Agricultural and Bio Waste Ashes as Alternate Cementitious Material – Strength Evaluation of Partially Blended Cement Mortars

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1. INTRODUCTION

Sustainable construction is a concept linked to convert waste management into resource management. As per a survey data only 17% waste is recycled in Japan and this recycling ratio is below 5% in the world as a whole. Over the years many industrial and agricultural by products and wastes have been tried and used in cement and concrete based products, partially replacing cement and or aggregates. More than 2 billion tones of agricultural and bio-wastes are burnt every year for various purposes leaving behind tones of ashes and often dumped as waste. These ashes are generally very rich in silica contents because plants and leaves of trees uptake various minerals during their growth process (Atchison, 1973).These ashes, if in reactive state, form the basis of pozzolan reaction; the reaction of silica oxides (SiO_2) with the excess calcium hydroxide [$Ca(OH)_2$] present in the cement gel during hydration process. In this study, various types of ashes obtained from agricultural and bio-wastes, such as dead tree leaves(AML), waste grass [Korai (KRI), Tifton (TFT), native shiba (AJG)], ground-nut shell (GNT), wheat straw (WSI, WSJ) were evaluated for their possible potential as pozzolanic or cementitious character.

2. EXPERIMENTAL PROGRAMME

The most important part of present study was the process of burning that defines the formation of crystalline or amorphous matter with the subsequent loss in weight due to the change in phases and loss of organic matter. To define the optimum burning condition, many trials were made by burning wastes at 450, 550, 600, and 800°C for 3hr. and 5hr. (Martirena, 2006; James et al., 1986). The target was to obtain ashes with maximum amorphous matter with minimum desirable carbon contents. The ashes obtained after 5 hour burning at 600°C and 800°C were selected to verify the amorphousness by X-ray diffraction (XRD) and thermo-gravimetric tests (TGA/DTA). Interpretation of the results showed that ashes obtained at 600°C/5hr were more amorphous. After grinding, sieving and characterization of physical and chemical properties (**Table 2**), ashes of AML, KRI and TFT were selected to study the pozzolanic or cementitious behavior as cement-pozzolana binder in mortars. For this study blended mortar specimens (40 x 40 x 160mm) were prepared as per JIS 5201, using standard sand and replacing ordinary Portland cement (OPC) with ashes as shown in **Table 1**. To check the strength development Destructive (compression and flexural strength) and non-destructive test [ultrasonic pulse velocity (UPV)] were carried out at the curing age of 3, 7, 14, 28, 56, and 91 days of all blended specimens. Representative paste specimens with 20% replacement ratio were also prepared and subjected to XRD, TGA/DTA and scanning electron microscopy (SEM) to define the hydration reaction and the pozzolanic or cementitious behavior of the ashes via the consumption of calcium hydroxide (CH) and formation of calcium silicate hydrates (C-S-H).

Table 1 Abbreviation used and properties of ash samples

Specimen (Symbol)	Replacement ratio (by weight)
AML10, KRI10, TFT10	90% OPC + 10% respective ash
AML20, KRI20, TFT20	80% OPC + 20% respective ash
AML30, KRI30, TFT30	70% OPC + 30% respective ash
CTR	100% OPC + 0% ash

Table 2 Chemical and physical properties of ash samples

Constituents (%)	Materials			
	AML	KRI	TFT	OPC
SiO_2	37.06	57.56	56.54	18.4
Al_2O_3	3.39	5.33	5.23	5.6
Fe_2O_3	6.02	6.37	7.57	3
CaO	36.81	8.73	5.33	66.8
MgO	1.45	0	0	1.4
SO_3	3.1	4.3	6.28	2.8
K_2O	7.02	9.27	19.72	0.5
Loss on ignition	0.34	0.89	0.87	2
Density (g/cm^3)	2.67	2.66	2.47	3.15
Av. particle size (μm)	38.9	54.7	67.1	36.2
Blaine area (cm^2/g)	5940	5240	4930	3250

3. RESULTS AND DISCUSSION

Though the carbon contents were lowest at 800°C/5hr burning but the X-ray diffractograms and thermo-gravimetric

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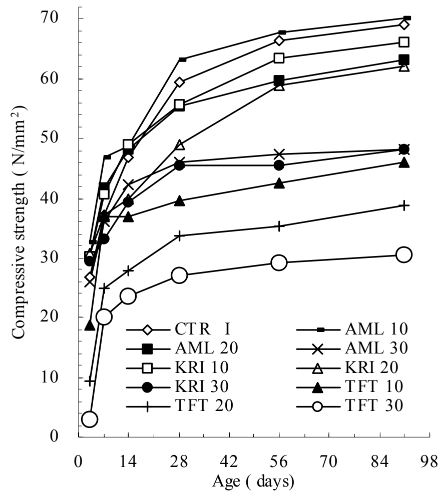
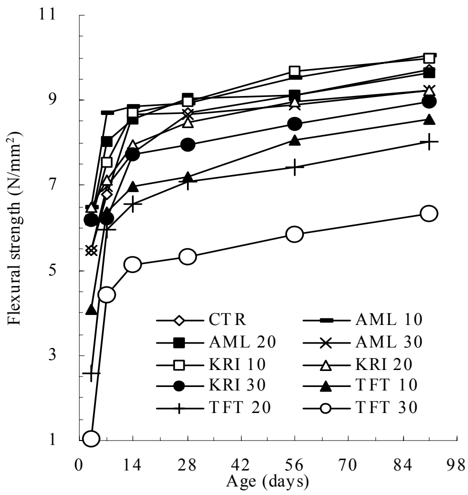
analysis indicated the crystallization of the matter at temperatures higher than 650°C. All ashes had higher surface area as compared to OPC, a basic requirement for a pozzolan material. Based upon the combined percentage of SiO_2, Al_2O_3, Fe_2O_3 and CaO, AML was classified as high calcium ash KRI and AJG as class C, and WSJ as class F pozzolan ashes (ASTM C618-03). TFT was also in class C category but of higher percentage of SO_3 (>5.0%). Setting time of blended mortar increased with the increase in the amount of ash. It was 21% more in case of AML10, 65% to 120% more in KRI blends (with in limits), but it was above 200% in case of all TFT blended mortars. Retardation in the setting time in AML and KRI might be attributed to the slow early reaction due to the increased percentage of silica. 91 day compressive strength (CS) of AML10 was 104% of CTR. In AML and KRI blends, 91 days CS values were above 90% of CTR with up to 20% replacement. Higher strength exhibited by AML samples might be due to combined effect of high calcium oxides and pozzolanic reaction due to increased SiO_2 content. TFT-blended cement mortar specimen did not show much development in CS at any stage of curing. It can be attributed specifically to water-soluble K_2O present in the cement (Neville, 1995). Almost same trends were observed in the flexural strength and ultrasonic pulse velocity test results which showed the steady development of strength though it decreased with the increase in the ash substitution ratio. Comparison of CH and SiO_2 peaks in the XRD patterns of blended and CTR specimen was made to evaluate the formation of the hydration products. At 91 days the XRD pattern had lower peaks of CH than at 28 days, indicating the pozzolanic reaction at later stage though with varying degree. Analyses of TGA/DTA and SEM results (**Table 3)** proved that AML blended paste reacted more than CTR and other blends.





4. CONCLUSIONS

1.) Interpretations of X-ray diffraction data and TGA/DTA analysis confirmed that optimum burning condition to obtain ashes was 600°C/5hr.
2.) Mechanical strength tests together with the interpretations of XRD and TGA/DTA data proved that substitution of OPC with 10% AML, significantly improved the compressive strength and flexural strength values. However TFT ash was not effective in improving the strength. Also up to 20% replacement of OPC by AML and KRI ash showed fairly good results; with the strength values reaching 90% of that of CTR.

Table 3 TGA analysis of blended and CTR pastes

Sample	C-S-H water loss (%) (70 - 400°C)		CH water loss (%) (450 - 700°C)	
	Day 3	Day 28	Day 3	Day 28
CTR	17.65	17.44	3.44	4.10
AML	18.39	19.37	3.81	4.15
KRI	17.72	19.82	2.63	4.02
TFT	16.90	19.14	1.53	4.14

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