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A Study of Mechanical Strength of Concrete Mixed Cotton Dust Ash as Replacement of Ordinary Portland Cement

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Abstract

This paper presents the results of an experimental study on the compressive flexural and splitting tensile strength of concrete mixed cotton dust (CD) ash. The dust particles less than 800 micron in diameter is used. The approach taken was to use the cotton dust ash as replacement of Ordinary Portland Cement (OPC) material in concrete. The mixtures were prepared with cementitious materials containing cotton dust ash at 0%, 5%, 10%, 15% and 20% by weight. The results showed that compressive of concrete mixed CD ash was in the range of 11.45-29.04 N/mm^2. The flexural and splitting tensile strength was in the range of 3.59-8.38 N/mm^2 and 1.05-3.27 N/mm^2 respectively. The compressive, flexural and splitting strength of concrete mixed cotton dust ash decreased with the content of CD ash increased. However, the ultimate compressive, flexural and splitting tensile strength can be obtained where the level of replacement of CD ash was at 5% of replacement. Based on results, it can be concluded that cotton dust ash can adequately be additive material for structural material in buildings.

Key words: Dust cotton ash; Concrete; Cementitious material

Introduction

Textile industry is the second largest industry in the world next to agriculture. The textile industry contributes substantially to the foreign exchange earned by exporting countries. The demand for natural cotton fibres and poly/cotton blend fibres has increased significantly in the past decade (World Bank, 2004). However, the emphasis on awareness about the environmental concern such as air, water and noise pollution during the processing from fibre to fabric is essential in the present circumstances. Cotton dust is one of industrial waste which is a dust waste generated into the atmosphere as a result of process of the weaving of cotton fibers in textile mills. Cotton dust can cause an occupational lung disease which caused by exposure to cotton dust in inadequately ventilated yarn and fabric manufacture industries. For decades, engineers and researchers have been interested in utilizing the waste products for value added to the waste product and reduce the depletion in natural resources. Currently, cotton dust is used as fuel for boilers and fertilizer (Li *et al*., 2003; Balasubramanian *et a*l., 1995). In the utilization of cotton dust as fuel of boiler in fabric manufacture process, cotton dust is burned to heat water in boiler to produce steam that will be used to drive power plants. From the combustion process will be generated cotton dust ash that has gray-black color. In manures and fertilizers aspect, cotton dust containing 50-60% moisture can be converted to good quality compost with a few turning within 20 days (Kolay, 2007). In civil engineering works, cotton dust is studied for improving the mechanical properties of concrete structures (Burgueno et al., 2004; Burgueno et al., 2005; Taniguchi, 2003). Owing to the different applications of concretes, studying the mechanical aspects of concrete mixed cotton dust ash has been an interesting and challenging topic for many researchers. The importance of research studies in this area is emphasized by utilizing CD ash as replacement material in concrete structure. However, outcome of research lies mainly in their competitive prices and performance. The effect of natural admixtures usage on concrete mixed can be focused on the reduction of materials used. Consequent, producing similar or even mix with less mixture quantities results in a sustainable concrete.

Experimental Details

Detail of Design Mix

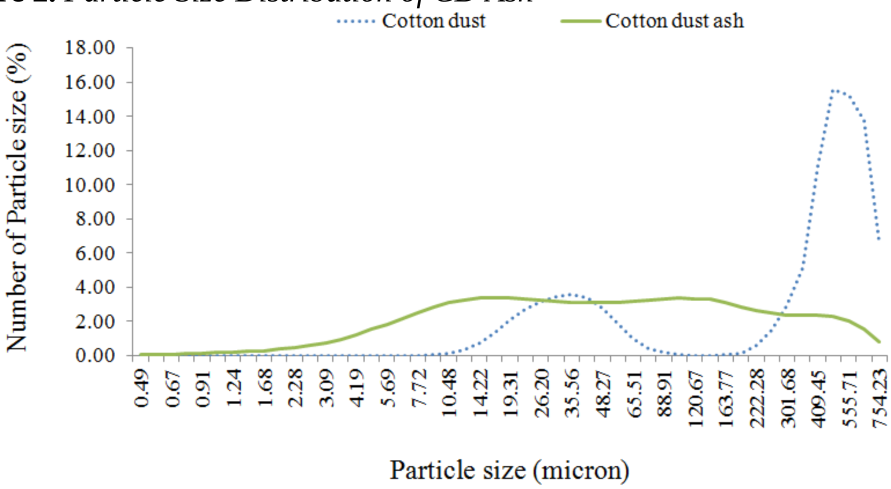
The materials used in this study were, Ordinary Portland cement (OPC) type I, which complied with BS 12:1991 and ASTM C150-12. Ordinary Portland cement corresponding to ASTM Type I cement with a specific gravity of 3.16 was used for all concrete mixtures. The chemical composition of these binders is presented in Table 1. Coarse aggregates were a crushed granite with a maximum size of 16 mm and a specific gravity of 2.68. Natural siliceous river sand having a fineness modulus of 1.85 and a specific gravity of 2.54 was used as a fine aggregate. Both coarse and fine aggregates were batched in a saturated surface dry (SSD) conditions. Cotton dust (CD) ash used in this research was generated from combustion of cotton dust which results of the mechanical processing of raw cotton in the spinning process. Figure 1 shows the CD ash used in this study. The results of particle distribution analysis of CD and CD ash are given in Figure 2.

Table 1. *Chemical composition and properties of cement and cotton dust ash*

Composition (%)	Cement	Cotton dust	Cotton dust ash
CaO	65.5	26.27	23.8
SiO_2	21.0	29.4	60.1
Al_2O_3	5.2	13.89	10.5
Fe_2O_3	3.2	0.46	1.02
MgO	3.1	0.58	3.8
SO_3	2.9	-	-
Na_2O	0.14	-	-
K_2O	-	-	-
Loss on ignition		29.40	-

Figure 1. *Cotton Dust and Cotton Dust Ash*

Figure 2. *Particle Size Distribution of CD Ash*



Preparation and Testing Methods

The concrete specimens were casted in cylinders of 100 mm diameter and 200 mm height and prisms of 150×150×800 mm steel moulds for compressive strength, splitting tensile strength and three point load flexural strength tests respectively. All specimens were compacted using a vibration table. The specimens were demoulded approximately 24 hr after casting. The method of curing was immersion in water at 23±3 ºC until the age of testing. In order to minimize the affect of surface moisture to the strength of specimens, all specimens were placed out of water and put in the air dry for 24 hr prior to testing. Three test results were compared for obtaining the means value for any test.

For dispersion effect of the mixing materials, the one-third of cotton dust ash was firstly added into running mixer after concrete was well mixed. The mixing time was 3 min. Then, Two-third of cotton dust ash was secondly added gradually to running mixer. The mixing time continues for 3 min. The specimens were casted in cylindrical and prism steel moulds. Two layers of placing mixed concrete into steel moulds were used, each layer being consolidated using a vibrating Table. Compressive strength, flexural and splitting tensile strength tests were carried out in accordance with ASTM C 39, ASTM C78 and ASTM C 496 respectively. Table 2 gives the details of the mixture proportions for a cubic meter of concrete.

Test Results and Discussion

Compressive Strength

The cylindrical specimens were tested for compressive strength test. The compressive strength of different CD ash replacement was presented in Table 1 for 3, 7, 14 and 28 days. Generally, by application of CD ash as substitute material for cement. The result showed that the compressive strength decreased as CD ash substitution increased. Similar to the normal concrete (0% of CD ash replacement), the compressive strength of CD ash concrete increased during time; however, the rate of increasing is different (Figure 5). The compressive strength of concrete mixed CD ash was in the range of 11.45-29.04 N/mm^2. It was further found that 5% of CD ash replacement gave the highest compressive strength when it compared with compressive strength of specimens mixed with 10%, 15% and 20% of CD ash replacement. In this regard, concrete contained 5% of CD ash replacement, developed averagely 55.34% of the 28 days strength in 7 days in comparison with 61.33% for normal concrete. This might due to thermal resistivity of CD ash which retained the heat of hydration and increased the cement reactions at early age. On the other hand, by using 20% CD ash as cement replacement, the compressive strength decreased. This might due to the amount of cement, hydration process and CD ash activity. From the results obtained in Table 1, Mixture of CD ash can be used in the production of normal weight concrete.

Substitution of the mixture should not be more than 5% of replacement level for the best result in the concrete production for concrete structures.

Table 2. *Result of Strengths of Concrete mixed CD Ash*

Compressive strength of Concrete mixed CD ash (N/mm^2)				
	Duration			
CD ash (%)	**3 days**	**7 days**	**14 days**	**28 days**
0	18.15	19.71	26.53	29.59
5	16.07	21.10	25.28	29.04
10	15.42	20.85	25.12	28.68
15	15.66	18.74	23.30	28.03
20	11.45	20.52	22.33	25.89
Flexural strength of Concrete mixed CD ash (N/mm^2)				
CD ash (%)	**3 days**	**7 days**	**14 days**	**28 days**
0	4.37	4.66	5.76	8.77
5	4.12	4.14	5.28	8.38
10	3.93	4.46	5.03	8.18
15	3.75	3.94	4.86	7.89
20	3.59	3.63	4.52	7.12
Splitting tensile strength of Concrete mixed CD ash (N/mm^2)				
CD ash (%)	**3 days**	**7 days**	**14 days**	**28 days**
0	1.92	2.22	2.79	3.49
5	1.83	2.09	2.63	3.27
10	1.64	1.92	2.26	3.05
15	1.49	1.73	2.17	3.03
20	1.05	1.29	1.56	2.65

Flexural Strength

The flexural strength of concrete mixed with CD ash was determined according to the ASTM C78 and the results were presented in Table 1 and Figure 4. The result showed that flexural strength has direct relationship with compressive strength results. Similar to the results of compressive strength, the increasing flexural strength of concrete mixed CD ash was found to relate to the decrease in level of replacement. As compressive strength increased, the flexural strength also increased. The flexural strength results agreed with those of compressive strength results. It was further found that the strength of specimens decreased when the content of CD ash increased above 5% of replacement. The maximum flexural strength of concrete mixed CD ash can be obtained where concrete mixed at 5% of CD ash replacement. The ultimate flexural strength was 8.38 N/mm^2 for 28 days. As can be observed, the application of substitution CD ash above 5% exhibited minor changes in the flexural strength, while using higher amount of CD ash replacement resulted in to some extent decrease. Similar results were found by Sarmomtazi, et al., (Sarmomtazi, et al., 2012). It should be noted that the failure mode observed to be more gradual by adding CD ash. In this study, the minimum and maximum flexural strength at the age of 7 days were 3.63 N/mm^2 and 4.16 N/mm^2 and the values at the age of 28 days were 7.12 N/mm^2 and 8.38 N/mm^2. Regard to the rate of increasing in flexural strength, it appeared that the rate of increasing in strength increased as the content of cement increased. Addition, the highest rate of increasing in strength per day was at 3 days. The rate of increasing in strength was 1.37 N/mm^2/day when compared with the rate of increasing in strength of normal concrete with 1.46 N/mm^2/day. However, the above results showed that flexural strength increased with decrease in CD ash volume fraction; this was due to the additional load taken by the CD ash present in the matrix. Addition, after increasing the volume percentage of CD ash beyond the optimum value (5%) improper mixing of CD ash with the matrix took place due to balling effect of CD ash, this increased the amount of vibrations required to remove air voids from the mix which in turn caused the problem of bleeding and decreased flexural strength of the mix. The failure pattern of plain and CD ash concrete in flexural strength test showed that CD ash concrete were more ductile as compared to plain concrete. This was because when the matrix cracked, the load was transferred from the composite to the CD ash at the crack surfaces, which prevents the brittle failure of the composite.

Figure 3. *Rate of Increasing in Compressive Strength*

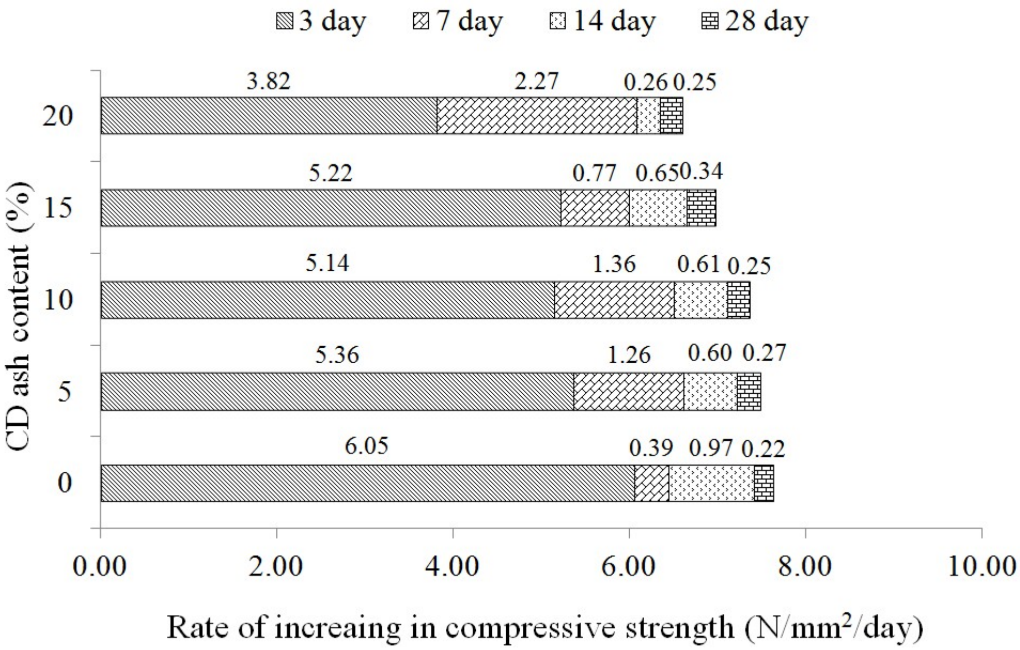


Figure 4. *Rate of Increasing in Flexural Strength*

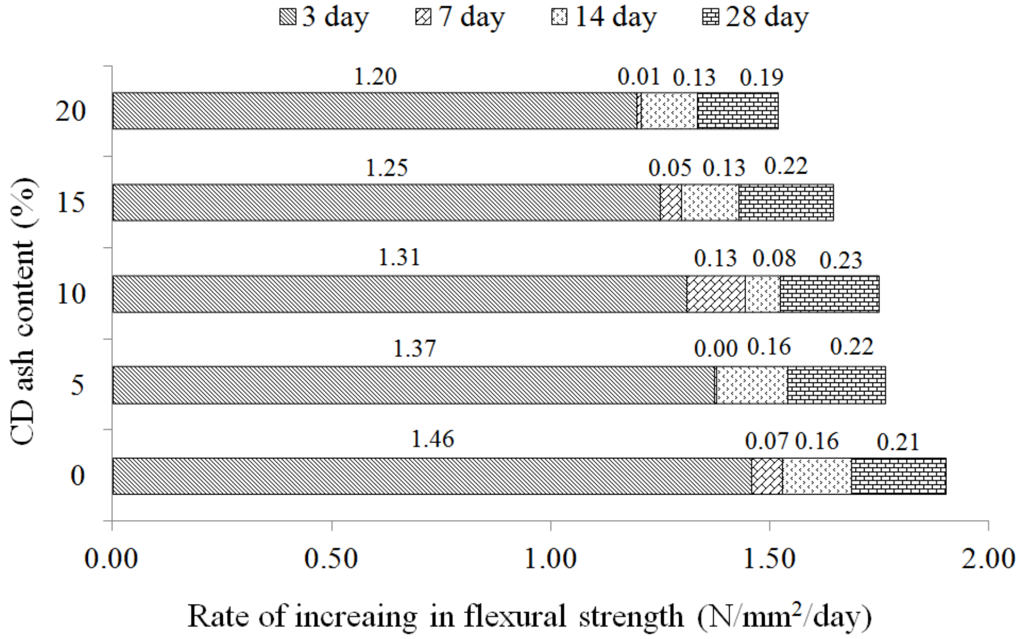
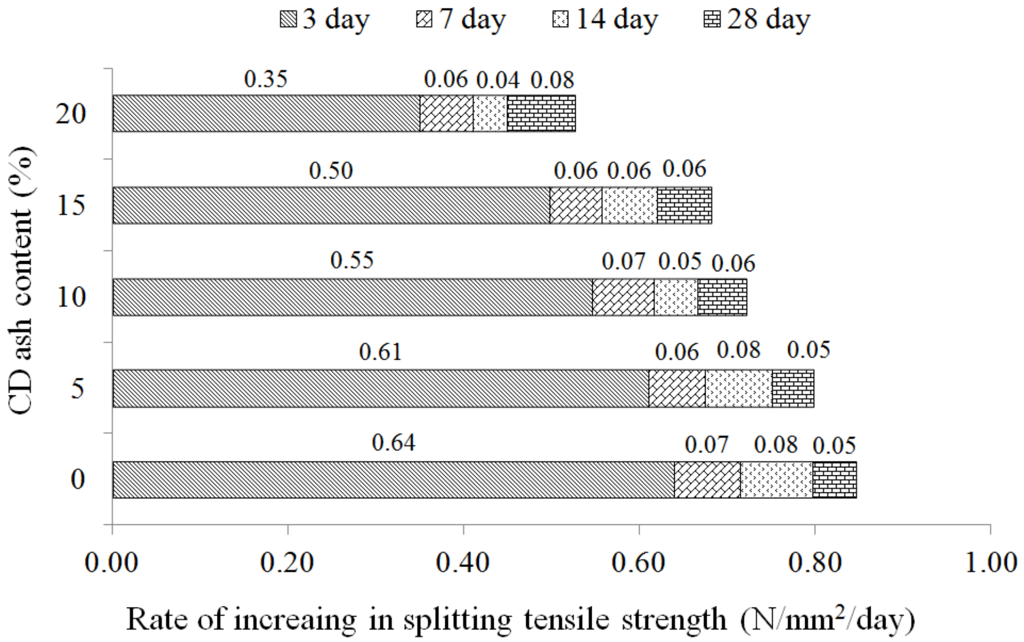


Figure 5. *Rate of Increasing in Splitting Tensile Strength*



Splitting Tensile Strength

For studying the splitting tensile behaviour, cylinders of concrete mixed CD ash were tested. The failure load was observed and the strength was calculated which was shown in Table 1. The splitting tensile strength of concrete mixed CD ash was determined based on ASTM C496. In Figure 5 showed the variations of splitting tensile strength with CD ash replacement percentage at different ages. The maximum value of 28-day splitting tensile strength was obtained as 3.49 N/mm^2 at 0% replacement level and the minimum was 2.65 N/mm^2 obtained at 20% replacement level. It was further noticed that CD ash did not significantly improve the splitting tensile strength rate. At earlier stages, benefits were not observed at any replacement level, and high percentages of CD ash tended to reduce strength. Benefits begin to disappear after 5% replacement level. The results indicated that the strength benefits were increased as the age of CD ash concrete increased. This might due to the amount of cement contained.

As seen, the splitting tensile strength decreased by application of CD ash, so that by replacing 5, 10, 15 and 20% of cement weight. The splitting tensile strength at 28 days decreased 6.7% 14.4%, 15.2% and 31.7% when it was compared with control specimens respectively. Effect of supplementary cementing material on splitting tensile strength was similar to the effects observed for compressive strength and flexural strength. In Figure 5 showed the rate of strength increase in percentage, it found that the CD ash decreased the splitting tensile strength. However, incorporating 5% of CD ash gave the highest tensile strength when it was compared with concrete mixed at 10, 15 and 20% of CD ash replacement. There was also a significant increase in strength over the control mix. This was believed to be due to the large pozzolanic reaction and improved interfacial bond between paste and aggregates. The above results showed that split tensile strength increased with decrease in CD ash volume fraction, because of the holding capacity of the CD ash which helped in preventing the splitting of concrete. However, after increasing the volume percentage of CD ash beyond the optimum value (5%), similar problem was found on workability of mixing matrix. It required further vibrations to remove air voids from the mix which in turn caused the problem of bleeding and decreased split tensile strength of the mix.

Ratio of Strengths

From Figure 6, it found that the ratio of splitting tensile to compressive strength was in the range 0.092 to 0.118. The ratio of splitting tensile to compressive strength depended on level of CD ash replacement. The ratio of splitting tensile to compressive strength was higher at early ages (3-days and 7-days). The ratio of splitting tensile to compressive strength at 5% of CD ash replacement was at 0.113 or 11.3%. While the highest ratio of splitting and compressive strength was 0.118 or 11.8% at 28 days (at 0 % of CD replacement). Similar to the ratio of splitting tensile to compressive strength, the ratio of splitting tensile to flexural strength decrease by replacing cement with CD ash. In addition, according to Figure 7 the ratio of splitting tensile to flexural strength was decreased by adding CD ash. However, in comparison with 0% CD ash replacement, the addition of 5% of CD ash led a reduction in ratio of splitting tensile to flexural strength at 1.78%. In this regard, the ratio of splitting tensile to flexural strength was 39.1% which classified as low strength concrete.

Figure 6. *Ratio of Tensile to Compressive Strength*

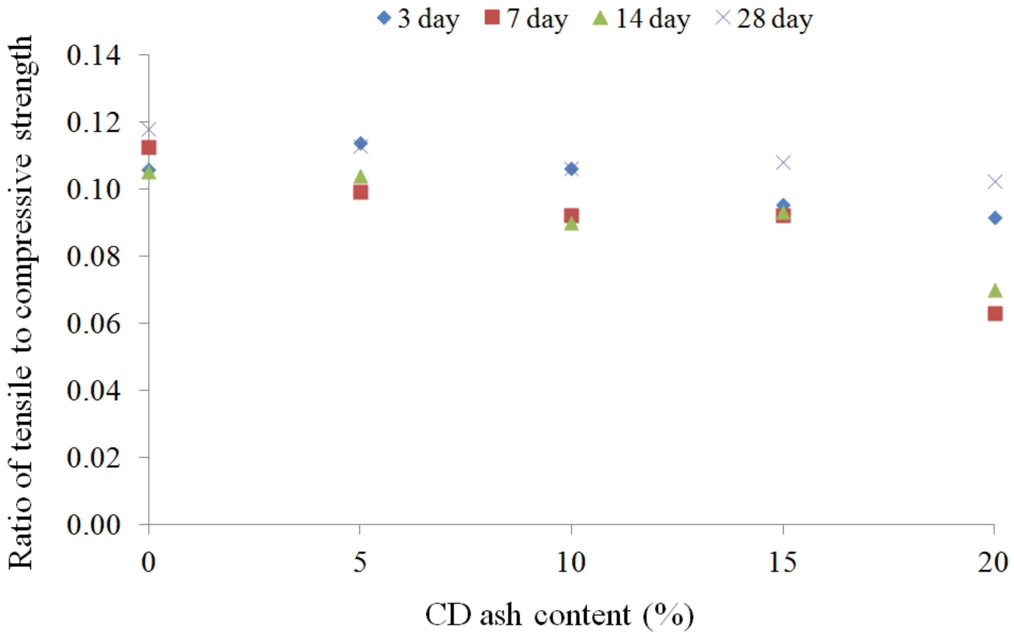
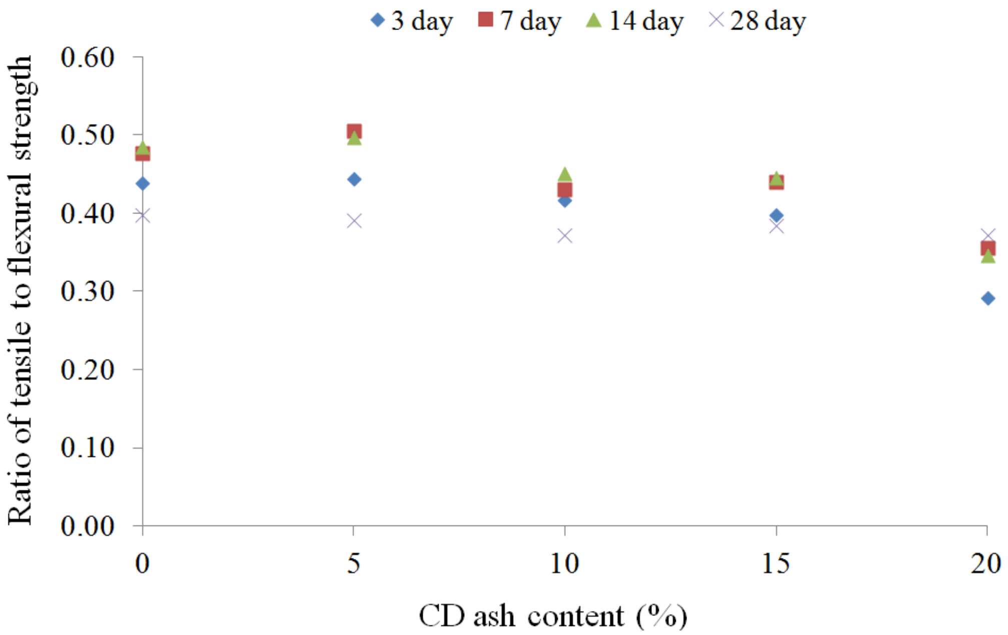


Figure 7. *Ratio of Tensile to Flexural Strength*



Conclusions

The experimental program reported in this paper dealt with assessing the compressive, flexural and tensile of concrete mixed CD ash. Based on the test results of this investigation, the following conclusions can be drawn:

1. Addition of CD ash to concrete can be conveniently achieved with the present day technology. This study has shown that it is possible to produce low strength concrete in Thailand using the locally available materials. CD ash replacement did not provide significant improvement levels as normal concrete (0% replacement).

2. Generally, application of CD ash decreased the strength properties; however, the results showed the potential for producing different strength-grades of concrete; in particular structural grade concrete can be produced by replacing cement with 5, 10%, 15% and 20% of CD ash.

3. Test results indicated that normal strength concrete, made with CD ash, tends to gain strength moderately similar to conventional concrete. The presence of CD ash increased the early strength of concrete. However, this increase in strength was not achieved with higher level of CD ash replacement.

4. The application of 10%, 15% and 20% CD ash led to the lower strength grade. Addition, increase the CD ash replacement resulted in a brittle failure mode in flexure, In this regard, using CD ash compensated some portion of cement, might not show significant improvement concrete properties including mechanical characteristics, Addition, CD ash with higher level of replacement caused unfavorable behavior, especially at the early ages.

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