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Influence of metal oxide (V_2O_5) in recycled waste materials for advanced durable construction technology

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HIGHLIGHTS

- Flyash-V_2O_5 has been sintered at different temperatures.
- The 5% V_2O_5 reduces the mullitization temperature < 1000 °C.
- Building composites are prepared by using sintered Flyash-V_2O_5 and alkali activator.
- Composite exhibits significantly higher mechanical strengths and better durability.
- Nano-mullite phases increase the strength and durability of building composite.

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ABSTRACT

For replacement of Portland cement as well as advancement of concrete technology, the low calcium based fly ash with alkali activators plays a significant role as cementitious material in current scenario. As efficacy of fly ash requires very high temperature (≥1400 °C) activation, alternative approach of fly-ash with addition of 5% vanadium pentoxide (V_2O_5) has been established for mullitization process at lower temperature (≤1000 °C) in this present exertion. The sintered fly ash has been used along with alkali activator for developing the construction composite at ambient temperature. Strength measurement, Ultrasonic pulse velocity, Chloride ion permeability, water absorption and sulphate resistant tests reveal that the V_2O_5 assimilated fly-ash based geopolymer structures possess higher mechanical strengths and durability. The microstructural studies (FESEM, EDS, XRD, FTIR) of the samples confirm the needle shaped nano sized mullite formation at 1000 °C temperature in its matrices. Thermal behaviour of the V_2O_5 based fly-ash depicted the synthesized nanoparticle was exothermic in reaction. The investigation demonstrates the formation of needle shaped mullite helps to enhance durability with higher bond strength of the composite structure and a new approach to utilize/recycle the vast resources of fly-ash with lower temperature requirement as an effective cementitious-based engineering materials.

1. Introduction

Fly ash, a solid industrial waste is generated in coal fired power stations as a result of the transformation, melting and gasification of the inorganic matter associated with the coal [1]. This inorganic material comprises about 5–20% of the mass of the coal, great amounts of fly ash are produced every year from electricity generation [2]. Approximately 600 million tons of coal ash are produced annually worldwide, of which fly ash accounts for approximately 80% [3]. Over 500 million tons of fly ash is generated in 2013 in China whereas predicted that nearly 3 Giga tons in 2020 [4]. About 20% of this fly ash is used in the concrete related applications, while the rest is disposed of in landfills or lagoons resulting a hazardous impact on the environment, polluting soils and groundwater [5,6].

World increasing population desires large number of construction as their basic needs where application of Portland cement shows an imperative role for the concrete structure. On the other hand, production of cement, an energy rigorous process, releases a large amount of greenhouse gas especially CO_2 to the atmosphere directly/indirectly gives a dissipated influence on atmosphere and mankind [7]. Therefore a worldwide concern has been arises to protect environment by balancing the level of CO_2 emission. In this

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context, reusing of waste materials in terms of fly ash from thermal power plant is a new way to find out an alternative cementitious products. Though it is very much cost effective and eco-friendly way, still it has some shortcomings such as heat activation, proper binder etc. which obstructs its importance as a true building materials [8,9]. It is very well established in different studies that various metal oxides are applied as an admixture for enhancing the mechanical and structural property of fly ash material [10,11].

Vanadium, a hard, ductile, silvery grey malleable transition metal can exist in a number of different oxidation states (2–5) which is quarried in South Africa, Russia and China [12]. The common viable form is vanadium pentoxide (V_2O_5; CAS No. 1314-62-1), – a pentavalent state of vanadium – brown/yellow crystalline powder, can be synthesized by different techniques [13].

In this present study, we have given an effort to reduce the very high temperature depended fly ash activator for better performance in concrete structure by adding Vanadium pentoxide (V_2O_5) at very lower concentration under an ambient temperature. The mechanical, physical and structural property behaviour of waste-product based cementitious materials have been investigated and Archimedes' method was conducted for density measurement of the building structures. The micro structural properties of metal oxide modified fly ash and mortars have been further assessed via FESEM equipped with EDS, XRD, FTIR and DTA-TG techniques.

2. Materials and methods

2.1. Ingredients

Low Calcium Class F (American Society for Testing and Materials 2001) dry fly-ash (SiO_2 = 48.13, TiO_2 = 1.66, Al_2O_3 = 39.03, Fe_2O_3 = 2.94, FeO = 0.77, MgO = 1.05, CaO = 3.30, Na_2O = 0.21, K_2O = 0.69, MnO = 0.017, P_2O_5 = 0.63) has been used as the base material. The sodium hydroxide (NaOH) was the commercial grade in pellet forms with 99% purity, Liquid sodium silicate (Na_2SiO_3) was also a commercial grade (45% solid content & specific gravity of 1.53 gm/cc) and all other fine chemicals were purchased from Sigma Chemical Co., USA, Merck, Germany and Spectrochem Pvt. India Ltd., India. To execute this study, standard Ennore sand and Vanadium pentoxide (V_2O_5) from sigma. Pvt. Ltd, USA were employed. All the chemical used were analytical grade. All the ingredients are shown in Table 1.

2.2. Experimental methods

2.2.1. Sample preparation and characterization

Class F fly ash was thoroughly mixed with the 5% vanadium pentoxide (by weight) in a ball milling machine. The mixture was sintered at 600, 800 and 1000 °C for 2 h and each type of sintered particles (F_6, F_8 and F_{10}) were cooled at room temperature. One part of the untreated fly ash-V_2O_5 mixtures were stored at room temperature named as F_{RT}. The samples (F_{RT}, F_6, F_8 and F_{10}) were crushed to prepare a uniform sized powder particles for its various characterization. All the sample preparation are shown in Table 2.

Table 2
Sample preparation at a glance.

Sample name	Preparation	
F_{RT}	Fly Ash + V_2O_5 (5%)	At room temperature
F_6	Fly Ash + V_2O_5 (5%)	Sintered at 600 °C
F_8	Fly Ash + V_2O_5 (5%)	Sintered at 800 °C
F_{10}	Fly Ash + V_2O_5 (5%)	Sintered at 1000 °C

A very small amount of each specimens (F_{RT}, F_6, F_8 and F_{10}) were taken and crushed for making uniform powder ($\leq$5 μm) for the microstructural analysis. The morphological analysis was conducted under the field emission scanning electron microscope, FESEM (INSPECT F50 SEM, FEI Europe BV, The Netherlands). The elemental investigation was also done by Energy dispersive X-ray spectroscopy (QUANTAX ESPRIT 1.9 software) equipped with FESEM machine. The preliminary phases were analysed by using X-ray diffractometer (Bruker AXS; Model D8, WI, USA) which was set up with Cu K_α radiation (1.5409 °A) and scan speed was set 0.5 s/step in the scanning range from 10 to 70 (2θ) running at 40 kV and 30 mA at 25 °C. The peaks in several positions of the spectra were marked, and identified from the JCPDS data files. FTIR spectrum was recorded in the region 500–4000 cm^{-1} on Brucker Optics Alpha-T spectrophotometer with samples as 99% KBr disks. The thermal reaction developments (i.e. phase change temperatures) were examined by using a dynamic thermal analyser/thermo-gravimetric analyser (DTA/TGA) (DTG-60H, Shimadzu) instrument. The DTA/TGA analysis was done on the untreated fly ash sample (F_{RT}) in presence of N_2 gas atmosphere.

2.2.2. Mortar preparation

Initially, 10 (M) NaOH were mixed with Na_2SiO_3 solution at 1:2 proportion (by weight) to make alkali activator fluid. Standard mortar cubes having dimension of 50 mm × 50 mm × 50 mm were cast for all samples. The fly-ash to sand ratio was affixed as 1:3 and alkali activator to fly ash ratio was maintained at 0.48 for all type of sample preparations. M_{RT}, M_6, M_8 and M_{10} named mortar samples were prepared by using the fly-ash F_{RT}, F_6, F_8 and F_{10} respectively. For conventional cement mortar (CM) sample preparation, the 43 grade ordinary Portland cement, ennore sand and water were used. The ratio of cement to sand was fixed at (C: S=) 1:3 and cement to water ratio was taken (C: W=) 1:0.4 for the preparation of CM sample. Mortar sample preparation are listed in Table 3.

2.2.3. Compressive strengths and ultrasonic pulse velocity

After different days of air curing (3, 7, and 28 days) the compressive strengths of the mortar samples (M_{RT}, M_6, M_8 and M_{10}) were carried out by using the compressive strengths measurement machine (1000 KN Instron) as per ASTM C109/C109M [14]. Before measuring the compressive strength, the ultrasonic pulse velocity through each specimens were performed by using Pundit plus PC1007 as per ASTM C597-02 [15].

2.2.4. Flexural and split tensile strengths

Specimens with dimension of 200 mm × 50 mm × 50 mm edges length were made for flexural tests whereas the fly-ash sand and alkali activator ratio was maintained the same. The specimens were air cured at room temperature (27 ± 2 °C) for 28 days. The flexural strengths of the samples were determined at 28 days of curing as per ASTM C348 [16]. Split tensile strength of all the mortar mixtures were carried out by using the cylindrical specimens (50 mm diameter × 100 mm height) after 28 days of curing.

Table 1
Ingredients used.

Materials	Chemical Information										
Fly ash	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5
	48.13	1.66	39.03	2.94	0.77	1.05	3.30	0.21	0.69	0.017	0.63
Sodium Hydroxide	NaOH										
	99%										
Cement	Ordinary Portland cement (OPC) 43 Grade										
Sodium Silicate	Na_2SiO_3 (specific gravity of 1.53 g/cc)										
	45% solid content										
Vanadium Pentoxide	V_2O_5										
	99%										
Sand	Ennore sand			Size				Amounts			
				2 mm–1 mm				33.33%			
				1 mm–500 μm				33.33%			
				500 μm–90 μm				33.33%			