

EFFECT OF FIRED CLAY BRICK AGGREGATES ON MECHANICAL PROPERTIES OF CONCRETE

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Abstract

This study presents an experimental program to evaluate the effect of using crushed brick waste in concrete as a replacement for natural coarse aggregates. Coarse aggregates from bricks were obtained by crushing fired clay bricks. The properties of the brick coarse aggregates concrete including density, compressive strength, tensile splitting strength, flexural strength, modulus of elasticity, and stress-strain behavior were determined and compared with concrete made of natural aggregates. Two replacement ratios of brick coarse aggregates i.e., 50% and 100% were investigated. Test results indicated that the strength-related properties of brick aggregates concrete reduced as the percentage of crushed brick aggregates increased in the concrete mixture. However, although the ultimate stress level for brick aggregates concrete was lower than that of the normal concrete, the resulting strain increased as the percentage of brick coarse aggregates increased in the concrete mixtures, indicating that concrete containing brick aggregates is more ductile as compared with the natural aggregates concrete.

Keywords: Brick waste, coarse aggregates, fired clay bricks, concrete

Introduction

Concrete is a construction material that has been used on a large scale since its discovery and its application increases day by day. Per capita consumption of 2½ tons per annum, makes concrete the single most extensively

used man-made material around the globe (Khaloo, 1994; Poon and Chan, 2007). The concrete industry is a major consumer of natural non-renewable resources including aggregates and, according to estimates, the

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annual consumption of aggregates in the concrete industry is over 13 billion tons (Akhtaruzzaman and Hasnat, 1983; Uddin *et al.*, 2015). Aggregates are commonly obtained either in crushed form from mountains or from riverbeds in the form of gravels. Recycling of aggregates is one of the solutions to preserve natural resources and to attain sustainability. A substantial volume of natural resources can be saved if construction and demolition waste is used as recycled aggregates for constructing new facilities. This can also be beneficial for the environment by reducing the landfills that are occupied by enormous quantities of waste from the construction industry. After World War II, Japan and Europe started replacing natural aggregates in concrete with crushed waste due to the satisfactory performance of recycled aggregates (Khaloo, 1994). The Hong Kong government has been producing aggregates by recycling different construction materials since 2002 in order to secure the available landfill capacity (Poon and Chan, 2007). It has been reported by many researchers that recycled aggregates can be utilized in varying percentages to produce concrete for low-level applications (Tavakoli and Soroushian, 1996; Topcu, 1997; Sagoe-Crentsil *et al.*, 2001; Poon *et al.*, 2002; Katz, 2003; Oikonomou, 2005; Tu *et al.*, 2006) and with a light weight, light density, and low cost (Husain *et al.*, 1995; Mansur *et al.*, 1999; Debieb and Kenai, 2008; Cachim, 2009; Kallak, 2009; Yang *et al.*, 2011; Mohammed *et al.*, 2014).

Most of the recycled aggregates are obtained now from concrete waste and the use of other wastes, such as brick waste, to produce recycled aggregates is still limited (Poon and Chan, 2007). In different regions of the world, fired clay bricks are extensively used as a building material. In the Indian subcontinent, most of the construction is comprised of fired clay bricks. Crushed fired clay bricks were used in concrete as coarse aggregates and it was reported that although the modulus of elasticity of the brick-aggregate concrete was lower than conventional concrete, the tensile strength of the concrete prepared with recycled brick aggregates was higher (Akhtaruzzaman and Hasnat, 1983). Concrete containing various percentages of brick aggregates was prepared and tested for various mechanical properties of fresh and hardened concrete and it was concluded that concrete mixtures containing 15% recycled aggregates showed satisfactory performance as compared to the normal concrete (Cachim, 2009). The possibility of using bricks as fine and coarse aggregates in concrete was explored (Debieb and Kenai, 2008) and it was determined that the performance of concretes made with brick aggregates was comparable with the normal concrete provided the replacement percentage of recycled coarse and fine aggregates was limited to 25% and 50%, respectively. An experimental program was carried out using recycled concrete aggregated and crushed clay brick aggregates to produce concrete mixtures

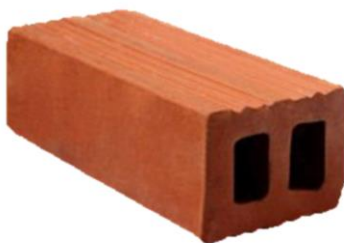


Figure 1. Typical fired clay bricks in Thailand (Thomson Tiles Factory, 2013)

(Yang *et al.*, 2011). It was established that the varying percentages of crushed clay brick aggregates mostly affect the compressive and split tensile strengths of concrete and the effect on the flexural strength of concrete was rather limited. The performance of recycled brick aggregates concrete was compared with virgin brick aggregates concrete and it was concluded that concrete with a compressive strength up to 31 MPa can be obtained using recycled brick aggregates (Mohammed *et al.*, 2014). Crushed clay bricks were utilized as coarse aggregates in concrete and it was determined that although the modulus of elasticity decreased for the brick-aggregate concrete, still the compressive and tensile strengths were comparable with those of normal concrete (Mansur *et al.*, 1999). The coarse brick aggregates were treated with cement syrups and were used in concrete (Husain *et al.*, 1995). It was concluded that although the 28-day's compressive strength of the brick-aggregate concrete was lower than that of the normal concrete, the splitting tensile strength of the recycled aggregates concrete increased.

Concrete manufacture is a thriving industry in Thailand as a vast amount of concrete is required for various building and infrastructure projects in the country. In Thailand, like rest of the world, aggregates for concrete are obtained from natural resources. Fly ash is also used as a supplementary cementitious product for concrete production in large quantities. Although different recycled aggregates (recycled concrete aggregate, waste foundry sand, and cement kiln dust) have been

introduced and used in the past to prepare concrete (Witchayangkoon *et al.*, 2013), the practice of using crushed bricks in the concrete is still very limited. The conventional bricks can be identified as burnt clay bricks (solid and hollow), as shown in Figure 1. In the past, these bricks were used to build load-bearing masonry walls, predominantly in historical structures, as shown in Figure 2(a). However, these bricks are used now mostly for partition walls and architectural walls (Figure 2(b)). At present, as an alternative to these bricks, compressed stabilized earth interlocking blocks are extensively used to build low-rise structures. These bricks are interlocking and therefore there is no need for mortar for bonding during construction. A typical cement-clay interlocking block is shown in Figure 3. These interlocking bricks are manufactured in small factories located in different regions of Thailand where there are now at least 700 brick manufacturing plants (Joseph *et al.*, 1990). No research has been conducted in Thailand so far to study the suitability of crushed aggregates obtained from bricks manufactured and used there such as fired clay bricks, compressed cement-clay bricks, and fired compressed cement-clay bricks. Therefore, in order to facilitate the use of brick aggregates in concrete, this preliminary study has been conducted to explore the possibility of using crushed brick aggregates derived from fired clay bricks as a partial or complete replacement for coarse aggregates in concrete. The performance of the concrete prepared with recycled aggregates is compared with normal



(a) Historical structure (Pinterest, 2018a)



(b) Architectural wall (Haxon Construction and Real Estate, 2018)

Figure 2. Different uses of fired clay bricks in Thailand

concrete produced with natural limestone aggregates, as currently used in Thailand.

Experimental Program

The current research work examines the effect of coarse brick aggregates on the physical and mechanical properties of concrete. The density of brick aggregates concrete was determined and compared with concrete made of natural aggregates (NA). The compressive, flexural, and split tensile strengths of hardened brick aggregates concrete were also determined and compared with that of natural aggregates concrete. Two percentages of brick aggregates, i. e., 50% and 100%, were used to replace natural coarse aggregates to study the feasibility of using brick aggregates to produce more economical and sustainable concrete. In Thailand different types of bricks such as fired clay bricks (FCB), compressed cement-clay interlocking bricks (CCIB), and fired compressed cement-clay interlocking bricks (FCCIB) are normally used for the construction of low-rise residential and commercial buildings. These bricks are also used for the reconstruction of historic structures. The current study aims to consider FCB to prepare brick aggregates for concrete. In the first step, the compression tests were performed on the brick specimens to determine the compressive strength of the bricks and, in the next step, these bricks were crushed to prepare brick coarse aggregates. The brick aggregates were then tested for absorption capacity, specific gravity, unit

weight, and abrasion resistance before being used to prepare concrete mixtures. Further details of the research methodology are discussed below:

Materials

Ordinary Portland cement (OPC) type I was used in all mixes. Natural river sand (Figure 4) was used as a fine aggregate with a fineness modulus of 2.4. Natural aggregates from a local quarry were used as the coarse aggregates, as shown in Figure 5. Hollow FCB, as shown in Figure 1, were used in this study to produce coarse aggregates. These bricks are usually prepared in 4 steps. In the first step, clay and water are mixed using a mechanical mixer. In the second step, the mixed clay is placed into the molds to be compressed. In the third step, the compressed clay bricks are placed in a natural room environment for 24 h. In the final step, the compressed and dry bricks are placed in kilns and heated up to 400-500°C. In this study, fired clay bricks were crushed using a grinding machine and the product obtained after crushing was sieved to separate the required size of coarse aggregates, as shown in Figure 6.

Mix Proportions and Specimen Details

In order to achieve the research objectives, an experimental program was carried out in which



Figure 3. Typical cement-clay interlocking brick (Pinterest, 2018b)



Figure 4. Natural sand used as fine aggregates

concrete cylinders were cast and tested to determine and compare the compressive and split tensile strengths of crushed brick aggregates concrete with natural aggregates concrete. Moreover, concrete beams were cast with crushed brick aggregates and natural aggregates to carry out flexural strength tests,



Figure 5. Natural coarse aggregates used for the experimental program

and Figures 7 and 8 show the batching and casting of the concrete mixes, respectively. Three different mixes were prepared with different types and percentages of coarse aggregates. The test matrix is summarized in Table 1 along with the mix designation and number of specimens for each mix. In Table 1, C and NA represent cement and natural coarse aggregates, respectively, whereas FCBA represents coarse aggregates obtained from fire clay bricks. The numbers in the mix designations represent the percentage by weight of different types of coarse aggregates along with natural coarse aggregates. Mix 1 (C-NA-100) was prepared with 100% natural aggregates with varying percentages of aggregates retained on different sieves, as shown in Table 1. Mix 2 (C-FCBA-50) contained 50% natural aggregates and 50% brick aggregates, whereas Mix 3 (C-FCBA-100) was prepared with 100% brick



Figure 6. Process of preparing coarse aggregates from fire clay bricks

aggregates. All concrete mixtures were prepared using a mix ratio of 1:2.5:4 (cement:



Figure 7. Batching of concrete mix with brick coarse aggregates

fine aggregates: coarse aggregates) by weight and a design strength of 20 MPa. The amount of water added to each mix was adjusted to achieve a slump of 100-125mm (Figure 9). Six cylindrical samples (150×300mm) and 3 beam samples (150×150×600mm) were cast for each mix. After 1 day, all samples were removed from the steel molds, submerged in water at standard temperature, cured for 28 days, and later on were tested for compressive, flexural, and splitting tensile strengths.

Testing Details

After 28 days, all samples were taken out of water and air-dried. Figure 10 shows the



(a) Casting of cylindrical specimens



(b) Casting of beam specimens

Figure 8. Casting of concrete samples

Table 1. Mix designation and experimental program for compressive strength of concrete

Coarse aggregates (%)											Number of specimens			
Mix	Mix designation	Natural aggregates (NA) retained on sieve size (kg)					FCB aggregates (FCBA) retained on sieve size (kg)					Compressive strength test	Split tensile strength test	Flexural strength test
		19 mm	12.7 mm	9.51 mm	4.76 mm	Total	19 mm	12.7 mm	9.51 mm	4.76 mm	Total			
1	C-NA-100	10	20	50	20	100	-	-	-	-	-	03	03	03
2	C-FCBA-50	5	10	25	10	50	5	10	25	10	50	03	03	03
3	C-FCBA-100	-	-	-	-	-	10	20	50	20	100	03	03	03

concrete specimens after 28 days, ready for testing after curing. Later on, specimens were tested for splitting tensile strength, compressive strength, and flexural strength as per ASTM standards (ASTM C496/C496M, 2017; ASTM C39/C39M, 2018; ASTM C78/C78M, 2018). In this experimental program the stress-strain curve, compressive strength, and modulus of elasticity (ASTM C469/C469M, 2014) of crushed brick aggregates concrete were determined by testing concrete cylinders (150×300mm) under the axial compression. An extensometer was installed with the cylindrical specimens during the compression test to record accurately the axial strain of the concrete cylinders during the axial compression (Figure 11). A typical load setup to test the concrete cylinders under axial compression is shown in Figure 12. The splitting tensile strength test on concrete cylinders (150×300mm) was carried out (ASTM C496/C496M, 2017) to determine the tensile strength

of the different concrete mixtures. Figure 13 shows a load setup to test the concrete cylinders for the splitting tensile strength. The flexural strength test on the concrete beams (150×150×600mm) was performed (ASTM C78/C78M, 2018). Strain gauges were installed on both sides of each concrete beam to record accurately the strain of the concrete beams during the flexural testing (Figure 14). The load setup to perform the flexural strength test on the concrete beams is shown in Figure 15.

Results and Discussion

During this study, the properties of brick aggregates concrete including the density, compressive strength, flexural strength, and split tensile strength of hardened brick aggregates concrete were determined and compared with the properties of natural



Figure 9. Slump test



Figure 10. Concrete specimen ready for strength testing after curing



Figure 11. Specimen with extensometer

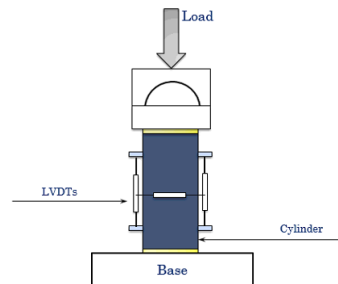


Figure 12. Load setup to test concrete cylinders under axial compression

Table 2. Strength test results at an age of 28 days

Mix designation	Compressive strength				Splitting tensile strength				Flexural strength			
	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
C-NA-100	24.5	23.2	23.5	23.7	2.98	2.83	2.62	2.81	5.37	4.04	4.76	4.72
C-FCBA-50	14.3	14.6	14.8	14.6	1.89	1.57	1.99	1.82	3.32	3.57	3.95	3.61
C-FCBA-100	10.8	9.50	9.10	9.80	1.34	1.39	1.36	1.36	2.05	1.90	1.99	1.98

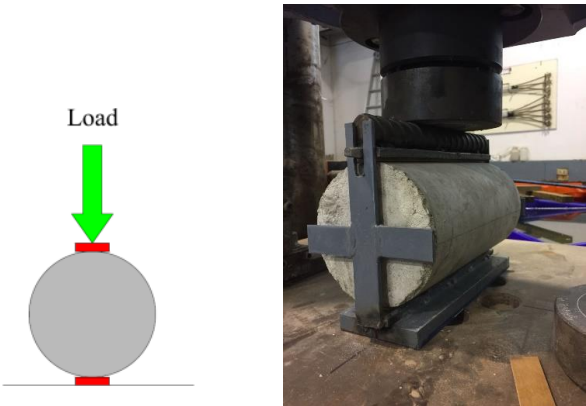


Figure 13. Load setup to test split tensile strength of concrete cylinders



Figure 14. Location of strain gauges on both sides of beam specimens

aggregates concrete. Moreover, the stress-strain behavior of various types of concrete was monitored under axial compression and flexural loading. The density of concrete decreases as the amount of brick aggregates increases in the concrete mix. Table 2 and

Figure 16 demonstrate the strength tests results of concrete mixtures with different brick coarse aggregates. It can be seen that the compressive strength of the concrete samples with natural aggregates (C-NA-100) is higher than the concrete mixtures containing brick aggregates. As the amount of brick aggregates increases in the concrete mix, the compressive strength also reduces. Similar trends can be seen when the concrete specimens were tested for the splitting tensile strength and flexural strength.

Concrete prepared with FCB aggregates acts as a composite system comprising mortar, natural and brick aggregates, and a mortar-aggregate bond. The behavior of this system is influenced by the characteristics of the above-mentioned ingredients and the mechanism of their interaction (Ghazi, 2011). The strength of the FCB concrete seems to be lower than the natural aggregates concrete because of various reasons. First of all, the strength characteristics

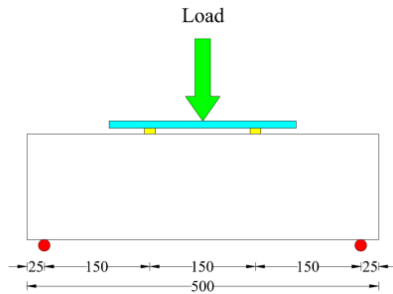


Figure 15. Load setup to test flexural strength of concrete beams

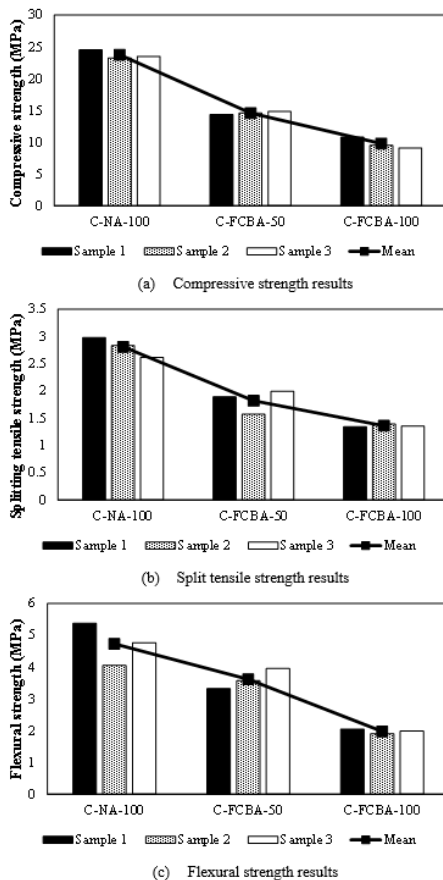


Figure 16. Strength test results of concrete mixtures with varying percentages of brick coarse aggregates at an age of 28 days

of the FCB concrete are affected by the strength of the original brick (Khalaf and DeVenny, 2004; Rashid *et al.*, 2012). Although Mansur *et al.*, (1999) stated that there was a higher strength of brick aggregates concrete (72MPa) as compared to the control mix (64Mpa), Mohammed *et al.* (2014) reported a 33% reduction in the compressive strength of 100% brick aggregates concrete when compared to the control mix prepared with 100% natural aggregates. This may be due to the quite high compressive strength of the original brick (153MPa) used by Mansur *et al.*, (1999) as compared to the lower compressive strength of the original brick (17.3 MPa) utilized by Mohammed *et al.* (2014). Similarly, in the current study, a significantly lower strength of the original fired clay brick (3.14 MPa) may be the reason for the 58% compressive strength reduction of the FCB aggregates concrete as compared to the conventional concrete. Secondly, the total volume of pores in the FCB aggregates is greater than that of the natural aggregates, making the FCB aggregates more porous. Due to a less dense and porous structure of the FCB aggregates, concrete prepared with FCB aggregates tends to fail at a lower ultimate stress level as compared to the control mix. This outcome corresponds with the previous findings (Poon and Chan, 2006a, 2006b; Debieb and Kenai, 2008; Ghazi, 2011; Aliabdo *et al.*, 2014). Moreover, due to higher porosity and micro-cracking, water absorption of the FCB aggregates increased and the concrete mixtures needed more water to attain

the

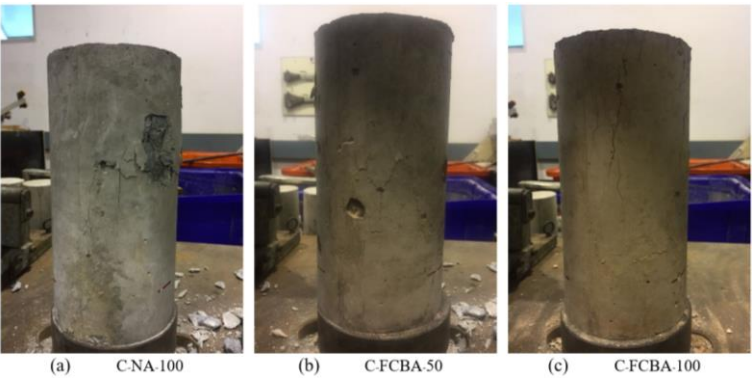


Figure 17. Concrete specimens with varying percentages of brick coarse aggregates tested for compressive strength

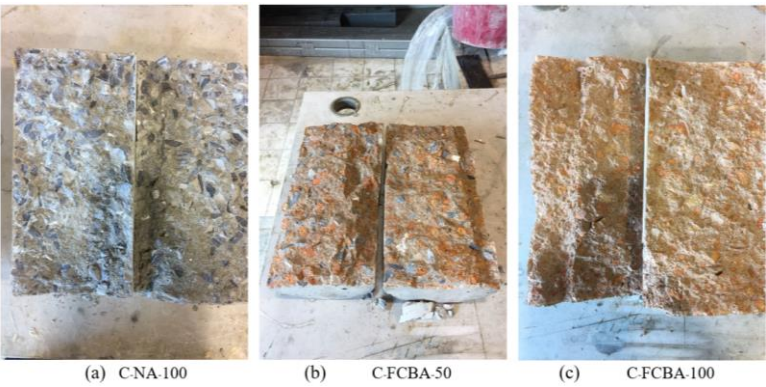


Figure 18. Concrete specimens with varying percentages of brick coarse aggregates tested for splitting tensile strength

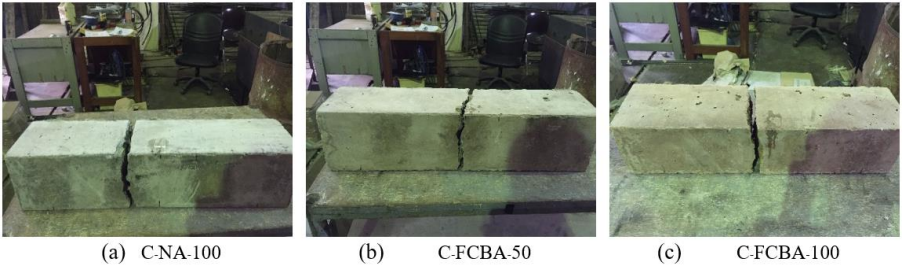


Figure 19. Concrete specimens with varying percentages of brick coarse aggregates tested for flexural strength

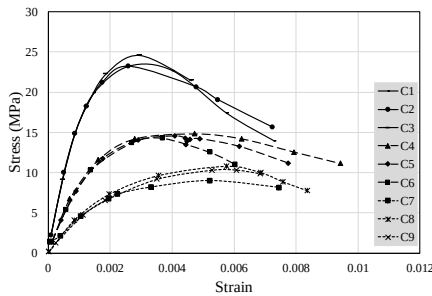


Figure 20. Stress- strain curves for various test samples under axial compression, (C1-C3 are C-NA-100 specimens, C4-C6 are C-FCBA-50 specimens and C7-C9 are C-FCBA-100 specimens)

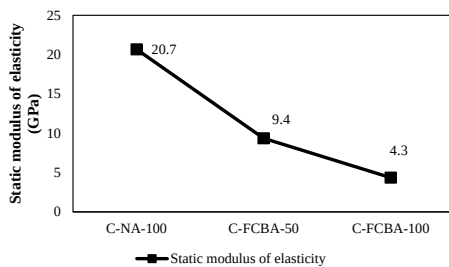


Figure 21. Static modulus of elasticity for various test samples

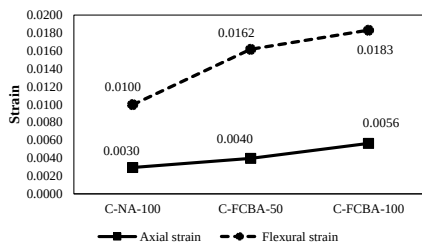


Figure 22. Comparison of axial and flexural strain for various concrete mixtures

Thirdly, during the crushing of the bricks, micro-cracking takes place within the FCB aggregates, consequently reducing the ultimate strength properties of concrete prepared with FCB aggregates (Ghazi, 2011). Finally, due to the rough surface of the FCB aggregates, the workability of the concrete mixture might have been reduced, affecting the compaction of the concrete layers (Kallak, 2009).

Figures 17-19 show concrete specimens with varying percentages of brick coarse aggregates tested for compressive strength, splitting tensile strength, and flexural strength, respectively. Visual inspection of the concrete specimens prepared with the FCB aggregates showed that the failure occurred at the FCB particles and, hence, making the crushed brick aggregates weaker and the controlling link in the composite system.

Figure 20 illustrates the stress- strain behavior for different concrete specimens obtained during the axial compression testing. It can be observed that although the failure and ultimate stress level for the brick aggregates concrete is lower than that of the normal concrete, the axial strain increases as the amount of brick coarse aggregates increases in the mix. As the value of the strain at failure is higher for the brick aggregates concrete, the static modulus of elasticity of brick aggregates concrete is lower than normal concrete, as shown in Figure 21. The value of the static modulus of elasticity for concrete with natural aggregates was 20.7 GPa and varied from 9.4 to 4.3 GPa for 50% and 100% brick coarse aggregates, respectively. The reduction of the static modulus of elasticity was also observed during the previous research incorporating waste materials in concrete (Akhtaruzzaman and Hasnat, 1983; Mansur *et al.*, 1999; Alengaram *et al.*, 2010; Amin and Choudhury, 2015; Jayaprithika and Sekar, 2016). The high magnitude of deformation due to the soft microstructure and higher porosity of brick aggregates concrete may lead to a lower modulus of elasticity that further on results in larger deformations and a dilation property under axial stress (Amin and Choudhury, 2015). Figure 22 shows the comparison of axial and flexural strain at failure for the

required slump (Kallak, 2009). This higher water absorption of the FCB aggregates could be the reason for the lower strength performance (Debieb and Kenai, 2008).

different types of concrete tested. It can be seen that both the axial and flexural strain at failure increases in the case of concrete prepared with the FCB aggregates as compared to the normal concrete. As discussed earlier, it has been reported that, due to higher porosities and micro- defects, the unit weight of the concrete mixtures prepared with brick and recycled aggregates is lower than the unit weight of conventional concrete (Hasnat *et al.*, 2015; Islam *et al.*, 2015). Therefore, concrete prepared with these aggregates should produce more fracture planes (Carrasquillo *et al.*, 1981; Zaitsev and Wittmann, 1981; Ravindrarajah and Swamy, 1989) and larger axial strains (Lim and Ozbakkaloglu, 2014), as observed in the current study (Figure 22). The larger axial strain experienced by the concrete mixtures prepared with the FCB aggregates results in higher ductility as compared to the control concrete mixture.

Failure Modes of Concrete Specimens

The ultimate failure modes of the different concrete specimens such as compression, splitting, and flexure are shown in Figures 17- 19, respectively. It can be seen that the ultimate failures of all concrete specimens are identical irrespective of the types and percentages of natural aggregates and brick aggregates. In the case of the compression test, vertical cracks were observed along the height of the concrete cylinders, as shown in Figure 17. The concrete specimens tested under splitting load showed a straight rupture at the middle region, as shown in Figure 18, whereas the flexural specimens mainly failed due to a straight crack at the middle region, as shown in the Figure 19.

Conclusions

The following conclusions were drawn from this study:

- The brick aggregates concrete required more water content to achieve the same flow as compared to the concrete with natural aggregates.

- The density of the concrete increased/ decreased as the amount of brick aggregates increased in the concrete.

- The static modulus of elasticity decreased by increasing the content of the brick aggregates in the concrete.

- The increase of brick aggregates resulted in lower compressive, split tensile, and flexural strengths.

- The test results indicate that concrete containing brick aggregates is more ductile as compared with the natural aggregate concrete.

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