passing through the aggregate.

Fig. 10. Failure surfaces of concrete specimens.

3.3 Relationships between compressive strength and tensile strength and modulus of elasticity

The variation of splitting tensile strength with respect to the square root of compressive strength of concrete is shown in Figure 11. The following relationship between compressive strength and tensile strength is proposed:

$$f_t = 4.1\sqrt{f_c'} \tag{1}$$

Where, f_t = tensile strength of concrete (psi), and f_c' = compressive strength of concrete (psi).

The variation of modulus of elasticity of concrete with respect to the square root of compressive strength of concrete is shown in Figure 12. The following relationship is proposed between modulus of elasticity and square root of compressive strength of concrete:

$$E_c = 44027\sqrt{f_c'} \tag{2}$$

Where, E_c = modulus of elasticity of concrete (psi) and f_c' = compressive strength of concrete (psi).

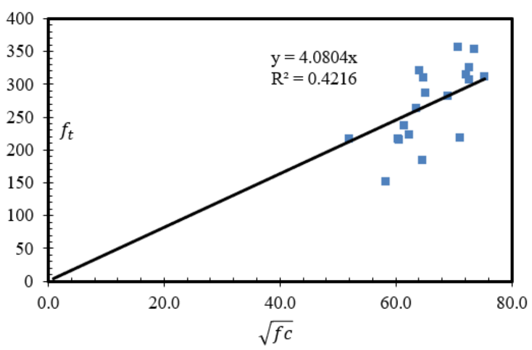

Fig. 11. f_t vs $\sqrt{f_c}$

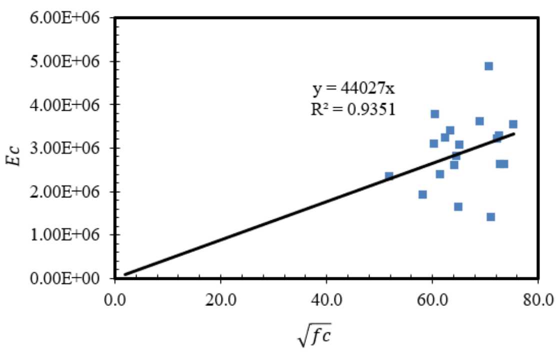

Fig. 12. E_c vs $\sqrt{f_c}$

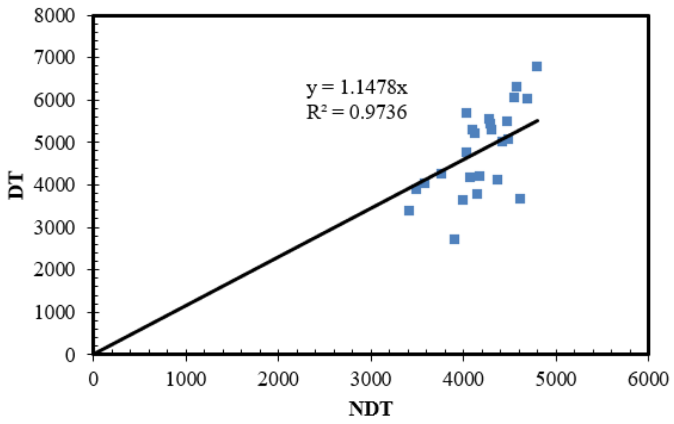

Fig. 13. DT vs NDT

3.4 Relationship destructive test and non-destructive test

Before conducting destructive test of the specimens, compressive strength of concrete was determined by a Schmidt's rebound hammer. Variation between compressive strength of concrete evaluated by destructive and non-destructive test is shown in Figure 13. The following relationship is proposed from regression analysis:

$$\mathrm{DT} = 1.15 \times \mathrm{NDT} \tag{3}$$

where DT= compressive strength of concrete (psi) by destructive test, and NDT= compressive strength of concrete (psi) by non-destructive test.

4. Conclusion

By reducing the size of coarse aggregate to 15 mm and utilization of a blended cement (50% CEM Type I cement + 20% slag + 20% fly ash + 10% silica fume), it is possible to make high strength concrete specimens at the age of 56 days or later. Due to higher abrasion value of brick aggregate, the mortar strength of concrete is significantly higher than the strength of concrete. Relationships between compressive strength and tensile strength, compressive strength and modulus of elasticity, compressive strengths obtained from destructive test and non–destructive test have been proposed.

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