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Original Article

Cotton dust ash from spining texttle industry as a secondary material in concrete

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Abstract

As cotton dust (CD) from spinning textile industry contains considerable amounts of cellulose, it can be used as an alternative secondary material for the production of concrete. This study was performed by replacing cementitious material with incinerated CD. Fresh and hardened cotton dust ash concrete was compared to a reference series. The level of replacement was at 0%, 5%, 10%, 15%, and 20% by weight. Observed results indicated that CD ash concrete had consistently led to improvement in strength performance. It was found that CD ash dosage at 10% by weight gave the ultimate compressive, flexural, and splitting tensile strength of 32.92, 8.36, and 4.84 N/mm^2, respectively. However, an increase in the percentage replacement of CD ash dosage resulted in an increase in the porosity of concrete. The results evidently exhibited that CD ash can be used for partial replacement of cement in concrete. Thus, the partial substitution of CD ash helps to contribute towards sustainable development in civil engineering practices

Keywords: concrete, cotton dust ash, industrial waste

1. Introduction

Under strong contemporary demand for modern and environmental friendly materials, natural unwanted wastes from industrial operation can be such materials and several researchers have focused their research efforts in using them as a partial substitute in the manufacturing of concrete and mortar (Joshi, 2003; Kelly-Yong *et al.*, 2011). In Thailand, total cotton fiber production is estimated to be 351,000 tons per year, of which approximately 240 tones cotton dust (CD), considered as micro dust and non-saleable waste, is produced during yarn manufacturing processes (Singhadeja, 2011). However, most of them are disposed by burning which increases the carbon dioxide level in the atmosphere and add on to global warming. Concrete is a material that is often seen as a potential place for wastes, because of its composite nature (binder, water and aggregates) and because it is widely used. The application and use of unusual wasted materials in concrete have been widely studied for improving mechanical properties and durability of their composites and reduce the cement consumption (Vaic¡iukyniene *et al.*, 2012). Cordeiro *et al.* (2009) investigated bagasse ashes, which were identified by their high pozzolanic activity, attributed to the presence of amorphous silica in small particle size with high surface area and low loss on ignition. Similar, Rodrigo *et al.* (2008) found that concrete mixed with banana leaves ash produced a good performance in terms of fresh state parameters and the mechanical behavior in the hardened mortar state. The compressive strength until 10% by weight of a banana leaves ash mortar mixture was nearly 25% higher than the reference sample and approximately 10% greater than that under tensile stress in bending on average.

2. Literature Review

The usage of carbonized renewable energy material has been widely studied and discussed for decades as an alternative cementitious replacement material. Carbonization

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is one of the possible thermochemical conversions of biomass into energy where a solid residue known as charcoal is produced through a slow process of partial thermal decomposition of wood in the absence or controlled presence of oxygen (Bridgwater, 2003). Cellulose, the major constituent of raw cotton lint, accounts for only 10 to 15% of the dust. Cotton fiber contains 67% cellulose and 33% lignin (Piotrowski and Carus, 2011). Lignin residue ash has been shown to have the potential to be used in concrete as a reactive supplementary cementitious material (SCM) to reduce concrete cement content as well as improve concrete quality (Ataie and Riding, 2014). However, the use of lignin residue ash in concrete depends on its physical and chemical properties, which depend on the burning conditions and composition of lignin residue (Galbe and Zacchi, 2012). The ash content of CD fractions increases with decreasing particle size. This trend is also observed for CD samples generated by Zhen *et al.* (2009). In this study, concrete was produced by using CD ash as a cementitious replacement material. Experiments on a laboratory scale were carried out with mixtures in which cementitious material was substituted by CD ash. The achievement of these series was to substitute primary raw material as well as to optimize strength. Furthermore, specimens were examined by mechanical methods to establish relationships between the replacement level and the mechanical properties. The mechanical properties of the CD ash concrete were studied using compressive and flexural strength and splitting tensile strength as these are the fundamental parameters for strength design of concrete structural element.

3. Materials and Methods

3.1 Cement

The cement used was ordinary Portland (OPC) cement corresponding to ASTM Type I cement with a specific gravity of 3.16 was used for all concrete mixtures. Initial and final setting times of cement were 130 min and 195 min, respectively. The chemical composition is given in Table 1.

3.2 Aggregates

Aggregates used in concrete mixture were washed and dried in the oven at 105±5°C to constant mass. The gravel was crushed granite with a maximum nominal size of 20 mm with 0.8% water absorption value, its relative density at saturated surface dry (SSD) condition was 2.70. The natural siliceous river sand having its relative density at saturated surface dry (SSD) condition of 2.61 and the fineness of modulus (F.M.) of 1.95 was used as a fine aggregate. Water absorption of sand used was 1%.

3.3 Plasticizer

A commercial carboxylic type super plasticizer (ADVA 208, W.R. Grace) was used to maintain the workability of fresh concrete. The dosage of super plasticizer was kept at constant in mass basis (500 cc per 100 kg of cement). The aim of keeping the amount of super plasticizer constant is to minimize, if any, the influence of super plasticizer on the properties of hardened concrete.

3.4 Cotton dust ash

Cotton dust (CD) ash used in this study was a waste material of CD which resulted of the mechanical processing of raw cotton in the spinning process. The CD was incinerated in furnace at 800°C. After that, CD was held at targeted temperature for four hours before the furnace was turned off and CD ash was then allowed to cool down naturally to room temperature. During the heating period, moisture in the specimens was allowed to escape freely. Then the surface dust was blown away. This dust was nothing but cotton dust ash powder. A picture of CD ash is shown in Figure 1. The variation of particle size distribution of CD ash was verified by materisizer S long bed ver. 2.19 and the result is showed in Figure 2. It varies in the range of 200-700 mm. The specific surface area of the CD ash used in this study was found to be 4,520 cm^2/g with 10.2% ash retained on 45 mm sieve. The composition of CD ash is shown in Table 1.

Table 1. Chemical composition of cement and CD ash.

Composition (%)	Cement	Cotton dust ash
CaO	65.4	30.80
SiO_2	19.4	11.69
Al_2O_3	4.8	1.75
Fe_2O_3	3.4	2.09
MgO	2.8	13.88
SO_3	3.0	1.54
Na_2O	0.2	10.03
K_2O	-	18.86
P_2O_5	-	4.07
TiO_2	-	1.39
Loss on ignition	1	3.90

Figure 1. Photo of CD ash.

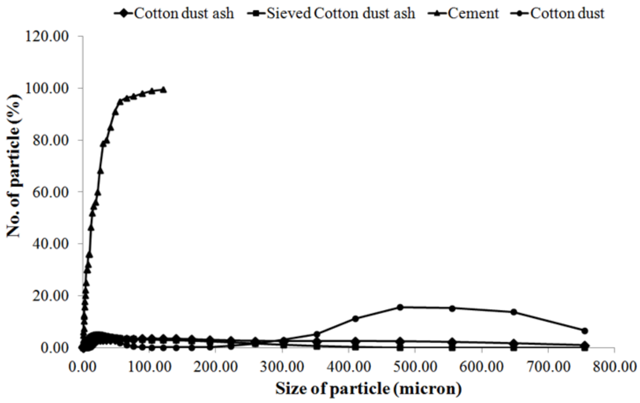


Figure 2. Particle size distribution of CD ash.

3.5 Methods of mixing

For dispersion effects of the mixing materials, one-third of CD ash was firstly added into running mixer after concrete was well mixed. The mixing time was three minutes. Then, two-third of cotton dust ash was secondly added gradually to running mixer. The mixing time continues for 6 min. The compressive and splitting tensile strength was investigated by using concrete cylinder of 100-mm in diameter and 200-mm in height as the specimens for testing. The flexural strength (three point bending test) was obtained by casting concrete prisms of 150×150×600 mm. Two layers of placing mixed concrete into steel molds were used, each layer being consolidated using a vibrating table. The specimens were demolded approximately 24 hrs after casting. The method of curing was immersion in water at 23±2°C until the age of testing. In order to minimize the effects of surface moisture to the strength of specimens all specimens were placed out of water and put in the air dry for 24 hrs prior to testing. Three test results were compared for obtaining the means value for any test. Mix proportions of binders are presented in Table 2.

3.6 Testing methods

Compressive strength, flexural and splitting tensile strength tests were carried out in accordance with ASTM C 39, ASTM C78 and ASTM C 496 respectively. In this study, the porosity of concrete was determined through the vacuum saturation method (Cabrera and Lynsdale, 1988). The measurements of concrete mixed CD ash porosity were conducted on 50 mm cubes. Specimens were placed in a desiccator under vacuum for at least 3 hrs, after which the desiccator was filled with de-aired, distilled water. In order to obtain fully dried, the specimens were dried in oven at 100± 3°C for 24 hrs. Each data point reflects three test results. Porosity was calculated using the following equation:

$$\text{Porosity} = \frac{W_{sat} - W_{dry}}{W_{sat} - W_{wat}} \times 100 \qquad (1)$$

where P is porosity (%), W_{sat} is weight in air of saturated sample, W_{wat} is weight in water of saturated sample, and W_{dry} is weight of oven-dried sample.

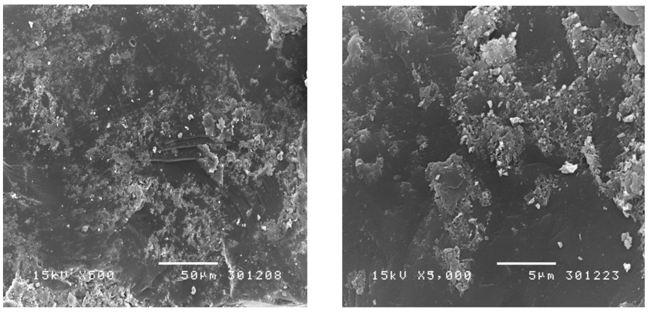
4. Results and Discussion

4.1 Properties of CD ash

In bulk, CD ash was grey in color and becomes darker with an increased proportion of unburned carbon. Like that of coal fly ashes and palm oil fuel ashes, the chemical composition of CD ash varies to a great extent since this material was carbonized by combustion process. The amount of carbon present in any ash varies depending on the combustion process. Loss on ignition detected in this study was 3.90%, which was lower than the maximum value of 6.0% stipulated in ASTM C618 (ASTM C618, 2004) for class N, class F, and class C. It was further found that the sulfur trioxide (SO_3) content was also lower than the chemical requirement. However, moisture content was slightly over than the maximum requirement. Both, identification of classification of CD ash and tests for the use of acceptable performance are further required. The surface morphology of the CD ash was also examined with a JEOL (JSM-5410LV) scanning electron microscope (SEM). The microstructure of concrete specimens made with a combination of 10% CD ash and 90% cement is showed in Figure 3(a) and (b). Figure 3(a) shows the surface morphology of a CD ash particle at a magnification of 500x. It was found that some amount of inter particle void spaces were presented and the particles

Table 2. Mixture proportion of concrete mixed CD ash.

Designation of the mix	CD ash (kg/m^3)	Sand (kg/m^3)	Aggregate x (kg/m^3)	Water (kg/m^3)	Cement (kg/m^3)	Superplasticizer (cc/m^3)
CDA-0	0.0	772.0	880.0	215.0	430.0	2,150.0
CDA-5	21.5	772.0	880.0	215.0	408.5	2,042.5
CDA-10	43.0	772.0	880.0	215.0	387.0	1,935.0
CDA-15	64.5	772.0	880.0	215.0	365.5	1,827.5
CDA-20	86.0	772.0	880.0	215.0	344.0	1,720.0



(a) (b)

Figure 3. (a) SEM images of concrete mixed with CD ash (500x). (b) SEM of concrete mixed with CD ash (5,000x)

were of multifaceted type. In addition, numerous fine particles of CD ash with sizes of approximately 10-60 mm and irregular morphology were found, which can be ascribed both by their mineralogy and grain size from sieve analysis. Figure 3(b) shows that the bonding of the CD ash particles was less prominent than that of the bonding at the interface of CD ash and C-S-H, which implies an increase amount of porosity of the specimens.

4.2 Workability and strength of concrete

The water to cement (w/c) ratio of all concretes used in this study was kept constant at 0.50 and the slumps of fresh concrete were examined. It found that a moderate slump value of 115, 110, 107, 105, and 100 mm were obtained for OPC, 5%, 10%, 15%, and 20% CD ash concrete, respectively. It can be seen that a higher replacement of cement with CD ash resulted in lower workability of the CD ash concrete as compared to the reference with OPC only. This was due to the high specific surface area and high carbon content of CD ash (shown in Table 4). Regarding strength, the highest compressive strength was observed in the OPC concrete, while specimen with 5%, 10%, 15%, and 20% replacements made up to 98.7%, 96.4%, 90.79%, and 87.80% of the control specimen strength at 28 days. Similar trends have been reported in concrete with fly ash (Awal and Shehu, 2013; Pei-wei *et al.*, 2007).

4.3 Compressive strength

The compressive strength of different CD ash replacement is presented in Table 3 for 3, 7, 14, 28, and 60 days. It was found that all values of strength at 28 days were lower than control mix. However, at 60 days, the strength of concrete mixed cotton dust ash (10% cotton dust ash) was 2.75% higher than the control mix. The compressive strength increased with blending percentage at corresponding values of curing period. Higher content of CD ash caused a loss in strength. This might due to an increase in CD ash content which increased the total surface area of CD ash in the mixes. Therefore, further water dosage for attaining workability of mixtures was required. It was found that the CD ash blending increased the relative strength at all ages. However, most pronounced was the increase during the first seven days.

Table 3. Compressive flexural and splitting strength test results.

Compressive strength of Concrete mixed CD ash (N/mm^2)					
CD ash (%)	3 days	7 days	14 days	28 days	60 days
0	18.16	19.75	25.13	29.05	32.04
5	16.08	19.59	24.57	28.73	32.43
10	15.67	19.14	24.33	28.06	32.92
15	15.46	18.77	23.33	26.64	31.44
20	11.48	17.55	22.36	25.93	31.19
Flexural strength of Concrete mixed CD ash (N/mm^2)					
CD ash (%)	3 days	7 days	14 days	28 days	60 days
0	4.38	4.68	5.79	6.39	8.13
5	4.15	4.48	5.49	6.37	8.23
10	3.95	4.16	5.29	6.19	8.36
15	3.77	3.96	5.12	5.74	6.99
20	3.59	3.66	4.76	5.16	6.89
Splitting tensile strength of Concrete mixed CD ash (N/mm^2)					
CD ash (%)	3 days	7 days	14 days	28 days	60 days
0	1.92	2.24	2.82	3.49	4.43
5	1.85	2.09	2.65	3.29	4.49
10	1.66	1.94	2.29	3.07	4.84
15	1.49	1.75	2.19	3.06	4.26
20	1.07	1.29	1.58	2.67	4.18

Table 4. Characteristics of CD and CD ash material.

Materials	Moisture (%)	Ash content (%)	Burnable substance (%)	Carbon content (%)
CD	5.63	7.35	76.00	16.65
CD ash	4.50	24.20	25.70	50.05

4.4 Flexural strength

The flexural strength of beam containing CD ash was reduced as the replacement percentage increased (Table 3). The highest drop of flexural strength was observed when the content of CD ash was above 10% by weight. However, the results showed that partial cement replace by CD ash did not have a significantly improved strength at early age, although the effect was pronounced only at later ages (60 days). It was further found that the flexural strength values of cotton dust ash blended concrete was lower than those of plain cement concrete at ages up to 28 days. At later age (60 days), the blended concretes have higher flexural strength than of the control concrete. However, it was noticed that the rate of increase of flexural strength was lower than that of the compressive strength. The optimum dosage for flexure strength was at 10% of CD ash. After increasing the volume percentage of CD ash beyond the optimum value (10%), improper mixing of CD took place due to specific surface effect of CD ash. The reaction between cement and water reduced the moisture content of the mixes. It caused the formation of loose lumps of CD ash. This effect was minimized by re-arranging the sequence of adding materials to concrete matrix. The CD ash dosage was discharged after superplasticizer was mixed to concrete matrix. The tines of the pan mixer broke up any lumps in the CD ash and in the cement. Therefore, mixing time was considerably longer than required for ordinary concrete. This also increased the amount of vibrations required to remove air voids from the mix which caused the problem of bleeding and decreased flexural strength of the mix. Adding of CD ash with cement provided less efficient particle packing due to the wider particle size range as compared to the cement. Hence, only moderate contribution was given by the filler effect to early-age strength. Furthermore, blending by higher amounts of CD ash put the strength of concrete at early ages in the more unfavorable position due to a diluting effect (Bui *et al.*, 2005). This might not be compensated by physical strength contribution due to the significantly overlapping particle size distribution curve of cement and CD ash. From this aspect, adding cotton dust ash higher than 10% appeared to be in a more disadvantage position.

4.5 Splitting tensile strength

The splitting tensile results are shown in Table 3. The average splitting tensile strength increased as CD ash substitution increased. Similar to the compressive and flexural strength, the splitting tensile increased with time. The splitting tensile strength of concrete mixed CD ash was in the range of 1.92-4.82 N/mm^2. It was further found that 10% of CD ash replacement gave the highest splitting tensile strength when it compared with splitting tensile strength of specimens mixed with 0%, 5%, 15% and 20% of CD ash replacement. In this regard, concrete contained 10% of CD ash replacement, developed in average 58.24% of the 28 days strength in seven days in comparison with 55.80% for normal concrete. Further, by using 20% CD ash as a cement replacement, the splitting tensile strength decreased. From the results obtained, a mixture of CD ash can be used in the production of normal weight concrete. Substitution of the mixture should not be more than 10% of replacement level for the best results in the concrete production for concrete structures.

4.6 Correlation between ratio of tensile to compressive and tensile to flexural strength

Regression analysis of the experimental and literature data on the ratio of splitting tensile strength to compressive strength (ft_{sp}/f_c) as a function of cylinder compressive strength of concrete, $f_{c,}$ was carried out (Gardner, 1990; Imam *et al.*, 1999). Figure 4 and 5 show the ratio of splitting tensile to compressive and splitting tensile to flexural. It was found that the ratio between tensile and compressive was in the range of 0.298-0.607, while the ratio between tensile and flexural was in the range of 0.071-0.147. The ratio of the two strengths (f_{tsp}/f_c) is strongly affected by the level of the

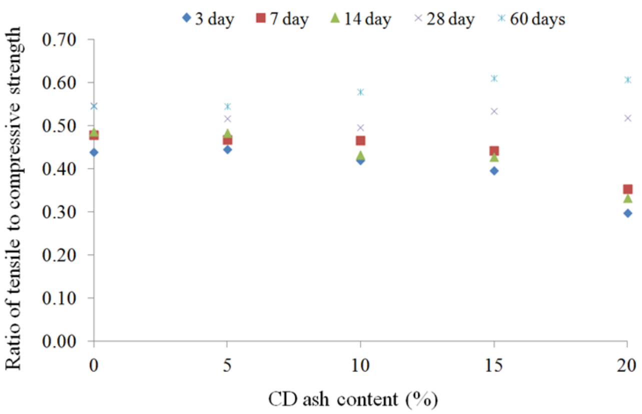


Figure 4. Ratio of tensile and compressive strength.

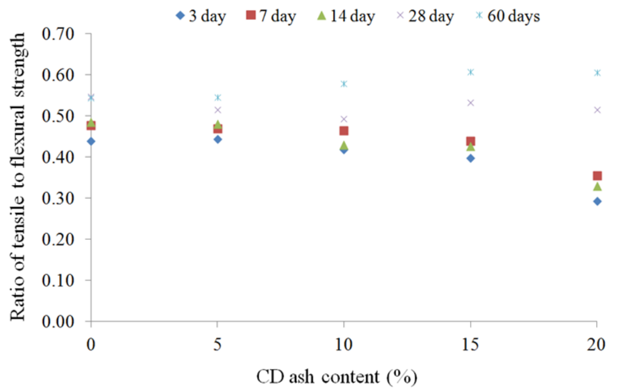


Figure 5. Ratio of tensile and flexural strength.

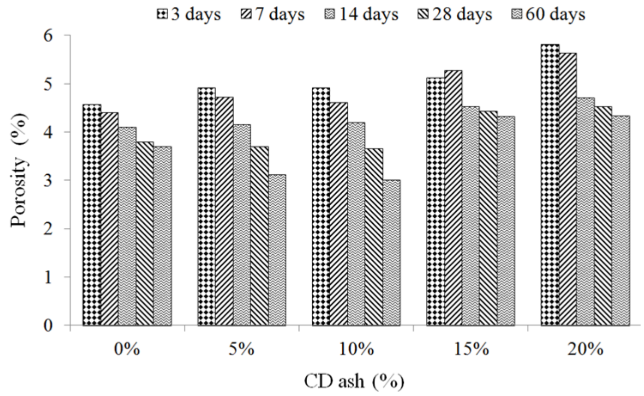


Figure 6. Porosity and content of CD ash.

compressive strength f_c. This ratio decreases with increasing compressive strength at a decreasing rate. These findings can be explained by the fact that an increase in the splitting tensile strength, f_{tsp}, occurs at a much smaller rate compared to the increase of compressive strength. It was found that CD ash concrete in this study was classified as low strength concrete. The result is in agreement with various researchers (Zain *et al.*, 2002; Aréoglu *et al.*, 2002).

4.7 Correlation between porosity and CD ash

From Figure 6 it can be seen that the porosity of concrete mixed CD increased when the content of CD ash increased. The compressive strength of concrete mixed CD ash was shown to be a function of porosity and age. The porosity of concrete mixed CD ash decreased as age of specimens increased. This might due to the fact that the amount of hydration of cement gel increased (Chindaprasirt and Rukzon, 2008). Further, from Figure 7 it can be seen that an increase of volume fraction of CD ash caused an increase in the amount for water, which was due to water absorption by CD ash. In this study, the measurement of the pore structure of cement based materials has proved to be extremely difficult; this was due to the special character of the hydration products formed (Day and Marsh, 1988). Hence, the results obtained will depend not only on the measuring principle but also on the drying method used prior to the porosity measurements (Vodak *et al.*, 2004).

5. Conclusions

Based on the experimental results of this study the following conclusion can be drawn:

1. The strength of material gradually increased as CD ash dosage increased up to 10% replacement. The replacement of cotton dust ash had a small impact on the compressive strength of concrete mixes. The dosage of CD ash above 10% by weight resulted in poor strengths. The maximum compressive, flexural, and splitting tensile strength on 28 days curing period was 28.71, 6.37, and 3.28 N/mm^2 respectively.

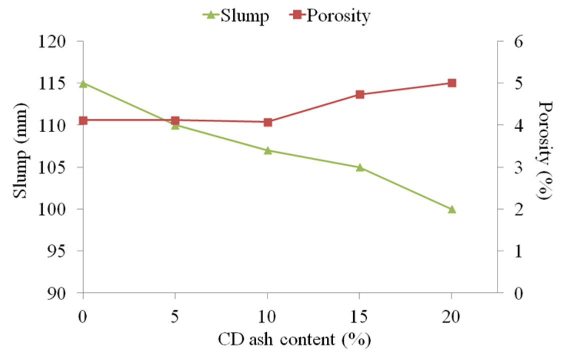


Figure 7. Relationship between slump and porosity of concrete mixed CD ash.

However, the strength of CD ash concrete at 10% showed a prominent result in strengths at 60 days curing period.

2. As the percentage of the cotton dust ash replacement increased the porosity increased.

3. It found that the ratio of the splitting tensile to compressive and the ratio of splitting tensile to flexural strength were in range of 0.092-0.146, while the ratio between tensile and flexural strength was in the range of 0.292-0.607. This ratio decreases with increasing compressive strength at a decreasing rate.

4. The use of CD ash as cement replacement material has proven to be beneficial not only for the obvious environmental benefits and saving raw materials but also in terms of the mechanical improvements of composites.

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