Bond Behavior of Concrete Using Waste Ceramic as Coarse Aggregates

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Abstract

Ceramic waste consumption is increasing day by day due to swelling of using of ceramic materials. This vast amount of waste may cause various environmental hazards and immediately require recycling which may minimize environmental menaces. Consequently, using these wastes in concrete production could be an effective measure in maintaining the environment as well as the properties of concrete. The present experimental study deals with the investigation of prospect of using waste ceramic in concrete. Hence, the crushed waste ceramic were used in concrete as a replacement of coarse aggregates with 25, 50, 75 and 100% of substitution. The paper reports on the performance of these different concrete mixes containing different ratios of crushed ceramic as coarse aggregate. Bond strength tests of 7 & 28 days and splitting tests of 28 days were carried out on concrete specimens. It was found that strength decreases gradually with the increase of the proportion of ceramic aggregates in concrete and hence waste ceramics as replacement of virgin aggregates can be mixed up to a certain portion in concrete.

Keyword: *Ceramic Material, Environmental Hazard, Bond Strength.*

1.0 Introduction

According to IDLC (2015) in Bangladesh, ceramic production is 40,000 ton per year and about 15-30% of ceramic waste is generating from the total production. Ceramic industrial waste is developing day by day and it causes serious environmental problems to the human health. Disposable cost is also increased for these industries, due to the ceramic nature. In various parts of Bangladesh, exhaustion of coarse aggregate is happening, hence to preserve coarse aggregate for future needs, crushed ceramic aggregate can be used to produce a new type of concrete without affecting strength. Mechanical properties of concrete are greatly influenced by the ingredient properties. Therefore, to meet the requirement of quality concrete aggregates, recycling, reuse and substitution are the available solution to save the virgin aggregates. Ceramic waste aggregate is generated in huge quantity because of its larger usage in building construction. It is produced from ceramic industries, construction demolition waste and nearly 30% of waste is generated during the manufacturing, transportation and usage of products (IDLC, 2015). Ceramic materials for domestic usage are wall tiles, floor tiles, sanitary ware, brick and roof tiles. In European Union a large ceramic sector is functioning. Figure 1 shows the global consumption and production of ceramic and Figure 2 shows the world manufacturing and consumption areas. The quantity of wastage is more due to its brittle nature. Ceramic coarse aggregate procures from industrial waste and crushed ceramic blocks has shape coefficient similar to that of a coarse aggregate obtained in the crushing of limestone. Usually ceramic aggregate has more irregular shape and non-porous but it can be made porous after crushing and chiseling with hammer. This is a reason to consume more percentage of water than natural coarse aggregate (Bakri et al., 2006). In present study, sanitary ceramic ware wastes are chosen because of its availability of wastage and suitability thickness thereby substitution of these waste aggregate carried out into the concrete production.

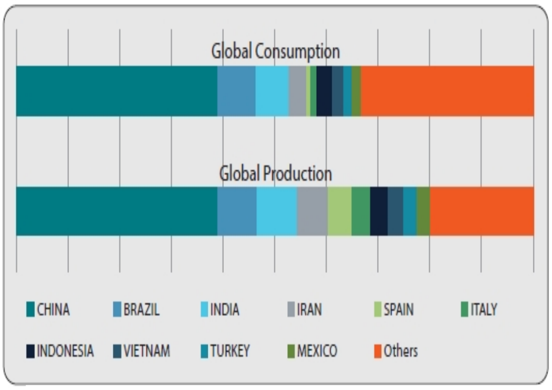

Figure 1. Global consumption and production of ceramic. (IDLC, 2015)

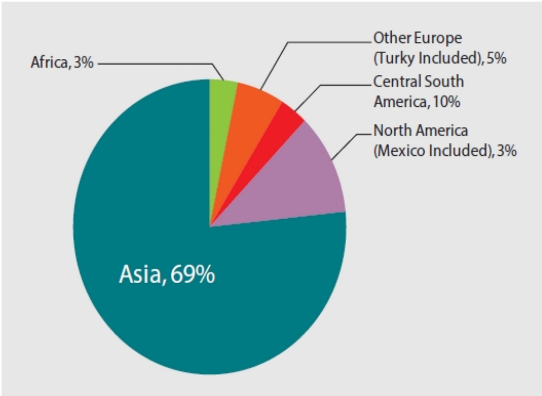

Figure 2. World manufacturing area of ceramic. (IDLC, 2015)

Crushed ceramic waste can be used to produce new type of light weight concrete without effecting its strength. Ceramics can be defined as heat-resistant, nonmetallic, inorganic solids that are made up of compounds formed from metallic and nonmetallic elements (Bakri et al., 2006; Correia et al., 2006). Most of the ceramics are hard, chemically inert and refractory and these properties make ceramics attractive for many applications. Ceramics are used as refractory in furnaces and as durable building materials like bricks, tiles, cinder blocks, and other hard, strong solids. Medina et al. (2012) experimented and concluded that use of ceramic aggregate as recycled coarse aggregate in concrete was benefited and water absorption of ceramic aggregate and natural gravel was 0.55 and 0.23% respectively. Bond between aggregate particles and the cement matrix is a main module for strength aspect. Bonding is greatly influenced by the shape and texture of the aggregate and it directly influences the strength of the concrete. A better bonding is obtained by angular aggregates. Smooth texture characteristic which permits no penetration of surface particles by the paste is not conductive to good bond. Hence, softer porous and mineralogical heterogeneous will show better results of bonding. On the experimental results that, Porosity of the ITZ (Interfacial transition zone) was increased in the ceramic waste aggregate. This was responsible for poor bonding between the aggregate and surrounding cement paste (Senthamarai et al., 2011). Effect of recycled coarse aggregate on damage of recycled concrete. Mechanical properties of recycled aggregate concrete were reduced and development of cracks in interfacial transition zone was observed due to old cement paste and higher water cement ratio (Fouad et al., 2005). Sekar et al. (2011) reported on properties of ceramic aggregate, its crushing value, impact value and abrasion value were 27, 17 and 23% respectively. These values were higher than natural stone aggregate values, thus strength of the ceramic waste aggregate concrete was influenced by strength of the ceramic aggregate. Veera (2010) reported on impact value and crushing value of ceramic scrap as 18.2 and 24.7% respectively.

The use of waste products in concrete not only makes it economical but also solves some of disposal problems. A significant amount of natural resource can be saved if the crushed ceramic is recycled for new constructions. In addition to the saving of natural resources, recycling of crushed ceramic will also provide other benefits, such as creation of additional business opportunities, saving cost of disposal, saving money for local government and other purchaser, helping local government to meet the goal of reducing disposal, etc. If technology and public acceptance of using crushed ceramic are developed, there will be no requirement for natural aggregate when 100% of crushed ceramic is recycled for new construction. Hence crushed ceramic waste can be used to produce new type of light weight concrete without effecting its strength. The study was conduct to investigate the feasibility of using of these waste in construction of new concrete. The objectives of the present work include to study the feasibility of using ceramic waste aggregate in concrete making by performing bond and elastic modulus test. Besides, finding research opportunities of using ceramic waste in concrete mixture.

2.0 Methodology

In this research, sanitary ceramic wastes were chosen because of its availability of wastage and suitability of thickness, thereby, substitution of these waste aggregate carried out into the concrete production. Physical properties of materials were determined. Ordinary Portland cement (OPC) was procured for experimentation work and tests were carried out according to the specifications. Locally available coarse sand (Sylhet Sand) was used as fine aggregate in the experimental work. Crushed stone chips were used as coarse aggregate in the mix design. In order to use the ceramic waste aggregate into concrete, it is necessary to determine the properties of ceramic waste aggregate and validate whether ceramic waste aggregate properties are within the range of aggregate properties or not. Maximum size of coarse aggregate chosen in this study was 20 mm.

2.1 Preparation of test specimens and test setup

Five types of concrete mixes have been used in production of concrete which is shown in Table 1. In the Table 1, C00 stands for reference mix means without ceramic composition and remaining compositions were cast with appropriate replacement of coarse aggregate by ceramic waste aggregate. The mixing ratio of all batches is 1:1.5:3 with the water cement ratio of constant value 0.5. Bond strength and static elastic modulus test of the concrete were determined.

Table 1. Nomenclature of mixes

Sample Designation	% of Coarse Aggregate		%Fine Aggregate
	Waste Ceramic	Natural Aggregate	
C 00	0	100	100
C 25	25	75	100
C 50	50	50	100
C 75	75	25	100
C 100	100	0	100

2.1.1 Fabrication and Casting

The cylindrical samples were cast in steel moulds with inner dimensions of 100x200 mm (Figure 3). All ingredients were weighed using electronic weigh balance according to the mix design proportions. After casting, specimens were kept for 24 hours for the setting of concrete. After completion of 24 hrs, the specimens were removed from moulds and placed into curing pond. Each of the mix proportion samples, three samples were used to evaluate 7 days strength and remaining three for 28 days strength. Special care has been taken during the mixing, casting, vibrating and demoulding of specimens.

2.1.2 Bond strength

To determine the bond strength of concrete, total 30 cylinder specimens were cast according to the same specified materials, composition and materials in addition with penetrating 12 mm diameter reinforcement at the middle of the cylinder specimens which is shown in Figure 4.

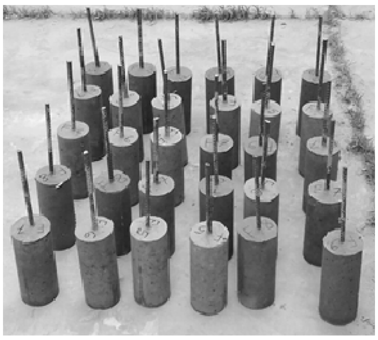

Figure 3: Fabrication of Cylinder

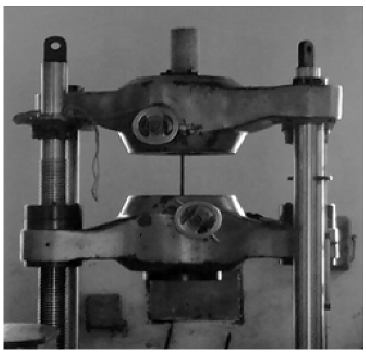

Figure 4: Bond strength testing machine

3.0 Result and Discussion

3.1 Bond strength

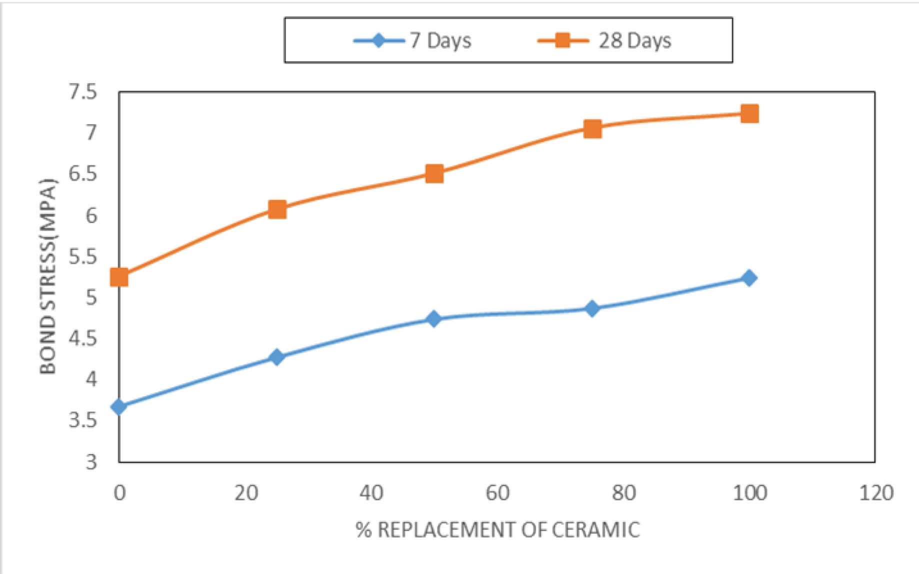

Table 2 shows the bond tests of the cylinder specimens. By observing, it is seen that 7 days bond strength with ceramic aggregate is 5.24MPa with natural coarse aggregate. As the replacement of coarse aggregate by ceramic aggregate increases, strength values are decreased to 3.67 MPa with 100% replacement. For 28 days strength, natural coarse aggregate concrete strength is 7.24 MPa whereas bond strength values are slowly decreased to 5.26MPa after 100% replacement which is depicted in Figure 5.

Table 2: Bond strength of cylinder specimen for ceramic waste aggregate concrete

Sl. No.	Mix Title	% replacement of ceramic waste aggregate	Bond strength (MPa)	
			7 Days	28 Days
01	C 00	00	5.2	7.2
02	C 25	25	4.9	7.1
03	C 50	50	4.7	6.5
04	C 75	75	4.3	6.1
05	C 100	100	3.7	5.3

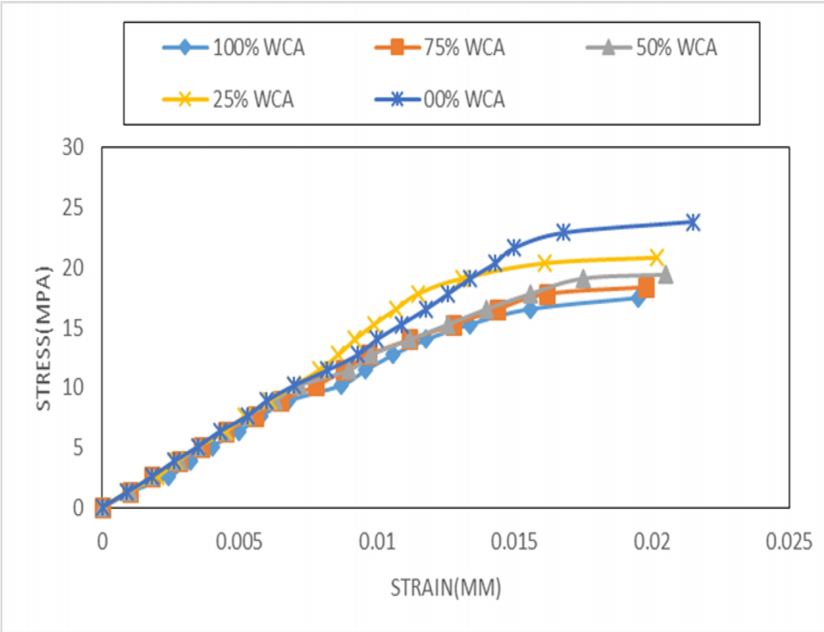

Figure 5: Bond strength vs. % replacement of ceramic

3.2 Modulus of Elasticity

3.2.1 Behavior of Cylinder under Compression

The specimens were tested for determining the ultimate compressive strength of cylindrical specimen and strain. All test results are tabulated in Table 3. It can be observed from Table 3 that the 28 days cylindrical compressive strength decreases as the replacement of natural aggregate with ceramic waste aggregate increases. Stress –strain diagram is depicted in Figure 6.

Table 3: Modulus of elasticity for compressive strength

Sl. No.	Title of Mix	% replacement of ceramic waste aggregate	Modulus of elasticity (MPa)
01	C 00	00	1589.1
02	C 25	25	1522.5
03	C 50	50	1480.75
04	C 75	75	1444.8
05	C 100	100	1318.4

Figure 6: Stress – strain diagram

3.3 Slip Bond Behavior

Figure 5 and 6 show the slip bond behavior of bond strength for 7 days and 28 days. For 7 days bond strength with natural aggregate the slip is 5.32 mm at ultimate strength of 40 KN load with natural coarse aggregate. As the replacement of coarse aggregate by ceramic aggregate increases, the value is 5.5 mm at ultimate strength of 27.3 KN load 100% replacement. For 28 days strength, natural coarse aggregate the slip value is 4.52 mm at 54.6 KN and 5.1 mm at 39.67 KN load of ultimate strength after 100% replacement.

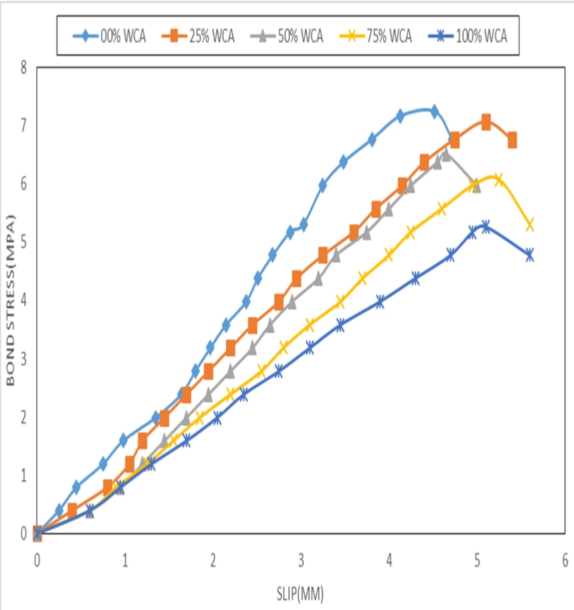

Figure 5: Slip bond behavior of concrete for 7 days

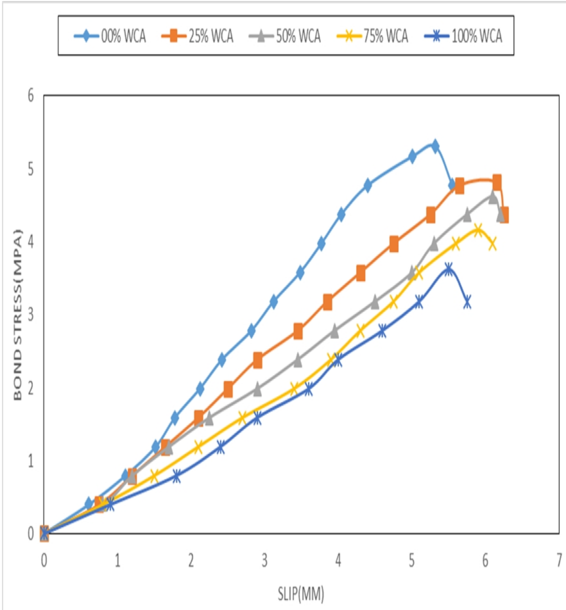

Figure 6: Slip bond behavior of concrete at 28 days

4.0 Conclusion

Substitution of ceramic waste aggregates into the concrete composition is one of the solutions for reducing the waste generation and through this way to improve eco-friendly environment by the usage of waste into concrete. The major findings from this research:

- Based on the test results, it can be concluded that ceramic waste aggregate has the potential to replace natural coarse aggregate in concrete as its physical and engineering properties are well within the range of normal weight aggregate. Hence, the ceramic waste aggregate can be safely used up to certain percentage in the concrete composition.
- Elastic modulus of ceramic waste aggregate concrete decreases with the increase of ceramic waste aggregate in composition. Even at 100% replacement, elastic modulus of ceramic waste aggregate concrete is 1318.4 MPa. This value is in satisfactory limit comparing with coarse aggregate.
- Modulus of ceramic aggregate concrete decreases with the increase of ceramic waste aggregate into the concrete composition. The percentage decrease in modulus at 25% level is 8.6% only. Hence, it is advised to use 25% of ceramic waste aggregate in concrete composition with respect to modulus considerations.
- Natural coarse aggregate the slip value is 4.52 at 54.6 KN and 5.1 at 39.67 KN load of ultimate strength after 100% replacement.

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Reference

Bakri, Al M.M., Norazian, M.N., Kamarudin, H., and Ruzaidi, Che Mohd G. (2008). The potential of recycled ceramic waste as coarse aggregates for concrete. Malaysian Universities Conferences on Engineering and Technology.

Correia, J.R., De Brito.J, and Pereira, A.S. (2006) .Effects on concrete durability of using recycled ceramic aggregates. Materials and Structures, Springer.

Fouad, Khalaf, M., Alan, S., Venny, De. (2005). Properties of New and Recycled Clay Brick Aggregates for Use in Concrete. ASCE, vol. 17, no. 4.

IDLC (2015). Monthly Business Review magazine.

Medina, C., Sanchez de Rojas, Frias. M.I. (2011). Cement and Concrete Composites, Reuse of sanitary ceramic wastes as coarse aggregate in eco-efficient concretes. ELSEVIER, 34, 48-54

Sekar, T., Ganesan, N., Nampoothiri. NVN. (2011). Studies on strength characteristics on utilization of waste materials as coarse aggregate in concrete. International Journal of Engineering Science and Technology (IJEST). 3, 5436-5440.

Senthamarai, RM., Devadas M.P., Gobinath, D. (2011). Concrete made from ceramic industry waste: durability properties. Construction and building materials, 25, 2413-2419.

Veera Reddy, M. (2015). Experimental Study on effect of silica fume on ultimate Bond strength of unconfined concrete. International Journal of scientific research. ISSN No. 2277-8179.