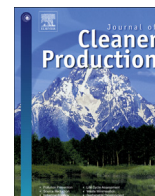




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## Durability studies on concrete containing wollastonite

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## ABSTRACT

Depletion of natural resources and emission of carbon dioxide are the major factors associated with cement production. Also, conventional concrete often fails to prevent the ingress of moisture and aggressive ions adequately. The concern for concrete durability surfaced globally by the time the structures built with high grade concretes started yielding to distress. Several materials such as fly ash, metakaolin, silica fume, stone waste, rubber tyre, slag, wollastonite etc. which are either industrial wastes or natural minerals, have been examined to make durable concrete. Among the various admixtures studied in the past, the effect of wollastonite on concrete has not been investigated in detail. Wollastonite is a calcium meta-silicate (CaSiO<sub>3</sub>) mineral with particles similar to cement particles by size. In the present investigation, eighteen concrete mixes at three w/b ratios (0.45, 0.50 and 0.55) were prepared, by substituting Portland cement with wollastonite at varying replacement levels (0–25%). Substitution of 10–15% cement by wollastonite resulted in improved strength and durability of concrete. SEM and MIP results indicated that substitution of cement by wollastonite upto 15% reduced porosity and densified the concrete microstructure.

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## 1. Introduction

Investment in the field of infrastructure development has increased manifold due to growing economy. Huge amount of concrete is being used for building infrastructure including dams, bridges, under water structures, roads and buildings. Portland cement is the key ingredient in concrete products and it is considered as one of the most important infrastructure building materials around the world. Portland cement production is accompanied by the release of similar amount of carbon dioxide as a by-product, which is major concern worldwide and is a primary factor in the “green house” effect. According to Pathak (2009), the Indian construction industry currently consumes about 400 Mt concrete every year, which is predicted to reach 1000 Mt in less than a decade. The country's annual Portland cement production is about 100 Mt which is expected to be doubled by 2020 at an annual growth rate of 10%.

Construction industry spends a huge amount of money on concrete structures every year and these structures deteriorate at a pre-matured stage due to their poor long term sustainability. It is estimated that a substantial share of the expenditure in construction industry is spent on repair, maintenance and rehabilitation of existing structures. On the one hand, the production of cement depletes natural resources, resulting in air, water and soil pollution. On the other hand, conventional concrete does not last for long. There are several factors affecting its durability.

The main factors affecting the durability of concrete are permeability, occurrence of micro-cracks in the concrete due to heat of hydration of cement and related stresses, carbonation, chloride ingress and corrosion. These can be controlled by restricting the movement of moisture in the concrete (fineness, indirectness of path, discontinuity etc.). Properties of concrete can be modified by the use of supplementary cementitious materials (SCMs), commonly used as an addition to Portland cement concrete mixtures to enhance the long term strength and durability properties and in some cases to reduce the material cost of concrete.

With addition of SCM in concrete it is possible to have a favourable influence on many properties through either purely physical effect associated with the presence of very fine particles or through physico-chemical effects associated with mineral

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admixture reactions, which results in modification of the pore structure. Utilisation of SCM in concrete not only improves its strength and durability but also makes it cost effective and environmentally sustainable. The sustainability of cement production means utilising less natural resources and reducing the emission of polluting gases (Li et al., 2014). Yang et al. (2014) observed that the substitution of 15–20% OPC by SCMs resulted in sharp decrease of CO<sub>2</sub> emission associated with OPC production. In a similar study, Blankendaal et al. (2014) reported that environmental impact due to cement production can be reduced upto 39% by utilising SCMs such as fly ash and blast furnace slag in concrete mixes. Available literature suggests that various waste and natural minerals such as fly ash, rice husk ash, blast furnace slag, silica fume, metakaolin, stone dust, wollastonite etc. can be incorporated as SCM in concrete mixtures. Wollastonite has a theoretical composition of up to 50% calcium oxide and up to 55% silicon dioxide along with some traces of aluminium, iron, magnesium, manganese, potassium and sodium. Moreover, particle size of wollastonite is also nearly similar to that of cement. However, the effect of wollastonite on concrete has not been investigated in detail.

The Table Spar and Tabular Spar were the early common names for wollastonite. In the late 17th century, Sir William Hyde Wollaston (1766–1828), an English chemist and mineralogist brought to the attention of the scientific community, the mineralogical peculiarities and uniqueness of Table Spar. In 1822, Dr. A. Haüy proposed the name “Wollastonite” in honour of Wollaston's work (Minerals Zone, 2014). Wollastonite occurs as bladed crystal masses, single crystals show an acicular particle shape and usually it exhibits a white colour but sometimes cream, grey or very pale green. Its specific gravity is 2.9 and hardness on Mohs scale is between 4.5 and 5.0 (Nycoco Minerals Inc., 2014).

The large reserves of wollastonite are in China, India, Finland, Mexico, Spain, United States, Australia and South Africa, which account for most of the global wollastonite production. Significant wollastonite resources were also found in Canada, Chile, Kenya, Namibia, Sudan, Tajikistan, Turkey and Uzbekistan. World production data for wollastonite is not available for many countries. Estimated world production of crude wollastonite ore was in the range of 530,000–550,000 t in 2010. Sales of refined wollastonite products probably were in the range of 450,000–490,000 t in 2010 (Virta, 2011). India and China are the leading producers of wollastonite in the world (Brown et al., 2005–2009). Table 1 shows the chemical composition of wollastonite found in various countries. Large deposits (56 Mt) of wollastonite are found in Sirohi, Pali and Udaipur districts of Rajasthan, India.

Wollastonite is available in aspect ratios of 3:1 to 20:1 and also modified with varying coating chemicals and coating levels as per the requirements for different applications. It is fibrous in nature (Fig. 1). The applications of wollastonite, include its use in ceramics (wall tiles and dinnerware), glazes, friction products (brakes and

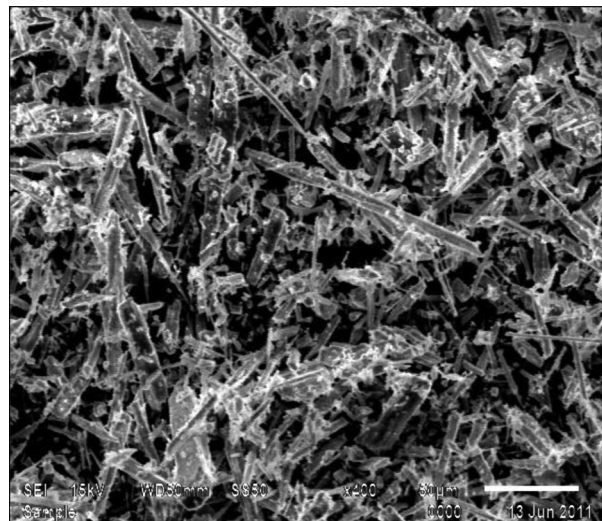


Fig. 1. SEM micrograph of wollastonite particles (400×).

clutches), metallurgy, paint, plastics and rubber, substitute for asbestos in floor tiles, adhesives, joint compounds, rubber and wallboard applications. Due to its high thermal shock resistance and low coefficient of expansion up to 20% wollastonite can be included in ceramic bonded abrasives, particularly wheels and stones. Wollastonite may replace limestone and sand in fibre glass to improve the surface (Crooks, 1999). Wollastonite is a unique among non-metallic industrial minerals for its combination of white colour, acicular crystal shape and alkaline pH (Peter and Sara, 2002). Alkaline pH is one of its most important properties responsible for improving corrosion resistance. Flexural strength characteristics of cement–wollastonite and cement–silica fume–wollastonite system reinforced with wollastonite between 2 and 15% by volume of cement were studied by Low and Beaudoin (1992). A small increase in flexural strength was observed as the hydration period increased from 7 d to 28 d. Flexural toughness of cement–wollastonite composites increased linearly with increasing wollastonite content whereas the toughness of cement–silica fume composites decreased as silica fume content was increased (Low and Beaudoin, 1993a,b,c). In another study, Colin et al. (1999) observed improvement in flexural strength when wollastonite was used in combination with materials, such as fly ash and silica fume. In a study conducted by CRR (2004), wollastonite was used as a partial replacement of cement, sand or both. Improvement in flexural strength was observed with incorporation of wollastonite in concrete. Low and Beaudoin (1993a,b,c) examined the effect of wollastonite's aspect ratio on parameters of cement composites. Flexural strength and porosity of composites were not affected by it. However, pore volume, pore size, ductility and flexural toughness of cement matrices were influenced by the aspect ratio. Compressive strength of concrete containing wollastonite decreased at each w/b ratio (Misra et al., 2009). However, Yog (2010) found that the compressive and flexural strengths increase up to 15% replacement of cement by wollastonite in comparison to the control mix. The optimum content of wollastonite and silica fume improved flexural strength, ductility, microstructure and promoted pore discontinuity of hydrated cement and cement–silica fume matrices (Low and Beaudoin, 1993a,b,c). In a recent study, Soliman and Nehdi (2014) observed that incorporation of wollastonite in concrete mixes improved early age compressive strength and promoted pore discontinuity, which in turn led to less drying shrinkage of ultra high performance concrete.

**Table 1**  
Chemical composition (%) of wollastonite from several countries.

Component	Finland	USA	India	Kenya	Mexico	China
SiO <sub>3</sub>	52.00	51.00	49.00	55.00	52.00	46–53
CaO	45.00	47.00	48.00	42.00	47.00	43–50
Al <sub>2</sub> O <sub>3</sub>	0.40	0.30	0.70	0.10	0.50	0.3–0.4
Fe <sub>2</sub> O <sub>3</sub>	0.20	0.60	0.40	0.07	0.20	0.1–0.2
TiO <sub>2</sub>	max. 0.05	0.05	Traces	0.01	0.06	NR
MnO	max. 0.01	0.10	0.10	0.01	0.40	NR
MgO	0.60	0.10	0.06	0.80	0.08	0.20
Na <sub>2</sub> O	0.10	NR	0.02	0.04	0.02	NR
K <sub>2</sub> O	0.01	NR	0.1	0.04	0.04	NR

max: Maximum; NR: not reported.

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