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Stability analyses of submicron-boron mineral prepared by mechanical milling process in concrete roads

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HIGHLIGHTS

- The particle size was reduced to submicron and thus its homogeneity was improved.
- The minimum particle size of C-25 μ was determined as 316 nm.
- Using small amounts of colemanite for smaller sizes increased compressive strength.
- Using high amounts of colemanite for larger sizes enhanced compressive strength.
- The C-25 μ has shown good adherence between cement and concrete aggregates.

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ABSTRACT

The main objective of this study is to investigate the possibility of utilizing nano/submicron sized boron mineral (colemanite) in Portland cement concrete. Colemanite was obtained from a mine in three different sizes as −3 mm (C-3m), −75 μm (C-75 μ) and −45 μm (C-45 μ), respectively. The C-3m was ground by mechanical milling process in a high-energy ball mill and then passed through a 25 μm (C-25 μ) sieve in order to obtain a smaller size/nano sized particles. The material information of these powders was investigated by using laser size analyzer, optical microscopes, and scanning electron microscope analyses. The particle size was respectively reduced for the C-3m, C-75 μ, C-45 μ and C-25 μ and therefore its homogeneity was improved. Five different ratios of Portland cement were used as 0.5%, 1%, 2%, 3% and 5% (wt). For each of rations, the C-75 μ, the C-45 μ, the C-25 μ different particle size colemanite and control samples (0%, no addition) were evaluated and 15 cm × 15 cm × 15cm cubic samples were produced. The fine and coarse aggregates were natural conventional aggregates. As a result, the highest compressive strength and elastic modulus were obtained in case colemanite with sizes C-75 μ and the C-45 μ added into the concrete in ratios 3% and 5%; and colemanite with a size of C-25 μ added into the concrete in ratios 1% and 0.5%, respectively. Since the C-25 μ is close to the ideal size of the cement, it becomes a good adherence by high specific surface area. Nano particle materials are used for their high specific surface area which has a great impact on the hydration. This is the reason why findings it could be observed that C-75 μ and C-45 μ required to be added at high percentage to probably have a concrete with the same mechanical properties as for C-25 μ that required a small percentage of addition.

1. Introduction

For many centuries, concrete is a crucial construction material in the worldwide. Especially on account of pavement engineering, concrete made by Portland cement commonly used. Pavement concrete is generally utilized for airfield, road surfaces, bridge decks and parking lots since the structures often endure repetitive loads when vehicles pass through them. Therefore, the fatigue behavior of concrete in these structures are crucial performance and design parameters [1]. Rigid pavements have some advantages. These are defined as stiffer pavement layer, little bending and distributes load over larger area of subgrade, good durability, long service life, minor variations in subgrade strength, withstand repeated flooding and subsurface water without deterioration (as long as base and/or subgrade are resistant to moisture damage), etc. Essential stress status in the rigid pavement is the max flexural stress taking place in the slab due to the temperature changes and wheel load.

Recently, many studies related to addition used have been conducted in order to improve the structural behavior of concrete. In this study, nano sized boron minerals (colemanite) were evaluated for producing concrete as a rigid pavement material.

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Nanotechnology is a developing research area in the civil engineering and material science [2,3]. Nano particles are used in engineering areas in order to produce stronger materials that offer better physical and mechanical properties than ordinary ones [4,5]. Nano science concerns with measurement and characterization of nano and micro sized structure of cement-based materials to have a better understanding of how this structure affects macro sized properties and performance by the use of advanced characterization techniques [6,7]. Thanks to advantages of nano materials technology, concrete behavior can be improved in terms of superior mechanical performance and durability, adhesive effect in interfacial interactions, self-sensing capabilities, self-cleaning, self-healing, self-control of cracks and high ductility. In this content, conducting studies related to nano sized boron addition in the rigid pavement technology is an innovative approach [8,9].

In our previous study, the performance of boron wastes as filler aggregate in the hot mixture asphalt concrete was investigated. It was concluded that the asphalt mixture produced is suitable to be used as the binder layer especially in the regions with warm climate according to the Technical Specifications of Highways in the Republic of Turkey [10].

It was seen that nano-SiO_2 improves concrete workability and strength and increases resistance to water penetration [11–14]. Nano-SiO_2 was determined to be more efficient in strength. Cement mortar including 10% nano-SiO_2 was observed to be increasing the compressive strength of cement mortars at 28 days by as much as 26% [15] (Fig. 1). Nano-SiO_2 addition both enhance strength value of cement and degrade mortar pozzolanic characteristics.

Some researchers produced concretes, containing polypropylene (PP) fibers and both nano-TiO_2 and PP fibers [16]. In addition to these properties, some studies indicated that nano TiO_2 can retard the early age hydration of Portland cement [17] has high catalytic activity, hydrophilic properties and high surface area that increase the rate of cement hydration process resulting in high compressive strength and less autogenous shrinkage. Relationship between increasing content of nano-TiO_2 and geopolymer compressive strength was examined by some researchers [18]. In agreement with result of the study, the treatment of nano-TiO_2 particles improved the resistance of carbonation and diminished the geopolymer's drying shrinkage.

The analyses showed that the addition of nano-particles can improve the pore structure of concrete and resistance to chloride penetration of concrete may be enhanced. According to a study conducted by Li et al. [19,20], performance of concrete containing nano-particles can improve as compressive as flexural strengths, abrasion resistance and flexural fatigue. According to another study, microstructure and self-sensing properties of mortar can be developed by nano-particles [21,22]. Supit et al. [23] produced concretes containing 2% and 4% of nano-silica (NS). They were prepared at a constant water/binder ratio of 0.4 for testing ages of 3, 7, 28, 56 and 90 days. The concrete containing 2% NS showed similar compressive strength of that containing 4% NS. The compressive strength and durability tests, volume of permeable voids, chloride permeability and porosity were investigated experimentally. Results indicated that the addition of 2% NS improved compressive strength and reduced the water sorptivity. It was also determined that the durability properties of concretes containing 38% fly ash and 2% NS have a better performance compared to control samples.

2. Experiments

2.1. Preparation and characterization of boron mineral

2.1.1. Materials

The raw colemanite materials used in this study were provided from Bigadic Boron Mine of General Management of Eti Mine Works (ETIMADEN). These materials (commercial products) were chosen in three different sizes as initial materials and passed through the sieves in the ASTM standard with a scale of −3 mm, −75 μm and −45 μm, respectively. The first one is the unmilled material (coarse-grained) and the other two are milled materials (fine-grained, i.e., powders). The chemical composition analysis of these materials was performed by ETIMADEN as presented in Table 1 [24,25].

2.1.2. Milling and sieving processes

The mechanical milling was performed at room temperature through a planetary high-energy ball mill (Retsch, model 'PM 100') by using a 250 ml zirconium oxide vial and zirconium oxide balls with a diameter of 5 mm [26]. The raw colemanite material with an initial size of −3 mm was milled for 30 min. Ball to powder

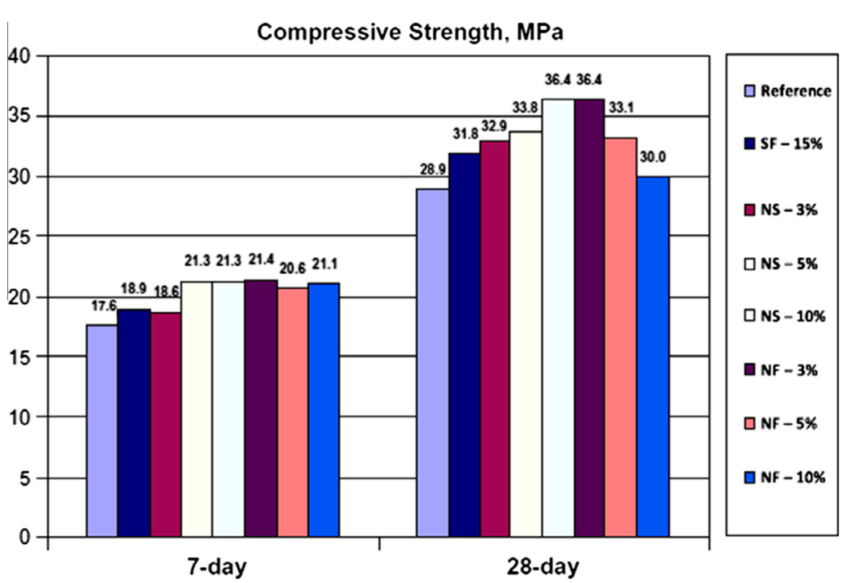

Fig. 1. 7 and 28 days compressive strength values of different sizes Nano-SiO_2 and Nano-Fe_2O_3 [15].