Journal of Scientific & Industrial Research
Vol. 66, December 2007, pp. 1029-1034

Influence of wollastonite on mechanical properties of concrete

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Received 30 March 2007; revised 07 August 2007; accepted 12 September 2007

Studies were made on cement concrete and cement-fly ash concrete mixes incorporating wollastonite as partial substitute of cementitious material and sand respectively. Improvements in compressive (28-35%) and flexural strength (36-42%) at 28 and 56 days respectively were observed by incorporation of wollastonite (10%) in concrete mixes. By incorporation of wollastonite, reduction in water absorption, drying-shrinkage and abrasion loss of concrete, and enhancement in durability against alternate freezing-thawing and sulphate attack were observed. Because of high concrete strength and abrasion resistance, a better utilization of concrete cross section is possible. Alternatively, thickness of pavement slab can be reduced by incorporation of wollastonite micro-fibres in concrete mixes.

Keywords: Drying shrinkage, Durability, Flexural strength, Micro-fibre reinforcement, Wollastonite

Introduction

High performance concrete exhibits only a very small formation of micro-cracks of its maximum stress (up to 80%). Energy is predominantly absorbed elastically and concrete fails very brittle due to sudden release of energy under compressive forces[1]. If pozzolanas like silica fume or metakaolin are included in mixture, strength of interfacial zone and brittleness increases with time but flexural strength decreases significantly as the amount of silica fume in cement matrix is increased (5-20%)[2]. Cement paste matrices reinforced with carbon micro-fibres have very high flexural strength and significant improvement in both pre-peak and post-peak load behaviour is observed[3,4]. Second phase dispersion of high modulus nickel particulates in a brittle cement paste matrix modifies flexural strength[5]. Reduced porosity and toughening mechanism result in strengthening of brittle cement materials. Composite product prepared by mixing asbestos with Portland cement has considerably higher flexural strength than Portland cement.

Wollastonite (Fig. 1) is a naturally occurring, easily available, acicular, inert, white mineral (calcium meta silicate) of high elastic modulus and its fibres are less expensive than steel or carbon micro-fibres. Wollastonite micro-fibres (WMFs: length, 0.4-0.6 mm; diam, 25-150 μ) are very fine fibres (aspect ratio 3:1-20:1) and used in many synthetic and ceramic products as micro-fibre reinforcement. Incorporation of wollastonite[6] enhances flexural strength and modifies pre-peak and post-peak load behaviour of hydrated cement and cement-silica fume system.

This study evaluates compressive and flexural strengths and other properties of concrete mixes with different proportions of wollastonite as partial substitute of cementitious material (cement and fly ash) and sand for paving applications.

Materials and Methods

Materials

Cement (53 grade OPC), blue quartzite (sp gr, 2.62; size, 20 mm) and sand (sp gr, 2.60; fineness modulus,

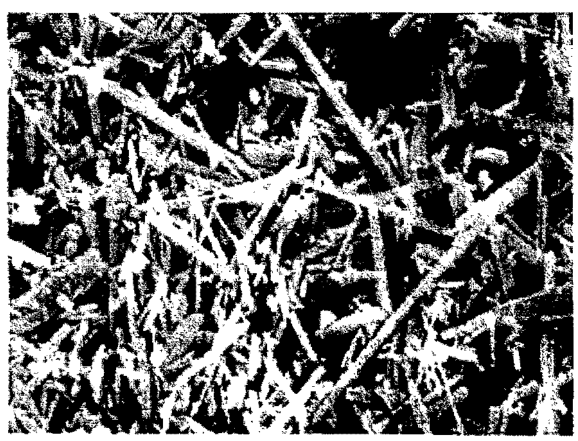

Fig. 1—Wollastonite mineral fibre, 1700X

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2.60) were used. Fly ash was collected from electrostatic precipitator of Thermal Power Plant, Dadri, India. WMF (NAYAD-400; aspect ratio, 3:1) was supplied by Wolkem India Ltd. Uaidpur, India. Physico-chemical properties of wollastonite are as follows: brightness (against 100% MgO), 76.60; moisture content, 0.10%; bulk density, loose, 0.60 g/ml & tapped, 0.89 g/ml; sp gr, 2.9-3.1; hardness, 5-5.5; modulus of elasticity, 200 GPa; and CaO, 45.60; SiO_2, 48.00; Fe_2O_3, 0.60; Al_2O_3, 1.40; and loss on ignition, 4.40%. Super plasticizer (Conplast SP 430 G8) was purchased from FOSROC chemicals (India) Pvt Ltd.

Mix Design and Tests

Cement concrete mix design was done as per IRC: 44-1976 and IS: 10262-1982 for 420 kg/cm^2 compressive strength at 28 days for a compacting factor (CF) of 0.85 (control mix). Cement - fly ash concrete mix design was done as per IRC: 68-1976. Workability of concrete mixes was determined by CF test as per IS: 1199-1959. Superplasticizer (0.6-0.8 % by wt of cement) was used for the required workability of mixes incorporating wollastonite as partial replacement of total cementitious material and sand.

Preliminary work was conducted with several wollastonite samples having different fineness, aspect ratio and chemical coatings to study their effect on workability, compressive strength and flexural strength of concrete. Mixes incorporating fly ash as partial replacement of cement and wollastonite (NAYAD-400) as partial substitute of total cementitious material and of sand were designed and studied. Concrete mixes selected for detailed laboratory study were: A) control mix; B) 20% cement replaced by fly ash; C) 20% cement replaced by fly ash and 10% of total cementitious material replaced by wollastonite; D) 20% cement replaced by fly ash and 10% sand replaced by wollastonite; and E) 10% sand replaced by wollastonite. Cube (10 cm x 10 cm x 10 cm) and beam (10 cm x 10 cm x 50 cm) specimens prepared for various tests were cured (90% humidity) for 24 h and then soaked in water for desired periods before testing.

Compressive and flexural strengths were determined after 7, 28 and 56 days, and 28 and 56 days of soaking respectively. To determine water absorption, 28 day soaked concrete cube specimens from each set were weighed in surface dry condition and then dried in electric oven at 110±1°C for 24 h. The loss in weight of specimen was determined and water absorption was expressed as percent loss in weight of the specimen. Drying shrinkage of concrete beam specimens (30 cm x 7.5 cm x 7.5 cm) was conducted as per IS: 1199-1959.

Abrasive resistance characteristics of concrete under physical effects were determined as per IS: 9284-1979. The test was conducted on 28 day soaked cube specimens from each set. Pneumatic sand blasting cabinet equipment was used and the abrasive charge used was Ennore sand driven by air pressure. Abrasion loss of specimen was taken as the percentage loss in mass (g) for two separate impressions on the same face of cube under test. To assess the durability of concrete, cube specimens from each set after 28 day soaking were subjected to two sets of durability cycles (freezing-thawing and immersion in sodium sulphate solution).

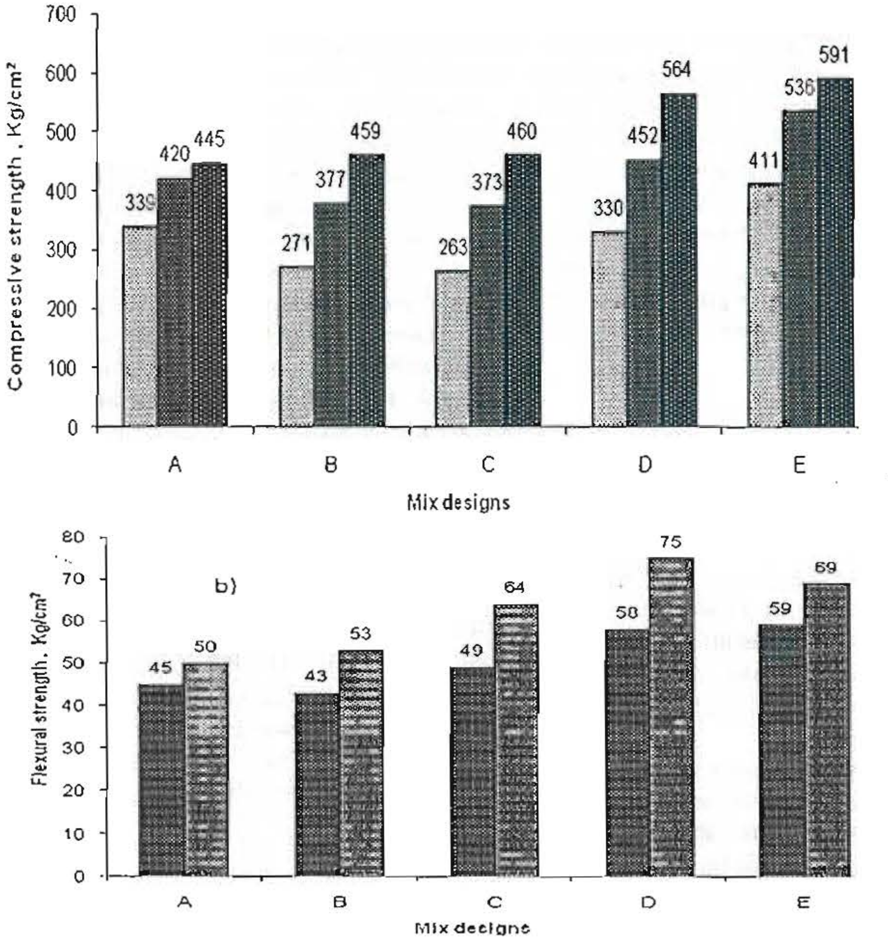
Freezing-thawing cycle comprised of freezing specimen at -10 ± 2°C for 6 h in an environmental chamber and thawing in air at 27 ± 2°C for 18 h. Immersion in sodium sulphate solution consisted of immersion of test specimen in sodium sulphate (5%) solution for 18 h and drying in air at 27 ± 2°C for 6 h.

Test specimens were subjected to 30 such cycles and then compressive strengths were determined. Results were compared with the compressive strength of corresponding samples continuously cured in water up to 56 days.

Results and Discussion

Compressive and Flexural Strength Properties

Control mix A was designed for 420 kg/cm^2 compressive strength at 28 day for a CF of 0.85 with the available materials (cement, sand and aggregates). Incorporation of fly ash made concrete mix more workable while wollastonite decreased workability of mixes and necessitated the use of plastisizer. Comparing strength results of control mix A with that of cement-fly-ash concrete mix B, there was reduction in 28 day compressive and flexural strengths. Thereafter at 56 day, due to pozzolanic action of fly ash, both compressive and flexural strengths were at par with the control mix (Fig. 2). In mix C, there was no significant reduction in compressive strength, but increase (14-20%) in 28 and 56 day flexural strength were observed. Comparing mix D with mix B, there was gain (28-35%) in 28 and 56 day compressive strength and increase (36-42%) in 28 day and 56 day flexural strength. In mix E, there was gain (32 %) in 28 day compressive and increase (37%) in flexural strength at 56 day.



A = Control mix; B = 20% cement replaced by fly ash; C = 20% cement replaced by fly ash and 10% cementitious material replaced by wollastonite; D= 20% cement replaced by fly ash and 10% sand replaced by wollastonite; E=10% sand replaced by wollastonite

Fig. 2—Strength properties of various mixes; a) Compressive strength (7, 28 & 56 day soaking); and b) Flexural strength (28 & 56 day soaking)

Improvement in compressive strength of concrete by incorporation of wollastonite can be attributed to the modification in microstructure of transition zone in the vicinity of wollastonite. Inclusions have an effect on pore distribution and large increase of pore volume (0.5-0.1 μm) has been reported by addition of wollastonite in cement matrix. Multiple cracking of cement matrix in post-peak load region and fibre pullout from fractured surface were regarded as the cause of improved ductility and flexural strength of cement matrix reinforced with WMFs. Increase in flexural strength can also be attributed to high modulus of elasticity (200 GPa) of wollastonite[6].

Other Properties

There was reduction in water absorption on incorporation of wollastonite in concrete mixes (Fig. 3a). WMFs promote pore discontinuity in cement system resulting in reduced water absorption. Inkbottle shape pores, which are inaccessible to fluids at normal pressure, are formed by inclusions like wollastonite[7]. Drying shrinkage value of concrete mix C having minimum cement content is the lowest. However, there was reduction in drying shrinkage on incorporation of wollastonite in mix E having the same cement content as A (Fig. 3b). Microstructure features of cement matrix components of the exposed surfaces determine abrasion

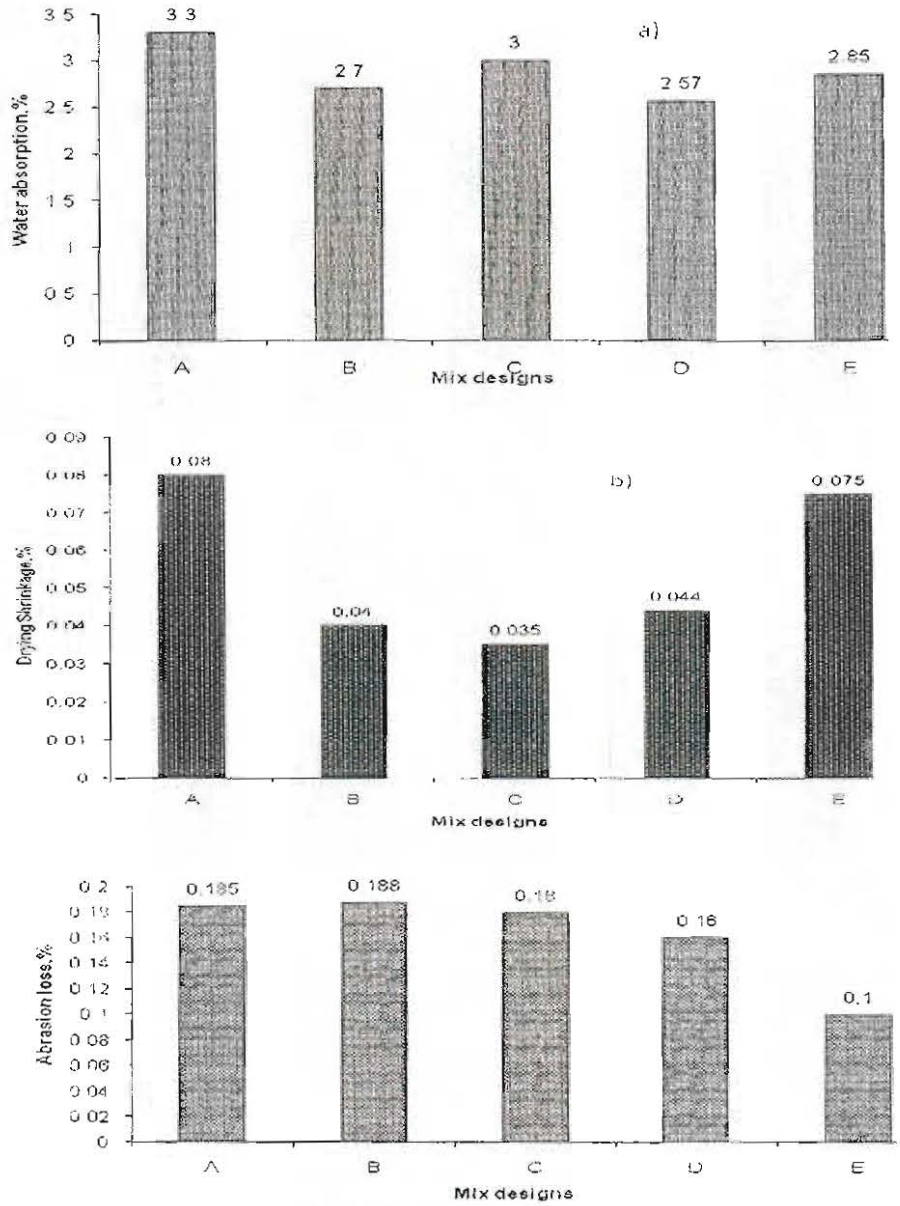


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Fig. 3—Other significant properties of various mixes: a) Water absorption; b) Drying shrinkage; c) Abrasion loss

resistance[8], which is largely determined by pore structure of surface zone. Since pore structure is significantly modified by WMFs, abrasion loss of concrete mixes decreases as compressive strength increases. Mix E, having highest compressive strength, has lowest abrasion loss (Fig. 3c).

Processes associated with transition zone formation in the vicinity of WMFs affect deposition of cement reaction products in this region. Wollastonite inclusion can affect rate and extent of hydration of cement in addition to CH formation and matrix permeability. CH reduction in the matrix due to its deposition at interfaces

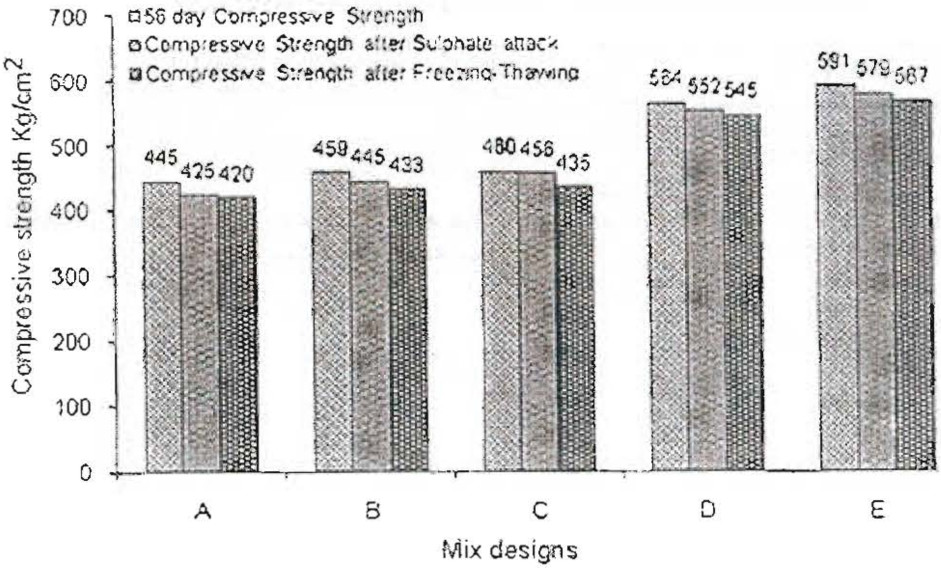

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Fig. 4 – Effect of sulphate attack and freezing-thawing cycles

can reduce permeability of the body and access to cement grains by water. This may result in limited hydration relative to mixes without wollastonite and can account for increased porosity[9,10].

Resistance of concrete against sulphate attack and freezing-thawing was determined as residual compressive strength. On comparing residual strengths with corresponding strength of continuously water cured specimens, it was observed that excepting residual strength in the mixes A (94%) and B (95%), all other mixes incorporating wollastonite had residual strength more (98%), showing increased durability of these mixes (Fig. 4). Increase in durability can be associated with decrease in permeability of the system due to formation of discontinuous pores. Absorption of fluids (water/ sulphate water) is restricted making concrete resistant to sulphate attack. Also, increased porosity of the matrix on wollastonite inclusion is likely to accommodate frozen water (ice) without development of stresses in concrete. Thus sequence of interactions within the matrix leads to unique pore size distribution by incorporation of wollastonite that can provide a mix capable of resisting many forms of chemical and physical attack.

Conclusions

WMFs improve compressive strength and abrasion resistance of concrete. Significant improvements in flexural strength, observed by substitution of sand (10%) in cement and cement fly-ash concrete by wollastonite can be used in reducing slab thickness of concrete pavements. There is reduction in water absorption and drying shrinkage of concrete by wollastonite incorporation. Improvement in durability of concrete against sulphate attack and alternate freezing-thawing are observed. WMFs improve inherent tensile properties of concrete whereby not only the reinforcement is provided to concrete member but also the mix properties are so improved as to resist any adverse chemical and physical attack to a great extent.

Acknowledgements

Authors thank Wolkem India Limited, Udaipur, India for financial support and Ms Madhurima Sharma and Mr Ashok Pant for assistance in experimental work.

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