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Original Research Article

Stabilization of fly ash and lime sludge composites: Assessment of its performance as base course material

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ABSTRACT

In the present study, two potential industrial waste materials, such as, fly ash (FA) and lime sludge (LS) that are generated in bulk quantities and poses environmental hazards were mixed and stabilized using lime (CL) and gypsum (G) in order to make them suitable for use in Civil Engineering construction applications. Different mix proportion of FA and LS stabilized with different % of CL and G were studied and tested for unconfined compressive strength (UCS), split tensile strength test (STS) and California bearing ratio (CBR) to check the suitability of prepared composite for construction industries. It is noted that the optimal composition consisted of FA and LS in 1:1 ratio, 12% CL and 1% G content. The composite was also found to be durable with no leaching of heavy metals. Further, the selected composite was further studied for the microstructural development through scanning electron microscopy (SEM) and X-ray diffraction (XRD) to understand the phenomenon of chemical process or reaction and reason for strength gain. The developed composite (50FA + 50LS + 12CL + 1G) is suggested for application as base course layer material in flexible pavements due to its good requisite strength and durability. It is further highlighted that issues of uncertainty in strength and stiffness characteristics of pavement layer materials and its implications on analysis and design of flexible pavements can be studied through reliability based approach in combination with numerical analysis and Monte Carlo simulations.

1. Introduction

Waste utilization is a major concern in today's world and safe disposal of these wastes is essential for the sustainable development and overall growth of the society. Alternatively, researchers are also exploring the possibility of utilization of these wastes in various civil engineering construction activities. On these lines of thoughts, several waste products, such as, rubber tyre, plastic, fly ash, etc. have been effectively

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utilized. Fly ash generated from thermal power plant and lime sludge from paper, acetylene, sugar, fertilizer, soda ash industries and water softening plants are the two most remarkable industrial wastes in India. The generation of fly ash is 184 millions tons per annum and its utilization is about 55% [1]; the output of lime sludge is about 10 million tons per annum, although the level of utilization is less than 10% and rarely reported [2]. Large amounts of these wastes are disposed without any treatment, which inhabit substantial land and cause risk to the environment in terms of air, water and soil pollution. Fly ash is considered as a pozzolanic material and is categorizes in two classes as per ASTM C618 [3], Class C and Class F based on the availability of free lime present in fly ash. Class C fly ash is rich in lime and does not need addition of external lime [4] for the pozzolanic reaction and strength gain. Class F fly ash holds lesser amounts of lime and needs stabilization with lime or cement and some admixtures to accelerate shear strength gain in short period. IRC-2012 [5] specifies the use of stabilized fly ash as road base course material with minimum target strength of 4.5 MPa after 28 days of curing. However, literatures have reported the strength of fly ash alone in the range of 3–4 kPa, which is much less than the target strength. After addition of lime/cement and gypsum to fly ash as stabilizing agents, the stabilized fly ash has provided a promising solution in pavement sectors and it has been successfully used as base course layer [6–8]. With advent of high volume of traffic and vehicular payload capacity, it is required to enhance the strength of fly ash further. Literature has reported that addition of calcium carbonate can further enhance the strength of stabilized fly ash due to chemical reactions between calcium carbonate and the pozzolanic product formed due to stabilization [9–12]. In a study evaluating the effect of fineness of the different materials in a ternary composite cement, a substantial strength increase was observed after 28 days of curing when combining fly ash and limestone powder compared to only using fly ash [13]. These developments have definitely helped in utilizing fly ash and lime sludge in bulk amount in areas like road construction. It provides an opportunity to use high volume of these industrial wastes as base and sub-base course material and to save the resourceful construction materials.

In this study, a composite material is developed after stabilizing fly ash and lime sludge mix with commercially available lime and gypsum and after thorough testing and investigation it is suggested for use as a road construction material. The optimum design of the mixing formulations, the properties and the strength formation mechanism of this binder are also studied. In addition to that the performance of pavement is also affected due to the variations in the properties of the materials used in different layers and it can also affect the accurate estimation of design traffic load, thickness of various layers for safe design. Studies show that reliability and probabilistic approach can be utilized or implemented in various ways for performance based assessment or design of flexible pavements as well as management of funds for maintenance and rehabilitation work [14,15]. In the present study, probabilistic approach is also utilized to address the issue of uncertainty in assessing the performance of pavement from fatigue and rutting criteria. First order reliability based method along with Monte Carlo simulation through numerical analysis is used for assessing the performance parameter β, popularly known as *reliability index*.

2. Testing programme

2.1. Raw materials

Fly ash was collected from Badarpur thermal power plant, Delhi (Fig. 1). The specific gravity of the fly ash was 2.2, its particle size distribution is illustrated in Fig. 2 and the chemical composition is listed in Table 1. It is observed that the sum of oxides of silicon (SiO_2), aluminium (Al_2O_3) and iron (Fe_2O_3) in Badarpur fly ash is 96% which is more than 70% (minimum limit) as specified by ASTM C618 [3] for class F fly ash. Fig. 3 shows the surface morphology of fly ash and depicts the presence of spherical and smooth particles of various sizes. The various minerals present in fly ash were studied by X-ray diffraction (XRD). The specimens were scanned from $2\theta = 10^\circ$ to 70°. The database of the 2000 JCPDS – International Centre for Diffraction Data was used to identify the mineralogical phases. The crystalline phases present were identified from the peaks in the pattern. XRD pattern of fly ash as in Fig. 4 (a) shows the presence of crystalline phases quartz (SiO_2) and mullite (Fe_2O_3).

The lime sludge (LS) was collected from water softening plant, New Delhi, India (Fig. 1). It was generated from the sedimentation tank and clarifier and contains high water content. Hence, a sludge thickening process was adopted at the plant site to convert the sludge into dry form for better

Fig. 1 – Fly ash and lime sludge used in the present study.