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Laboratory Study on Use of Wollastonite Micro-Fibers for Abrasion Resistance of Pavement Quality Concrete

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Abstract

Deterioration of concrete surfaces occurs due to various forms of wear such as erosion, cavitations, and abrasion due to varying degrees of exposures. Deterioration of concrete surfaces in concrete pavements is most significantly contributed by abrasion wear. Abrasion wear occurs due to repeated rubbing, scraping, skidding of wheel tyre on the concrete pavement surface. Concrete abrasion resistance is markedly influenced by a number of factors including concrete strength, aggregate properties, water-cement ratio, microstructural features of cement matrix, pore structure of surface zone and surface finishing. The paper presents an initial part of an on-going research to evaluate the performance of hardened concrete surface with respect to abrasion resistance using wollastonite micro-fibres as a new material. A concrete specimen of water-cement ratios of 0.4 was made using ordinary Portland cement (OPC), and OPC admixed with wollastonite micro-fibres. A total of five concrete mixes were considered with varying proportions of wollastonite micro-fibres. Admixing of wollastonite micro-fibres improves the flexural strength significantly irrespective of days of moist curing, but decreases the compressive strength beyond 20 percent replacement level. Marked improvement in resistance to abrasion was observed for wollastonite micro-fiber admixed concrete up to 30 percent of its admixing with OPC. The abrasion resistance is more pronounced for admixed concretes with prolong curing duration.

Keywords: abrasion resistance, deterioration of concrete, microstructural feature, wollastonite micro-fiber, flexural strength

1. Introduction

It has been reported that the abrasion resistance of concrete depends mainly on variables such as strength, aggregate properties, the finishing method of concrete surface and type of hardeners or toppings. Different authors have reported that abrasion resistance increases with an increase in strength [Hadchti and Carrasquillo (1988); Li Hui et al. (2006); Kilic et al. (2008) and Lui Yu-Wen et al. (2006)] and that this characteristic is the most important governing factor for the abrasion resistance of concrete [Lapplante et al. (1991)]. Naik et al.,(1994) indicated that the relationship between the compressive strength and abrasion resistance is linear. Numerous studies [Hadchti and Carrasquillo (1988); Witte and Backstrom (1951); Laplante et al. (1991)] have shown that compressive strength is the most important factor governing the abrasion resistance of concrete. However, Atis (2002) was of the view that this relationship was hyperbolic. Type of finishing and curing practices also have strong influence on the abrasion resistance [Ytterburg (1971); Naik et al. (1995)] of the same as aggregate types [Laplante et al. (1991)] in improving it considerably when they are correctly chosen. Therefore, to control the abrasion resistance of concrete, it is not sufficient to specify just an appropriate concrete strength. It is obvious that the weakness of concrete to abrasion forces leads to reduction in the thickness of the concrete slab and increases dusting on the road surface due to fractionated particles of concrete. Reduction in the thickness of concrete slabs causes an increase in tensile stress in the material used, which leads to tensile cracking that shortens the design service life of concrete. In addition, inadequate abrasion resistance of concrete can affect the resistance to skidding [Hosking, 1992]. Microstructure features of cement matrix components of the exposed surfaces determine abrasion resistance, which is largely 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 (10% sand replaced by wollastonite), having highest compressive strength (536 Kg/cm^2), has lowest abrasion loss (0.1%) when compared to control mix (0.185%) [Renu Mathur et al., 2007]. Ransinchung and Kumar (2010), have reported that wollastonite is a Class C pozzolan as per ASTM C 618 (ASTM 2008b). When ground to fine powder, it attains an average particle size of 4 microns which is about 4.5 times finer than OPC

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and wollastonite is capable of reducing the OPC and microsilica proportion in the cementitious material which is costly ingredients of concrete. Inclusion of wollastonite and microsilica in cement system leads to refinement of microstructure leading to improvement in durability properties of concrete [Ransinchung et al. (2009)].

The aim of the present study was to evaluate the efficacy of wollastonite micro-fiber for use in pavement quality concrete.

2. Properties of Materials

Ordinary Portland cement (OPC) 43 grade conforming to IS: 8112 and wollastonite micro-fibers (WMF) were used as a binder to produce concrete. Specific gravities of the cement and wollastonite micro-fiber were 3.15 and 2.90 respectively. The cement and wollastonite micro-fiber remaining on 45 micron sieve were 9.0 percent and 3.0 percent. Figs.1 & 2 show the particle size and shape of OPC and wollastonite micro-fiber in their amorphous conditions respectively. It was seen that OPC grains were irregular and rough in surface texture whereas wollastonite micro-fiber grains were acicular and has relatively higher aspect ratio. The coarse aggregates used were a well graded having average fineness modulus of 5.97 and dolomite natural aggregate with a nominal maximum size of 20 mm conforming to IS: 383. The proportions of 20 mm and 10 mm aggregates sizes decided for the present investigation were 55 and 45 percent respectively considering all-in aggregate grading as specified in IS:383 Table 5. Similarly, grading of fine aggregate (river bed sand) satisfied the criteria (IS: 383 specifications). The fine aggregate used has fineness modulus of 2.69 conforming to grading zone-II as per IS: 383. The physical properties of aggregates are presented in Table 1. Chemical admixture conforming to IS: 9103-1999 was selected as a workability and strength enhancers. Specific gravity and chloride content in admixture was 1.260 and nil respectively. Potable water conforming to IS: 456 were used for casting concrete mixes as well as for curing purposes throughout the investigation.

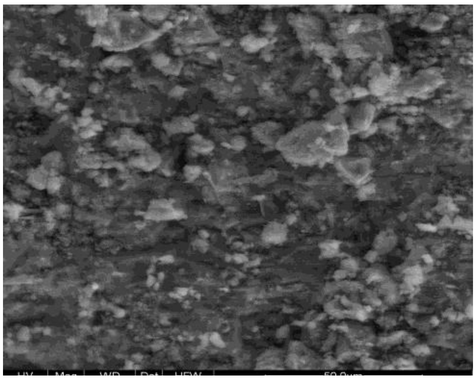


Fig.1. SEM image of OPC.

Fig.2. SEM image of Wollastonite micro-fiber.

Table 1. Physical properties of aggregates

Material	Property	Results
	Water absorption (%)	0.77
	Specific gravity	2.67
20 mm	Impact value (%) [for material passing 12.5 mm sieve but retained on 10 mm sieve.	15.0
	Flakiness index (%)	28.2
10 mm	Water absorption (%)	0.81
	Specific gravity	2.65
	Flakiness index (%)	36.0
Sand	Water absorption (%)	1.01
	Specific gravity	2.63

3. Mix proportions

The mixes used in the present investigation were designed to have target compressive strength of 48.25 MPa and W/C 0.40 for M40 grade concrete in accordance with IRC: 44. The mix designations of M40 grade concrete mix is prefix by M letter. Five mix proportions of cementitious materials were used as shown in Table 2.

Table 2. Mix proportions of cementitious materials

Mix designation	Cement (kg/m^3)	Fine agg. (kg/m^3)	Coarse aggregate (kg/m^3)		Wollastonite Micro Fibres (kg/m^3)	Water (kg/m^3)	Plasticizer (Lts/m^3)
			10 mm	20 mm			
M-1	450	445.06	496.28	809.72	0	180	2.25
M-2	405	445.06	496.28	809.72	45	180	2.03
M-3	360	445.06	496.28	809.72	90	180	1.8
M-4	315	445.06	496.28	809.72	135	180	1.58
M-5	270	445.06	496.28	809.72	180	180	1.35

4. Preparation of samples and testing

Eighteen 150 mm cubes were prepared for M40 grade of concrete without admixing wollastonite micro-fiber (referral mix) so that three cubes each were available for every mix designation after 3, 7 and 28 days of moist curing for ascertaining compressive strength. Similarly, eighteen prism moulds of 100 mm x 100 x 500 mm were prepared for ascertaining flexural strength of concrete. Additional thirty six cubes were made for different percentage replacement levels of wollastonite micro-fiber in order to ascertain their compressive strength at the ages of 3, 7 & 28 days. In order to obtain correlation between compressive and flexural strength of admixed concrete, additional twenty four prism moulds of 100 mm x 100 x 500 mm were also cast for M40 grade of concrete.
Total sixty concrete samples having dimensions of 70.6 x 70.6 x 43 mm were also prepared for conducting abrasion resistance test so that two samples each were available at the age of 3,7 and 28 days for the concrete mixtures M1 to M5 and N1 to N5. The weight loss of samples after subjected to abrasion was determined as per IS: 1237.

Effort was also made to map the scanning electron microscopic images (SEM) of selected concrete admixed concrete to study the change of morphology due to admixing of wollastonite micro-fiber.

5. Results and discussion

Figs.1 & 2 shows that there is a substantial improvement in compressive & flexural strength of concrete with inclusion of wollastonite micro-fiber. Similar nature of increase or decrease exhibits on compressive and flexural strength for all the mixtures irrespective of days of moist curing. The percentage of increase of compressive strength for M2 (10 percent WMF) with respect to M1 (referral concrete) at 3, 7 & 28 days of moist curing were 8.4, 13.4 and 11 percent respectively. Increase of these strengths for M3 (20 percent WMF) at 3, 7 & 28 days of moist curing were -1.5, + 5.5 and +5.2 percent respectively.

The results obtained on flexural strength from the present investigation, presented in Fig. 2 infer that notable increment in flexural strength exhibit for wollastonite micro-fiber admixed concrete. For M2 (10 percent WMF), about 13 percent flexural strength enhancement w.r.t. M1 (referral concrete) were observed at 3 & 7 days moist curing. This increased was up to 20.5 percent at 28 days moist curing. Similarly, for remaining admixed concretes M3 (20percent WMF) & M4 (30 percent WMF), the flexural strength increment slackened gradually to 10 and 3 percent on an average respectively.

In overall, it is found that inclusion of wollastonite micro-fiber improves the compressive strength up to 10 percent partial replacement of ordinary Portland cement by WMF. The percentage of increase of compressive strength at 28 days was about 8.4 percent in comparison to referral concrete (M1). This compressive strength starts decreasing gradually from 20 percent partial replacement onwards.

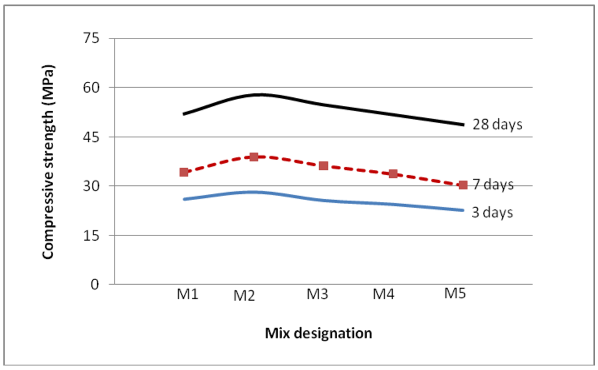


Fig.1.Compressive strength of hardened concrete with or without WMF.

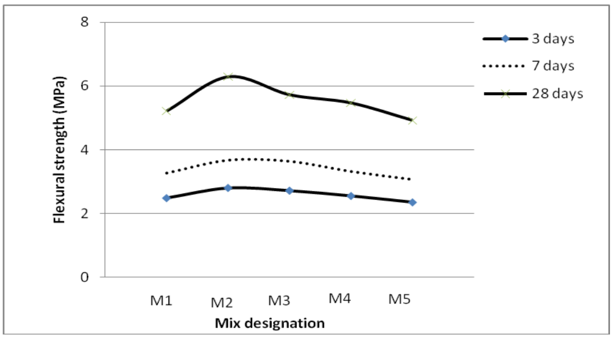


Fig.2.Flexural strength of hardened concrete with or without WMF.

However, the compressive strength at 20 percent partial replacement is comparable with the compressive strength of referral concrete (Fig.1). Partial replacement of ordinary Portland cement (OPC) by wollastonite micro-fiber improves the flexural strength substantially. This improvement is very significant up to 30 percent wollastonite micro-fiber replacement (Fig.1). The rates of increase of flexural strength for M2, M3 and M4 with respect to referral concrete (M1) are in the order of 13%, 9.5% and 2.73% respectively. Based on this detailed laboratory study, it is marked that there is significant influence of wollastonite micro-fiber on the development of compressive and flexural strength of concrete. Wollastonite micro-fiber has a high potential for use in concrete work that requires high compressive and flexural strength. As wollastonite micro-fiber helps in producing higher flexural strength than compressive strength, it would be a promising material for cement concrete pavements where high flexural strength of concrete is important.

Regression analysis was carried out to establish relationship between compressive and flexural strength of all the selected five concrete mixes including referral concrete. A typical example of results obtained is illustrated in Figs. 4 to 8. Based on this analysis, it shows that the variation of compressive strength and flexural strength maintained linear relationship for all the selected mixes irrespective of days of moist curing.

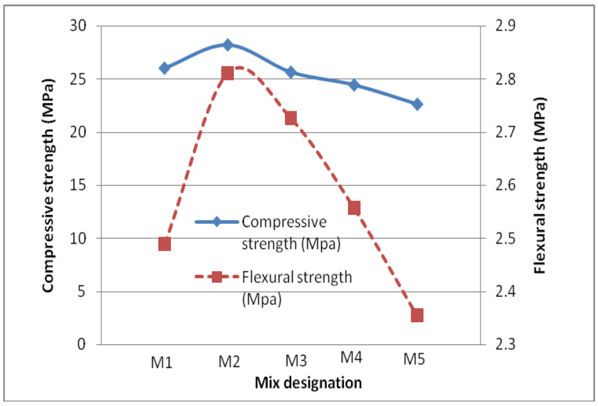


Fig.3. Compressive and flexural strength of concrete with or without WMF.

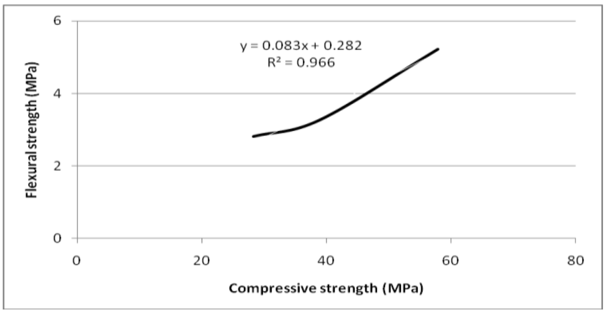


Fig.4.Correlation between flexural and compressive strength of M1

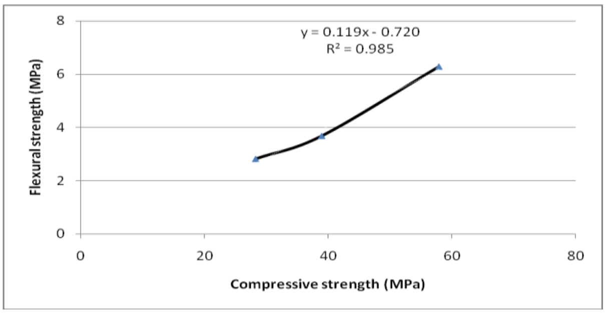


Fig.5.Correlation between flexural and compressive strength of M2

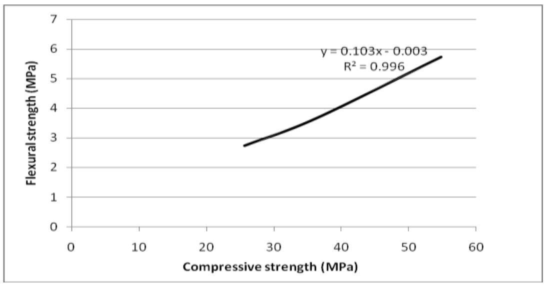


Fig.6.Correlation between flexural and compressive strength of M3

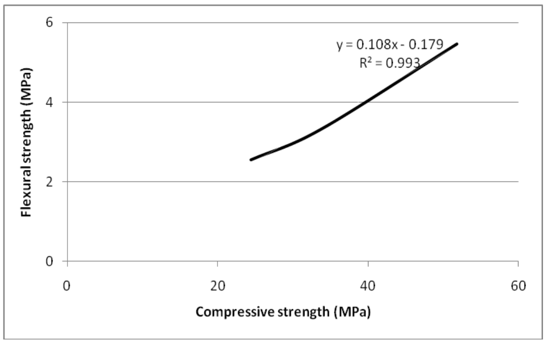


Fig.7.Correlation between flexural and compressive strength of M4

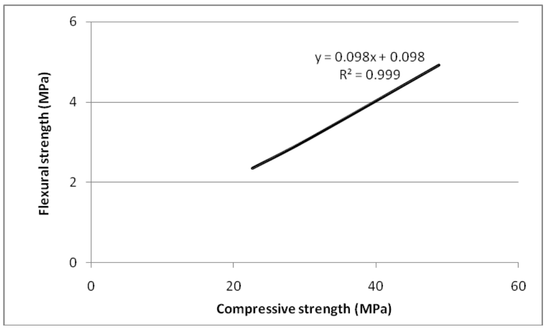


Fig.8. Correlation between flexural and compressive strength M5

Fig. 9 shows that there is a good correlation between Of all the selected mixes, M2 showed the least abrasion value followed by M3, M4, M1 & M5 respectively.

Another regression analysis was also made to establish whether a general relationship between abrasion value and compressive strength of concrete existed. A typical example of results obtained is illustrated in Figs.10 (a to e). The relationship between abrasion value and compressive strength were seemingly linear statistically, however, on closer observation, it was seen that a non-linear relation might be the better description of the relationship. As hyperbolic equation produced higher correlation coefficient in comparison to linear relationship, it would be more appropriate to establish the equations in hyperbolic equations. Ozturan and Kocataskm, 1987 who worked on the abrasion resistance of concrete as a two-phase composite material gave a similar expression.

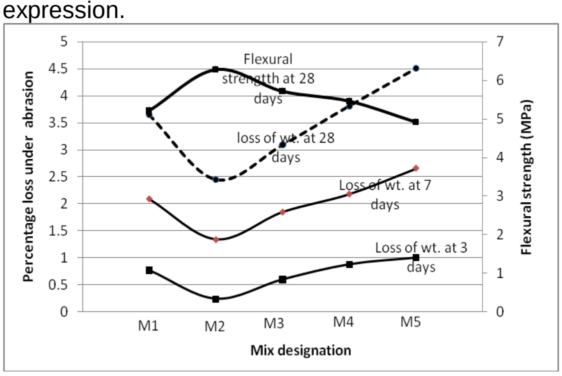
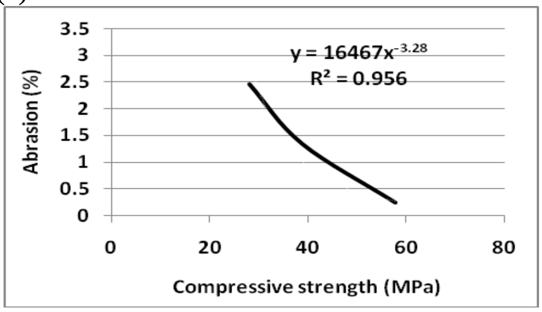
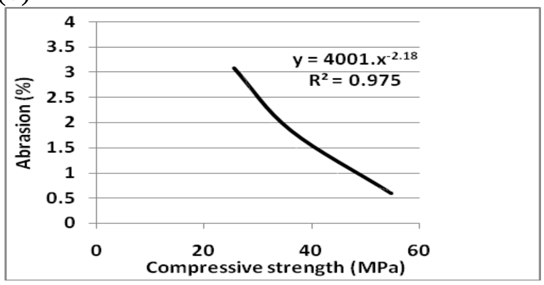


Fig. 9. Correlation between flexural strength at 28 days and % loss of weight under abrasion

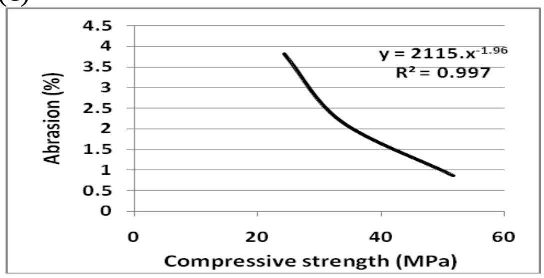
(a)



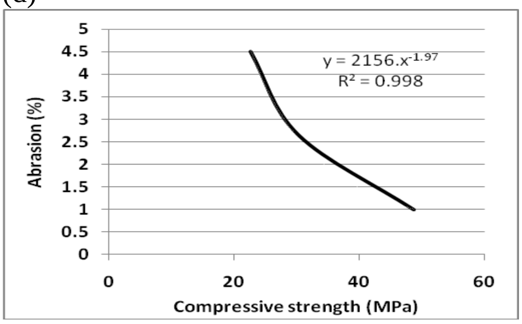
(b)

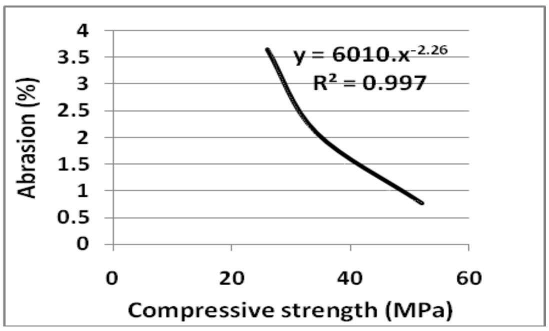


(c)



(d)





(e)

Fig. 10. Best fit between abrasion and compressive strength (a) M1; (b) M2; (c) M3; (d) M4 and (e) M5.

6. Conclusion

From the above laboratory investigation, the following conclusions have drawn:

1. Part replacement of OPC by wollastonite micro-fiber upto 10 percent improves the compressive strength of concrete substantially. This replacement level can even be increased to 20 percent as the compressive strength obtained at this replacement level was at par with the compressive strength of referral concrete. However, further study in this regard is suggested. The trend of increase of flexural strength was very similar to that of compressive strength but the rate of increase in flexural strength for the same concrete

mixes was significantly high as compared to compressive strength. It is also noted that the variation of compressive and flexural strength showed fair linear relationship irrespective of days of moist curing.

2. Good correlation between flexural strength and abrasion resistance was observed for all the mixes including referral concrete. This relation holds better between compressive strength and abrasion resistance. The abrasion resistance of concrete is mainly dependent on the compressive strength of concrete. Higher correlation coefficient between compressive strength and abrasion resistance was observed in hyperbolic form.
3. Days of moist curing influenced the general trend of concrete strength development. Prolong curing produced higher strength of admixed concrete.

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