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# Wollastonite Mineral Fibre in Manufacturing of an Economical Pavement Concrete

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## ABSTRACT

This research study presents extensive laboratory work carried out to explore the use of wollastonoite mineral fibre (WMF) in the manufacturing of an economical pavement concrete. Wollastonite is a naturally occurring mineral micro fibre. In this study, wollastonite mineral fibre was used to replace 10% and 20% of sand while fly ash was used to replace 20% of cement of the control concrete. The influence of the addition of WMF and the combination of WMF and fly ash on the fresh as well as hardened state properties of concrete mixtures was evaluated. The fresh properties of concrete that is the slump and fresh density and hardened state properties i.e. compressive strength, flexural strength, and abrasion resistance of concrete mixtures were determined. The study suggets that the addition of WMF significantly reduces the slump of concrete mixes but increases the density, the compressive, and flexural strength of concrete. It further shows that the combination of fly ash and WMF (fly ash as a replacement of cement and WMF as a replacement of sand) has an synergic effect on the enhancement of flexural strength which gives a possibility to reduce concrete pavement slab thickness such pavement is more economical and durable than that constructed with conventional concrete.

## INTRODUCTION

The last few decades, have remained very active research field for using supplementary cementitious materials and other additives such as minerals, admixtures, fibres, etc. to enhance strength, durability, and other properties of concrete. Concrete possesses sufficient compressive strength but weak in tension which could be overcome by adding suitable metal, mineral or synthetic fibres but the addition of these materials adds to the cost besides requiring specialized handling. A very limited study [Kumar 2015; Soliman and Nehdi 2012; Mathur et al. 20007; Norman and Beaudoin 1993, 1994; Xiao et al. 2013, Zhang 2013] has shown a great potential for wollastonite mineral micro fibre for these purposes. Wollastonite mineral fibre (WMF) is a calcium inosilicate mineral ($CaSiO_3$) that may contain small amount of iron, potassium, sodium and magnesium. It is gray to white in color. It forms when unclean limestone is subjected to high temperature and pressure. Some of the properties that make it useful for cement based materials include its high brightness and whiteness, low moisture absorption, low volatile content, high elastic modulus, low coefficient of thermal expansion, and inertness. There are two main components in WMF, CaO and $SiO_2$. In general, it is finding growing acceptance as a source of micro reinforcing fibres and fillers in various types of industrial applications such as ceramic, construction materials, paint and coating, metallurgy, and frictional materials etc. In the construction industry, wollastonite is finding growing acceptance in many types of products including cement mortar and concrete. In addition to providing improved strength and dimensional stability, the use of wollastonite in construction products also offer other important advantages such as improved weather resistance, a greater resistance to structural damage such as scratches, cracks etc. The potential of using wollastonite microfiber as a natural material to improve properties of concrete along with achieving lower environmental impact and lower investment cost was investigated. Wollastonite microfibers were reported to act as a local restraint for shrinkage (Soliman and Nehdi 2012). Previous studies [Mathur et al. 20007; Norman and Beaudoin 1993, 1994; Xiao et al. 2013, Zhang 2013] have shown the potential for using natural wollastonite microfibers as a reinforcing material in cementitious materials. The addition of wollastonite in cement-silica fume matrices showed significant improvements in pre-peak and post-peak load, flexural toughness and ductility. Moreover, wollastonite microfibers imbedded in cementitious materials achieved high stability without surface or bulk deterioration with time. A study by Mathur et al. 2007, has showed that use of wollastonite as partial replacement of sand can enhance the strength and durability of concrete. However, very little work has been done to use this material in the construction of road. Therefore, the study presents the results of an extensive study carried out for the use of WMF in the construction of concrete pavements. Further, the study also explores the possibility of a reduction in the thickness of concrete pavement slab.

## EXPERIMENTAL INVESTIGATION

The experimental program included testing of materials, development of trial mixes, preparation of specimens, and testing of concrete for the evaluation of the important properties in fresh as well as hardened states. Fresh properties of concrete that is the slump and fresh density as well as hardened state properties such as compressive strength, flexural strength, and abrasion resistance of concrete with and without WMF were evaluated. In this study, WMF was used to replace 10% and 20% of concrete sand by volume. In order to make concrete economical, fly ash was used to replace 20% of cement by volume.

**Materials.** An ordinary portland cement, well graded crushed quartzite coarse aggregate of nominal maximum size 20 mm and important physical properties as shown in Table 1, land quarried concrete sand (specific gravity, 2.66; percent water absorption, 0.16; fineness modulus, 2.39; and silt content, 3% by volume), and a polycarboxylate ether-based high range water reducing agent (HRWRA) were used. The wollastonite mineral micro fibre supplied from Wolkem India. The WMF (Figures 1 and 2) has physico-chemical properties as shown in Table 2. A class F fly ash with 32% retained on the 45 micron sieve and specific gravity 2.4 was used as a replacement of cement. The lime reactivity of fly ash was 5.1 MPa. Potable water available in CRRI laboratory was used for the mixing and curing of the concrete mixes.

**Table 1. Physical Properties of Coarse Aggregate**

| Properties | Measured value | Permissible value as per IS:2386 Part III & Part IV, 1963 |
|---|---|---|
| Specific gravity | 2.72 | -- |
| Aggregate impact value (%) | 13.8 | Not more than 30 % for wearing course and not more than 45 % for non-wearing course. |
| Aggregate crushing value (%) | 26.9 | Not more than 30 % for wearing course and not more than 45 % for non-wearing course. |
| Aggregate abrasion value (%) | 26.0 | Not more than 30 % for wearing course and not more than 50 % for non wearing course. |
| Bulk density (gm/cc) | 1.55 | -- |
| Water absorption (20 mm) | 0.42 | Less than 2 % |

**Table 2. The Physico-chemical Properties of Wollastonite (Mathur et al. 2007)**

| Typical properties | Values |
|---|---|
| Appearance | White |
| Shape | Acicular |
| Length | 0.4 – 0.6 mm |
| Transverse dimension | 25 µm - 150µm |
| Aspect ratio | 3:1 – 20:1 |
| Coefficient of expansion ( mm/mm/˚C ) | $6.5 \times 10^{-6}$ |
| Specific Gravity | 2.9 |
| Water solubility (g/100 cc) | 0.0095 |
| pH | 9.9 |

**Figure 1. Wollastonite Mineral Fibre (WMF)**

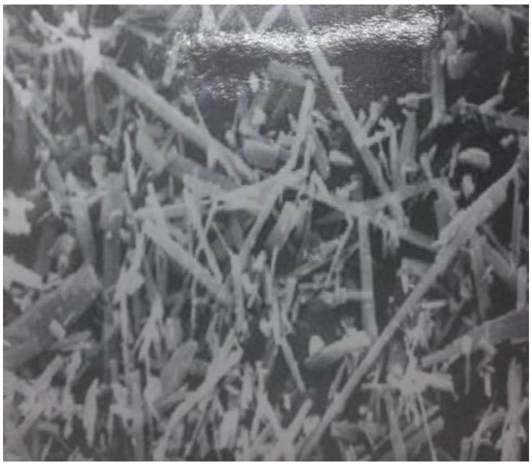

**Figure 2. Micro graph of WMF (1700x)**

**Concrete mix designation and mix proportions.** Five concrete mixes were used in this study. The concrete mix was targeted to have M30 strength. The mix design of concrete was developed according to IS- 10262: 2010. After obtaining the control mix, WMF was used as a replacement of sand (10% and 20% by volume) while fly ash was used to replace 20% of portland cement. Table 3 presents concrete mix designations. Table 4 presents mix proportions detail of concrete mixes.

**Table 3. Concrete Mix Designations**

| Mix Designation | Description |
|---|---|
| M | Control concrete |
| MW1 | 10% sand by volume was replaced by WMF |
| MW2 | 20% sand by volume was replaced by WMF |
| MW1F | 10% sand was replaced by WMF and 20% cement by was replaced by fly ash |
| MW2F | 20% sand was replaced by WMF and 20% cement by was replaced by fly ash |

**Table 4. Mix Proportions for Concrete Mixes**

| Description | Concrete Mix | | | | |
|---|---|---|---|---|---|
| | M | MW1 | MW2 | MW1F | MW2F |
| Cement, kg | 375 | 375 | 375 | 300 | 300 |
| Wollastonite,kg | - | 83 | 168 | 83 | 166 |
| Fly ash, kg | - | - | - | 59 | 59 |
| Sand, kg | 710 | 639 | 568 | 638 | 638 |
| Coarse aggregate, kg | 1183 | 1183 | 1183 | 1183 | 1183 |
| Water, kg | 165 | 165 | 165 | 165 | 165 |
| HRWRA, l | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |

**Mixing and specimens preparation.** Mixing and concrete specimens' preparation was done as per standard procedure. During mixing, first of all, coarse aggregate followed by sand was put in a tilted drum type mixer. Then cement and fly ash and/or WMF were added in the mixture. The materials were mixed in dry state for a few seconds. Then two third of the water required was added to the mix and mixing was continued for another two minutes. At the final stage of the mixing the remaining 1/3$^{rd}$ water containing high-range wáter reducing agent (HRWRA) was added to the mix and mixing was further continued for 4-5 minutes before evaluation of the fresh properties of concrete mix. The standard specimens i.e. cubes of dimension 150 mm x 150 mm x 150 mm were cast from each concrete mix for the evaluation of compressive strength. Beam specimens with the dimension 100 mm x 100 mm x 500 mm were cast for the determination of flexural strength of the mixes. 100 mm cubes were cast for the evaluation of abrasion resistance and water absorption of the concrete mixes. These specimens were demolded after 24 hours of casting and curing in steel moulds. Thereafter, the specimens were marked for their identification and kept submerged in curing tanks at room temperature (27˚±2˚C) till the age of testing.

**Testing of concrete.** The slump of concrete mixes was determined by using Abrahm's slump cone method. The fresh density of concrete was determined by just dividing the mass of the concrete filled in 150 mm cubes and 150 mm x 300 mm cylinders by their respective volume after the compaction of the concrete mix.

Hardened concrete properties i.e. compressive and flexural strength of concrete mixes were determined as per IS: 516 -1956, while the abrasion resistance was determined as per IS: 9284-1979. The overall durability of concrete was assessed by water absorption test. Abrasion resistance was determined on 100 mm cube specimens. Abrasion resistance of concrete is one of the important parameters to measure durability of the concrete pavements. Deterioration of concrete pavement surface may occur due to abrasion by sliding, scraping, percussion or action of abrasive materials carried by water and vehicular movement. Abrasion loss of concrete is used to determine its abrasion resistance. The sand blasting method as per IS: 9284 -1979 is used for this purpose. This method determines the abrasion resistance of concrete under physical effects only by subjecting the cube of 100 mm to the impingement of air-driven silica sand. Silica sand passing through 1.00 mm IS sieve and retained on 0.50 mm IS sieve was used for determination of abrasion resistance of concrete. In this method (Figure 3), abrasive charge of 4000 gm impinged with a pressure of 0.14 N/mm² on the side faces of the cube. The loss in mass in grams for two separate impressions on the same face of the concrete cube was taken as the abrasion loss.

**Figure 3. A Concrete Specimen under Abrasion Testing**

Water absorption by concrete specimen is used to know its overall durability. Durability of a concrete depends largely on the rate of the movement of aggressive ions within it. In order to estimate water absorption rate by concrete mixes, 100 mm concrete cubes were kept in oven for 48 hrs at a temperature of 100±5 $^{o}$C to make them complete dry. Thereafter, cubes were submerged in water. The level of water was kept just above the top surface to avoid the pressure and then the cubes were weighed at different time interval such at 5 min, 10 min, 20 min, 30 min, 1hr, 24 hr. to determine the water absorption rate of concrete mix at different time interval.

## RESULTS AND DISCUSSIONS

**Fresh properties of concrete.** The workability or consistency of fresh concrete mixes is measured in the term of slump. Table 5 presents the effect of the addition of WMF and the combination of WMF and fly ash on the slump and fresh density of concrete mixes.

**Table 5. Effect of the Addition of WMF on Fresh Properties of Concrete**

| Concrete mix | Slump of concrete (mm) | Fresh density (kg/m$^3$) |
|---|---|---|
| M | 50 | 2435 |
| MW1 | 30 | 2445 |
| MW2 | 20 | 2460 |
| MW1F | 30 | 2430 |
| MW2F | 15 | 2450 |

The table shows that the slump of the concrete mixes reduces drastically with replacement of sand by WMF. As the amount of WMF increases the slump further decreases. This reduction in slump of concrete is due to a large increase in the specific surface area of wollastonite micro fiber in comparison to that of sand. Furthermore, the increased internal flow resistance of WMF due to acicular shape and high aspect ratio of WMF might be responsible for the reduction in the slump. But the combination of WMF and FA appears to have a lesser effect on the reduction in slump than only WMF. It is also obvious from the table that the fresh density of concrete mix increase with the increase in the addition of the wollastonite natural mineral fibre as a replacement of sand, which is mainly due to a better packing and higher specific gravity of wollastonite.

## Hardened properties of Concrete

**Compressive strength.** The average compressive strength obtained on triplicate specimens of concrete mixes at 7 days, 28 days and 56 days are presented in figure 4.

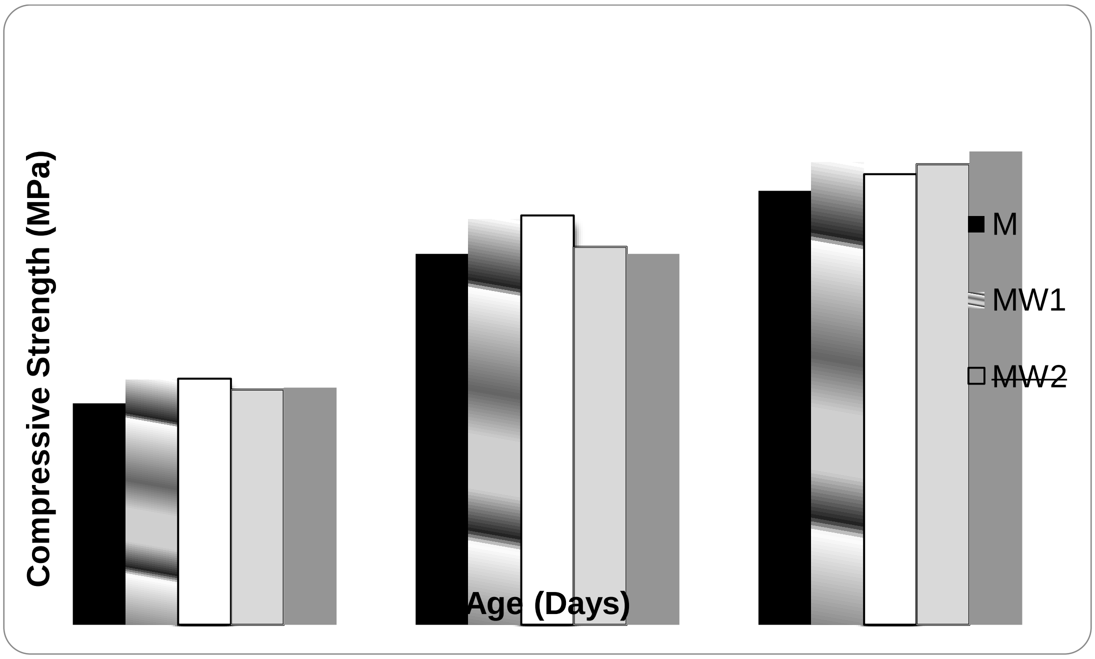


**Figure 4. Compressive Strength of Concrete Mixes**

It can be seen from Figure 4 that the addition of WMF increases the compressive strength of concrete (MW1, MW2) in comparison with control concrete (M), irrespective of the test ages. Further, it can be noticed that the 10% and 20% addition of wollastonite fibre as a replacement of sand has similar effect. However, in comparison with control the addition of wollastonite fibre as a replacement of sand enhances the compressive strength in the range of 26-33%. The improvement in compressive strength of concrete by incorporation of WMF is due to the modification in the microstructure of transition zone in the vicinity of wollastonite micro fibre besides densification of the microstructure. The finer size of the WMF is responsible for a significant increase in smaller size pore volume.

The concrete mixes containing combination of 10% wollastonite fibre and 20% fly ash (MW1F) and 20% wollastonite fibre and 20% fly ash (MW2F) have developed compressive strength similar to that of the control mix (M) at 7-day but slightly higher at later ages. Therefore, for the production of an economical concrete MW1F should be preferred as this contains 20% less cement and only 10% sand replacement by WMF. The improvement in compressive strength of concrete by the combination WMF and FA is due to the modification in the microstructure of transition zone in the vicinity of wollastonite micro fibre besides densification of the microstructure and further contribution in the same by the pozzolanic effect of fly ash.

**Flexural strength.** The development of flexural strength by concrete mixes is shown in figure 5. The increese in flexural strength of concrete mixes containing WMF and the combination of WMF with fly ash ranges from 20% to 30% with reference to controlled ones. Mix MW1F has developed about 27% more flexural strength at 28-day tan the control concrete. Mix MW2F has also developed similar flexural strength. Improved microstructure, acicular shape of WMF, improved interlocking between the particles of concrete and a higher modulus of elasticity (200 GPa) of WMF may be responsable for this increase in the flexural strength of concrete.

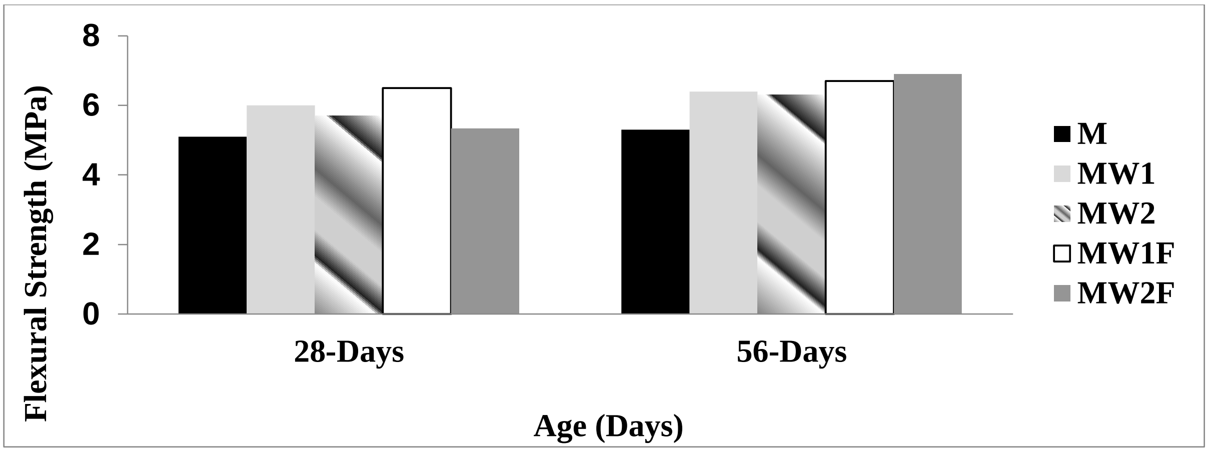


**Figure 5. Flexural strength of concrete mixes**

From economy point of view, MW1F is more economical than MW2F.

**Abrasion resistance.** The abrasion resistance of concrete mixes was determined by knowing the loss in mass of cubes at 28 days under abrasion test by sand blasting method. The results obtained are shown in Table 6.

**Table 6. Abrasion resistance of concrete of mixes**

| Concrete Mix | % loss in mass of concrete |
|---|---|
| M | 0.054 |
| MW1 | 0.041 |
| MW1F | 0.035 |

It is obvious from the table that there is a significant reduction in abrasion loss for concrete mixes containing WMF and the combination of WMF and FA in comparison with control concrete mix. The increase in strength and denser micro structure of concrete may be responsible for this improvement in abrasion resistance of concrete. The microstructure features of the mortar matrix components of the exposed surfaces determine abrasion resistance [Low and Beaudoin 1992; Feldman 1986] which is largely determined by the pore structure of surface zone of concrete, the combination of WMFand fly enhances the pore structure resulting in improvement in the abrasion resistance of concrete.

**Water absorption.** The rate at which water is absorbed by concrete determines its overall durability. Therefore, the water absorption test was performed to determine the overall durability of concrete containing WMF and a combination of WMF and fly ash besides control concrete mix. Table 7shows the water absorption rate of concrete mixes.

**Table 7. Rate of Water Absorption by Concrete Mixes**

| Concrete Mix | Rate of water absorption, % | | | | | |
|---|---|---|---|---|---|---|
| | 5 min | 10 min | 20 min | 30 min | 1 hr | 24 hr |
| M | 0.7 | 0.9 | 1.2 | 1.4 | 1.9 | 4.5 |
| MW1 | 0.6 | 0.8 | 1.0 | 1.2 | 1.8 | 4.1 |
| MWIF | 0.6 | 0.7 | 0.9 | 1.1 | 1.5 | 4.2 |

It can be seen that there is more reduction in water absorption rate for concrete mixes containing WMF and a combination of WMF and fly ash than the control concrete mix. This reduction in water absorption is mainly due to modification in microstructure of concrete containing WMF and a combination of WMF and fly ash. Due to the filling effect, promotion of inkbottle shape pores, and densification of microstructure due to the addition of WMF and fly ash in the concrete mix reduces the accessible voids pores in concrete thereby restricting the movement of water through the concrete matrix. The combination of WMF and fly ash also perform slightly better than the case of the addition of only WMF to concrete mix.

## ECONOMICAL AND ENVIRONMENTAL APPRAISAL OF SYNERGIC EFFECT OF WMF AND FLY ASH IN CONCRETE

In the age of global climate change, environmental factors are moving against portland cement based construction industry. A large amount of $CO_2$ and other GHGs emissions are created by portland cement production. On the other hand, at many places, the mining of sand is banned. Therefore, the synergic effect of WMF and fly ash in concrete based construction industry may reduce the raw materials needed for the cement manufacture and also for the manufacturing of concrete. Based up on the study reported in this paper, synergic effect of WMF and fly ash can be used to reduce 20% of cement and 10% of sand without adversely effecting concrete properties. This will not only reduce $CO_2$ emission from cement production but also reduces raw materials required for cement clinker and concrete sand. Further, by taking advantage of enhanced flexural strenfth of concrete (let us consider a minimum 20%) the thickness of concrete slab can be reduced as the thickness design of the concrete pavement slab is mainly governed by its flexural strength. Saving in portland cement and concrete by using this technology for the reduction in slab thickness, raw materials needed for the manufacture of cement as well as concrete would result in the manufacture of economical pavement concrete.

## CONCLUSION

The major conclusions emerging from the study are as given below:

- The addition of WMF to the concrete as a partial replacement of sand adversly effects the slump of concrete. The reduction in slump increases with increase in replacement level of sand by WMF. However, the combination of WMF and fly ash has less affected slump.
- Concrete containing WMF is more denser than concrete without WMF.
- The addition of WMF increases the compressive strength, flexural strength, abrasion resistance and overall durability of concrete in comparison with concrete without WMF.
- The combination of fly ash and WMF (fly ash as a replacement of cement and WMF as a replacement of sand, MW1F and MW2F) gives the comparable strength and durability performance parameters.
- The flexural strength of concrete containing WMF and WMF with fly ash ranges from 20% to 30% with reference to controlled concrete. However, MW1F results in an economical concrete for the same performance parameters.
- WMF can be economically used in combination of fly ash in reducing the thickness of concrete pavement slab for the construction of more economical and durable pavements.


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## REFERENCES


Deng, X., Xiao, W., Liu, X., Cheng, B., and Liu, T. (2013). "Study on Properties of Wollastonite Micro Fiber Reinforced Mortar." *Advance Materials Research,* 785-786, 151-156. <http://www.scientific.net/AMR.785-786> (Dec. 1, 2015).

Feldman, R. F. (1986). "The Effect of Sand/Cement Ratio and Silica fume on the Micro-structure of Mortar." *Cement and Concrete Research,* 16(1), 32-39.

IS: 9284 (1993). "Method of Test for Abrasion Resistance of Concrete ." *BIS, Bureau of Indian Standard,* New Delhi, India.

IS: 2386 (1983). "Method of Test for Aggregate for Concrete, Part -IV – Mechanical Properties." *BIS, Bureau of Indian Standard,* New Delhi, India.

IS: 2386 (1963). "Method of Test for Aggregate for Concrete, Part-III- Specific Gravity, Density, Voids, Absorption." *BIS, Bureau of Indian Standard,* New Delhi, India.

IS: 10262 (2010). "Recommended Guidelines for Concrete Mix Design." *BIS, Bureau of Indian Standard,* New Delhi, India.

IS:516 (1959). "Method of Test for Strength of Concrete." *BIS, Bureau of Indian Standard,* New Delhi, India.

Kumar, R. (2014). "A Study on Multifilament Polypropylene Fibre (PPF) Vis-À-Vis Wollastonite Mineral Fibre (WMF) for Use in the Construction of Rigid Pavements." *(Report No. QSP/CRRI/PDRG/OLP- 0551).*

Low, N. M. P., and Beaudoin, J. J. (1993a). "Flexural Strength and Microstructure of Cement Binders Reinforced with Wollastonite Micro-Fibres." *Cement and Concrete Research,* 23(4), 905-916.

Low, N. M. P., and Beaudoin, J. J. (1993b). "The Effect of Wollastonite Micro-Fibre Aspect Ratio on Reinforcement of Portland Cement-Based Binders." *Cement and Concrete Research,* 23(6), 1467-1479.

Low, N. M. P., and Beaudoin, J. J. (1994a). "The Flexural Toughness and Ductility of Portland Cement-Based Binders Reinforced with Wollastonite Micro-Fibres." *Cement and Concrete Research,* 24(2), 250-258.

Low, N. M. P., and Beaudoin, J. J. (1994b). "Stability of portland cement-based binders reinforced with natural wollastonite micro–Fibres." *Cement and Concrete Research,* 24(5), 874-884.

Mathur, R., Mishra, A. K., and Goel, P. (2007). "Influence of Wollastonite on Mechanical Properties of Concrete."*Journal of Scientific & Industrial Research,* 66(12), 1029-1034.

Soliman, A., and Nehdi, M. (2012). "Effect of Natural Wollastonite Microfibers on Early-Age Behaviour of UHPC." *Journal of Materials in Civil Engineering*, 24(7), 816-824.

Zhang, L. C. (2013). "Durability of Concrete Containing Wollastonite and Fly Ash." *Advanced Materials Research,* 800, 361-364.