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RESEARCH PAPER

Rehabilitation Prospects of Concrete Pavements with Self-Compacting Concrete Containing Wollastonite Micro-Fiber

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ABSTRACT: Full depth repair remains to be the favored pavement restoration method amongst the common rehabilitation and repair activities carried out for concrete pavements. This paper explores the prospects of utilizing behavioral benefits of Self-Compacting Concrete (SCC) with the inclusion of Wollastonite micro-fiber, for repair and rehabilitation of concrete pavements. Wollastonite was included in the study by replacing fine aggregates in concrete mix in proportions 10%, 20%, 30%, 40% and 50%. The mixes were investigated for their behavioral properties including flow ability, resistance to segregation, filling ability and mechanical properties i.e. compressive strength, flexural strength, water absorption and hardened density. The rehabilitation prospect of concrete pavements with SCC was studied by conducting a joint repair study on pavement prototypes specially designed and tested for the purpose. It was found that the concrete mix with Wollastonite were more cohesive and workable which is attributed to its acicular structure and lustrous appearance. During the rehabilitation study, prototypes representing a jointed section of concrete pavement were repaired with SCC mixes. The prototypes repaired with SCC having Wollastonite micro-fiber at levels of 10%, 20% and 30% reported better flexural strength in comparison to those repaired with conventional concrete or with plane self-compacting concrete mix.

Keywords: Concrete Pavement, Rehabilitation, Self-Compacting Concrete, Wollastonite Micro-Fiber.

1. Introduction

Repair and rehabilitation of concrete pavements involves many pavement restoration techniques depending upon the desired repair effects. Pavement restoration techniques available for concrete roads include full depth repair, partial depth repair, diamond grinding, dowel bar retrofit, joint and crack resealing, slab stabilization, cross stitching, grooving, retrofitting edge drains and retrofitting concrete shoulder etc. (National Concrete Pavement Technology Center, 2014). Out of all pavement restoration methods full-depth repair is the most common technique implemented for

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rigid pavements, as they provide better ride ability, structural integrity, and extend pavement service life (Federal Highway Administration, 2019).

The repair of concrete needs materials with different properties and techniques for application which also require material compatibility and structural efficiency while finalizing a material and requisite technique for implementation. Pavement repairs often need material in minor quantities which makes selection of proper material important considering service life of repaired pavements. Furthermore, the restoration and repair techniques also differ from techniques for new construction which is also a point of consideration while finalizing a material for repair.

While implementing patch repairs, generally the repair and maintenance is approached with the thought of general concrete paving thus leading to many factors overlooked which otherwise are important for patch repairs. Furthermore, the repair techniques and complexities involved for existing roads are different then the construction of new pavements thereby involving proper investigation of failure cause and thus recommending requisite repair methodology.

Self-compacting concrete with the benefit of its flowing property is preferred for applications finding heavy / congested reinforcements thus omitting the need for any external compaction (Center for Portland Cement Concrete Pavement Technology, 2005). Repairing concrete pavements with conventional concrete requires proper compaction, which would cause stress generations in adjoining previous parts thus compromising with its service life. However, SCC on the other hand once laid does not require any aided compaction or vibration, which makes it more advantageous in context of repairs for rigid pavements. Furthermore, the added advantage of a levelled surface reduces the need for surface finishing thereby saving time and energy for the same.

2. Review of Literature

The history of concrete pavements goes back to 1890’s with the construction of first PCC pavement in Ohio (Rao et al., 2013). In 1909, Wayne County, Michigan, constructed a rural pavement upon testing of materials such as brick, stones, blocks of wood, and concrete. The inclusion of dowel bars started around 1917 in Virginia, which led to various slab configurations considering sections, joints and reinforcements (Thomas, 1998).

With the passage of time, lot of work has been done in this field and has widened the area with regular additions from new discoveries. As the research progressed, different researchers explored different techniques and materials for construction and maintenance of concrete pavements. Gibbons (1999) discussed different materials for construction of pavements such as asphalt, concrete, brick, stone, tile, wood, earth materials and synthetics. Concrete Pavement Maintenance/Repair report, discussed the repair and rehabilitation of concrete pavements by distress classification and highlighted different techniques used for maintenance of concrete pavements (Cement Concrete and Aggregates Australia, 2009). Mailvaganam (2001) outlined the issues and trends in the sphere of concrete repair and rehabilitation and gave a compelling description of the latest developments which could shape the future along with its potential for further innovation. Kumar and Kaushik (2003) highlighted the development of concrete as a building material with focus on infrastructure development and discussions on recent research scenario concerning utilization of concrete in different forms in the country. Dhir et al. (2019) highlighted the environmental impact and specifications associated with use of waste materials such as recycled aggregates etc. and their effects on concrete and concrete pavements. Sharifi et al. (2019) discussed different design practices and materials for concrete pavement in addition to conditions leading to inadequate or reduced pavement performance.

With advent of time, self-compacting concrete came into existence to achieve durability amongst structures with heavy reinforcement and where external compaction is not feasible. Hajime Okamura and Masahiro Ouchi (1998) shared that the first prototype of self-compacting concrete was prepared with the objective of achieving durability amongst concrete structures. Over the period of time, advancement in research has led to SCC applications in various structures by major construction houses (Okamura and Ouchi, 1998). Collepardi (2003) highlighted that the application of SCC came into effect around 1980’s in Europe, parts of Asia and United States. Some other pioneering application include discussion of Akshi Kaikyo bridge by Tanaka et. al. (2003) in Japan (The European Project Group, 2005).

European Project Group (2005) defined self-compacting concrete as “concrete that has ability to flow under its own weight thereby completely filling the formwork in the presence of dense reinforcement, without compromising with homogeneity and requirement of external compaction”. Gesoglu et al. (2009) defined SCC as a concrete which is characterized by its self-flowing property owing to higher cement content and higher levels of superplasticizers. Despite the self-flowing behavior of SCC, the cost factor involved with SCC motivates researchers to include different types of mineral admixtures or additives to reduce the cost of SCC.

Literature could be found on use of different materials depicting pozzolanic behavior (likes of fly ash and silica fume) in SCC leading to improvement in concrete properties. Few studies include study of lower strength grade concrete (20 MPa to 30 MPa) with fly ash as replacement of cement (by volume) at 70% to 85% and higher strength grade concrete for replacement levels of 30% to 50% of cement by fly ash by Dinakar et al. (2008). Gutha (2010) discussed incorporation of fly ash as replacement of fine aggregate upto 15% resulting in compressive strength of SCC mix. Sharma et al. (2018) studied the effects of including Wollastonite, fly ash and micro silica to produce an economical SCC. They reported that SCC with 20% Wollastonite and 5%-7.5% micro silica showed higher flexural strength and lesser shrinkage. Uysal and Yilmaz (2011) studied the inclusions of rock powder such as limestone, basalt and marble as a partial replacement of binder in SCC. They reported an increase in elastic modulus and compressive strength of SCC with mineral admixtures improved with reduction in cost. Sharma (2019) investigated the properties of SCC prepared with addition of different pozzolans and recycled concrete aggregates and recommended a part replacement of binder up to 30% by Wollastonite micro-fibre, fly ash and microsilica for production of high strength self-compacting concrete. Hemlatha and Ramujee (2021) studied the influence of TiO_2 on self-compacting concrete with flyash, GGBS and wollastonite. Khayat and Roussel (1999) studied the inclusion of steel fibres in SCC to produce fibre reinforced concrete. They reported an increased flow ability and filling capacity with the inclusion of fibres in SCC.

Gru¨newald and Walraven (2001) studied the effects of including steel fibres in SCC by investigating the material behavior of fresh concrete along with the impact of content of aggregates, their types and amount of steel fibres on the flowing capacity of SCC. Bui et al. (2003) suggested reduced ratio of aggregates (coarse to fine) in order to achieve better cohesiveness of mix by surrounding coarse aggregates with a mortar layer. Furthermore, they also concluded that for increased fibre volume, higher volume of paste and lower content of coarse aggregate has to be maintained in the mix. Johnston (2001) also concluded that in order to ease the pumping of concrete, the content of coarse aggregates must be reduced by 10%. Bertil (2001) carried out practical and analytical studies of behavioral properties of concrete and concluded that the elastic modulus parameters, creep and shrinkage behavior of self-compacting concrete was not found to have significant difference from that of conventional concrete. Gnanaraj et al. (2020) discussed the effects of different mineral and chemical admixtures in self-compacting concrete and their impact on mechanical behavior of SCC. Gholamzadeh-Chitgar and Berenjian (2021) proposed a neural network-based model to forecast the property parameters of SCC with low test error using data from literature.

Wollastonite is a mineral which occurs naturally and is majorly used in ceramic, porcelean and paint industries. For past few years Wollastonite has been a material of interest for researcher’s owing to its chemical composition and its ability to enhance the behavior of cement matrix and concrete. Ransinchung et al. (2009) studied the feasibility of using Wollastonite micro-fibre and micro silica for part replacement of binder in concrete. They highlighted that incorporating 15% Wollastonite upto 15% and micro silica up to 7.5% leads to improvement in pore behavior of concrete. Jindal et al. (2020) discussed that incorporating Wollastonite micro-fibre as a part replacement of cement in by 30% leads to improvement in flowability, cohesiveness and higher strength values. Öz and Güne (2021) studied the effects of Wollastonite alongside calcite and quartz on high performance mortars. Kalla et al. (2015) highlighted the feasibility of substituting 10%-15% cement by Wollastonite to improve the concrete’s strength and durability along with reduction in porosity and more dense concrete. Investigations have been made on self-compacting concrete using Wollastonite and other materials such as Kumar et al. (2017) incorporated ultrafine stealite powder; use of recycled concrete aggregates in self-compacting concrete by Santos et al. (2019). Similar discussions on benefits of incorporating Wollastonite in concrete were observed from Abdel et al. (2017), Sharma et al. (2018), Huang et al. (2019), Zareei et al. (2019), Abdolrasool and Mousavi (2020), Kuldasheva et al. (2020), Vishnu et al. (2021), Nair et al. (2021), Dutkiewicz et al. (2022), Bong et al. (2022), Gouse et al. (2022) and many more.

3. Objective of The Study

Incorporation of self-compacting concrete for general / structural applications have been into practice for past few decades. Various mineral and chemical admixtures have been included in SCC in different proportions for enhancement or behavior improvement. However, very scanty work has been done with the application of SCC for rehabilitation of concrete pavements. Moreover, only a few handful of studies could be found pertaining to repair and rehabilitation of concrete pavements with SCC incorporating Wollastonite micro-fiber.

This study thus investigates the potential of SCC for repairing and rehabilitating concrete pavements. The SCC mixes used for repair purposes were also admixed with Wollastonite micro-fiber, to estimate the likelihood of part replacing fine aggregates by Wollastonite micro-fibre.

4. Experimental Programme

Pavement prototypes repaired and rehabilitated using self-compacting concrete having Wollastonite micro-fiber were tested for investigating the efficacy of the mix for rehabilitation prospects. In previous part of study, it was established that partial inclusion of Wollastonite micro-fiber by replacing fine aggregates improves the cohesiveness and flowability with recorded increase in flexural strength when compared with referral mix (Jindal et al, 2020). The study reports the effects and change in behavior of self-compacting concrete upon the inclusion of Wollastonite micro-fiber as part replacement to sand at 5 levels namely 10%, 20%, 30%, 40% and 50%.

The design mix was prepared in accordance with IRC: 44 (2017) for pavement quality concrete, however iterative process using slump flow of mix was adopted to work out the proportions for SCC. Finally, mix with flow diameter greater than 600 mm were considered to be suitable. Referral mix without any Wollastonite is designated as mix S0, while mix incorporating Wollastonite micro-fiber at levels of 10%, 20%, 30%, 40% and 50% are designated as S1, S2, S3, S4, and S5 respectively. The composition of different mix in study are summarized in Table 1.

The rehabilitation study for pavement prototypes was carried out by repairing the prototypes at their joints using different mixes of self-compacting concrete incorporating Wollastonite micro-fiber at different levels as discussed above. In order to investigate the efficacy of rehabilitating concrete pavement using self-compacting concrete, a total of 16 pavement prototypes (2 prototypes for 1 set) were prepared and studied for failure loads under flexure in order to ascertain joint efficacy with the use of SCC. One set of prototype was repaired with conventional M40 mix i.e. RC, one set of prototype were prepared of SCC mix alone and designated as SS0, one set of prototypes each were repaired with SCC mixes S1, S2, S3, S4 and S5 designated as RS1, RS2, RS3, RS4 and RS5 respectively. These prototypes were then investigated for their flexural behavior at age 7 and 14 days.

5. Results and Discussions

5.1. Study on SCC Mixes

5.1.1. Fresh and Hardened State Investigations

SCC unlike conventional concrete requires much detailed investigation in fresh and hardened states in order to assess its efficacy. In the light of same, SCC mixes used in study were studied for fresh state properties such as horizontal flowability by slump flow test, filling ability by v-funnel test, segregation by probe ring test. The hardened state behavior of mix was studied by testing specimens under compressive and flexural conditions.

Table 1. Mixture compositions

Mix No.	Mix name	Water Kg/m^3	Cement kg/m^3	Fine materials Kg/m^3		Coarse aggregate kg/m^3		SP Kg/m^3
				Sand	Wollastonite	10 mm	6.3 mm	
S0	100 S	255	425	888.5	0	444.25	444.25	12.75
S1	90 S	255	425	799.65	88.85	444.25	444.25	12.75
S2	80 S	255	425	710.8	177.7	444.25	444.25	12.75
S3	70 S	255	425	621.95	266.65	444.25	444.25	12.75
S4	60 S	255	425	533.1	355.4	444.25	444.25	12.75
S5	50 S	255	425	444.25	444.25	444.25	444.25	12.75

Table 2. Test results for fresh SCC mix

Mix No.	Slump flow value (mm)	V-funnel reading (sec)	Probe test reading (mm)
S0	672	9	7
S1	663	9	8
S2	651	10	8
S3	637	11	8
S4	625	11	9
S5	610	12	9

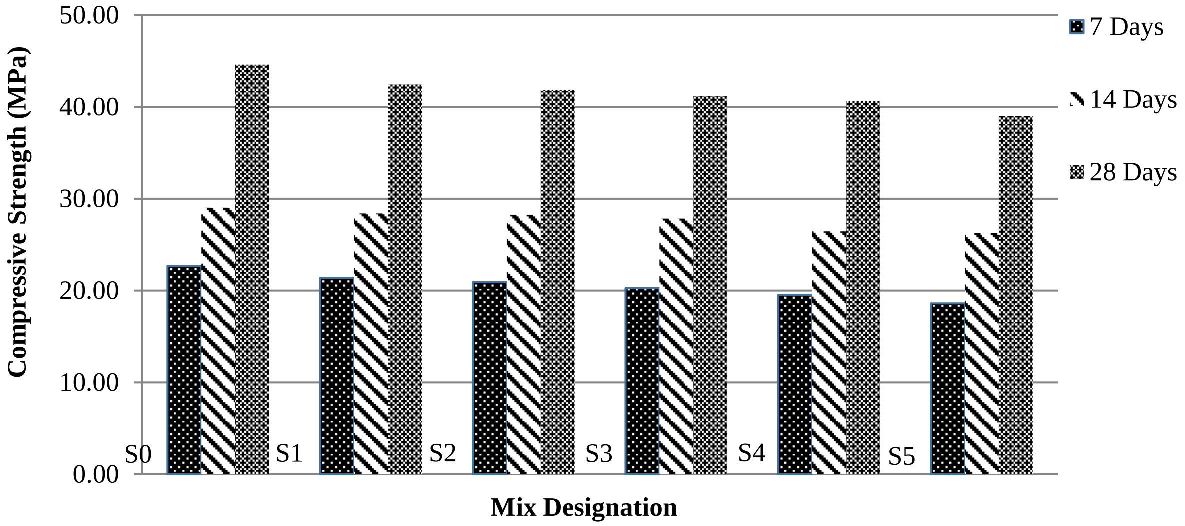

Fig. 1. Compressive Strength trend for SCC mixes

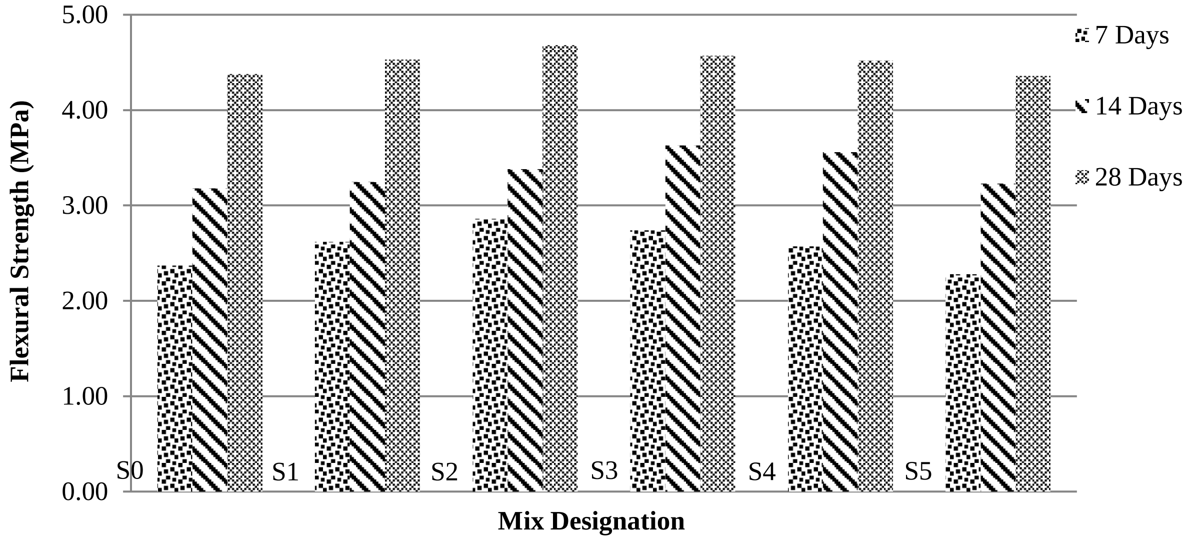

Fig. 2. Flexural Strength trend for SCC mixes

Table 2 discusses the fresh properties of SCC mix under study while Figures 1 and 2 illustrate the strength parameters obtained for the SCC mixes after testing. Results discussed for SCC mixes in earlier part of study (Jindal et al, 2020) concluded that Wollastonite micro-fiber when incorporated in self-compacting concrete results in more cohesive and flowable mix. Furthermore, the study of Jindal et al. (2020) concluded that SCC mix with Wollastonite micro-fiber recorded comparable compressive strength and better flexural strength values, thus indicating the acceptability of admixing Wollastonite micro-fiber in SCC mix.

5.1.2. SEM and XRD Investigations

SEM and XRD investigations were performed on hardened cement pastes of SCC mix under study to assess the impact of admixing Wollastonite as a micro-fibre at microscopic levels. The investigation of SEM images discussed in earlier part of study (Jindal et al., 2020) concluded that the SCC mixes upon incorporation of Wollastonite micro-fiber reported more cohesive rich and dense mix due to increase in fine content of the matrix.

The powdered specimens of cement mortar matrix as a representative of different mixes under study were analyzed using XRD technique to determine the crystalline phases developing in the concrete mixes. The results obtained from phase analysis illustrates the peaks for respective compounds identified for mix under study shown in Figures 3 to 8. During the phase analysis the labeled peaks show that a particular peak may represent diffraction patterns of one or more phases in consideration. Thus, intensities of all probable compounds were matched to find out the presence of a given compound in the mix under study.

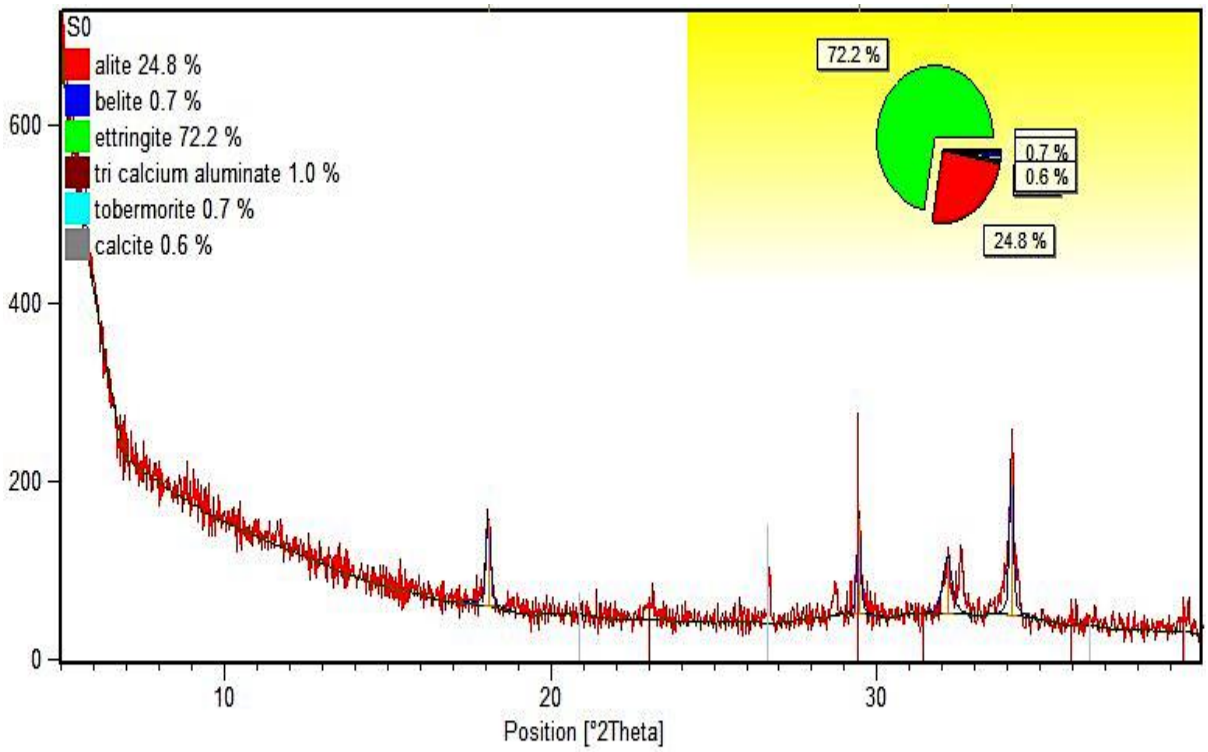

Fig. 3. XRD pattern for S0

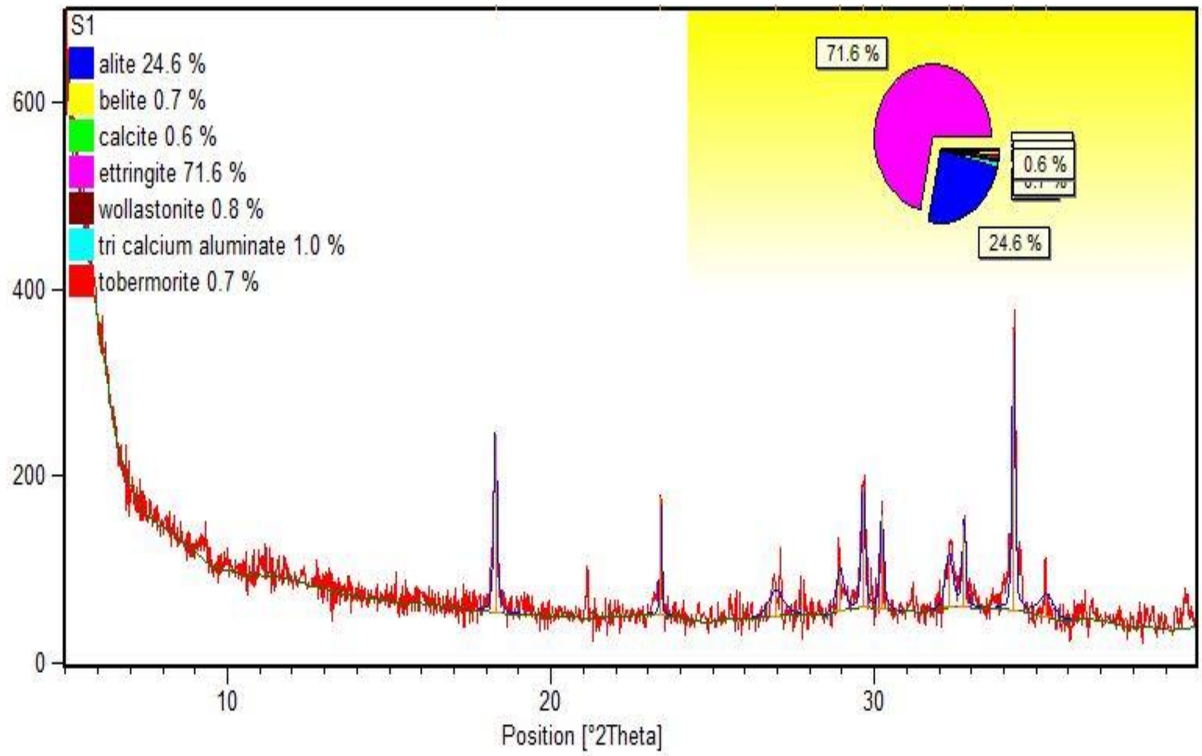

Fig. 4. XRD pattern for S1

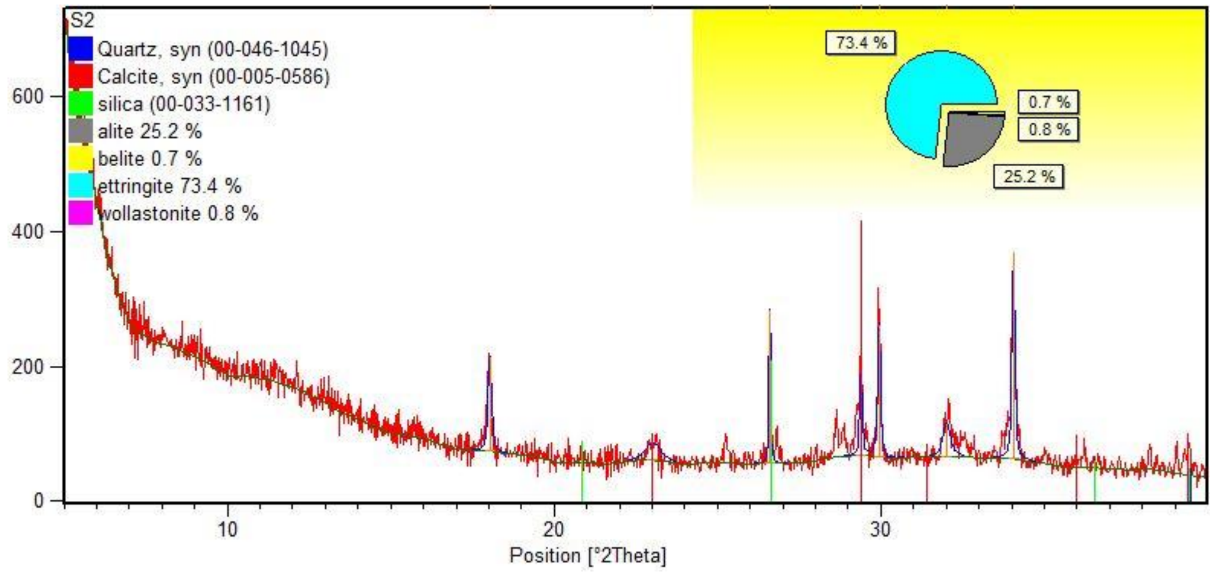

Fig. 5. XRD pattern for S2

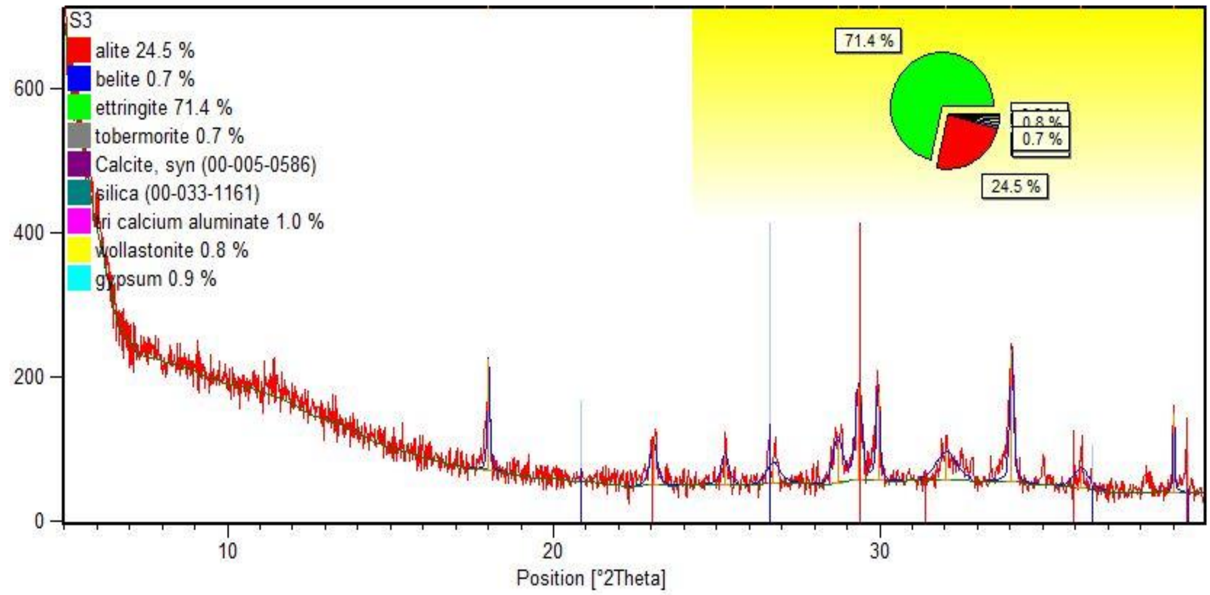

Fig. 6. XRD pattern for S3

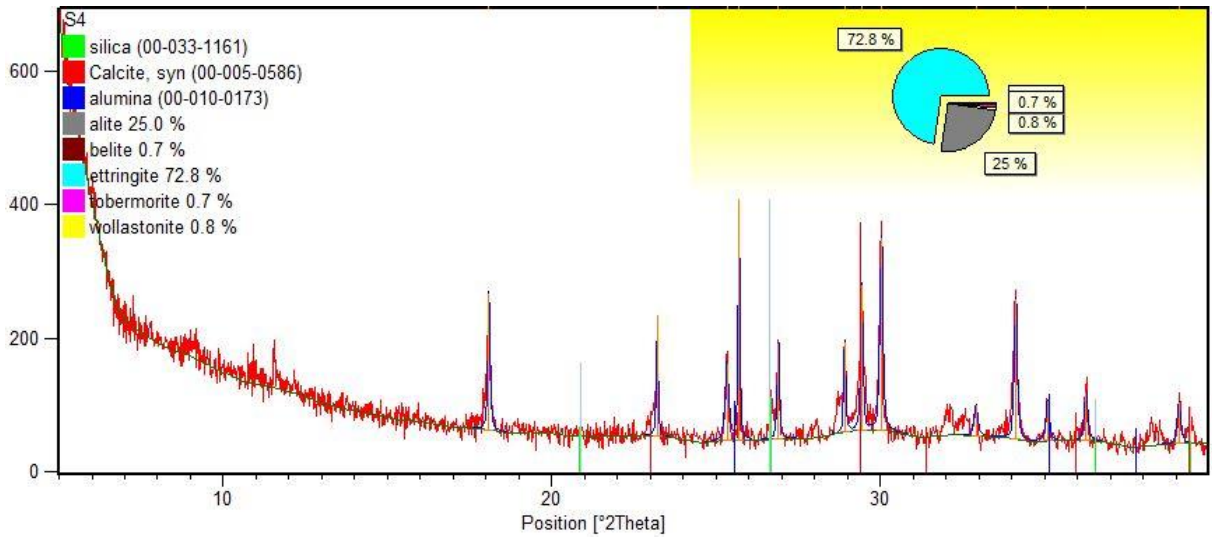

Fig. 7. XRD pattern for S4

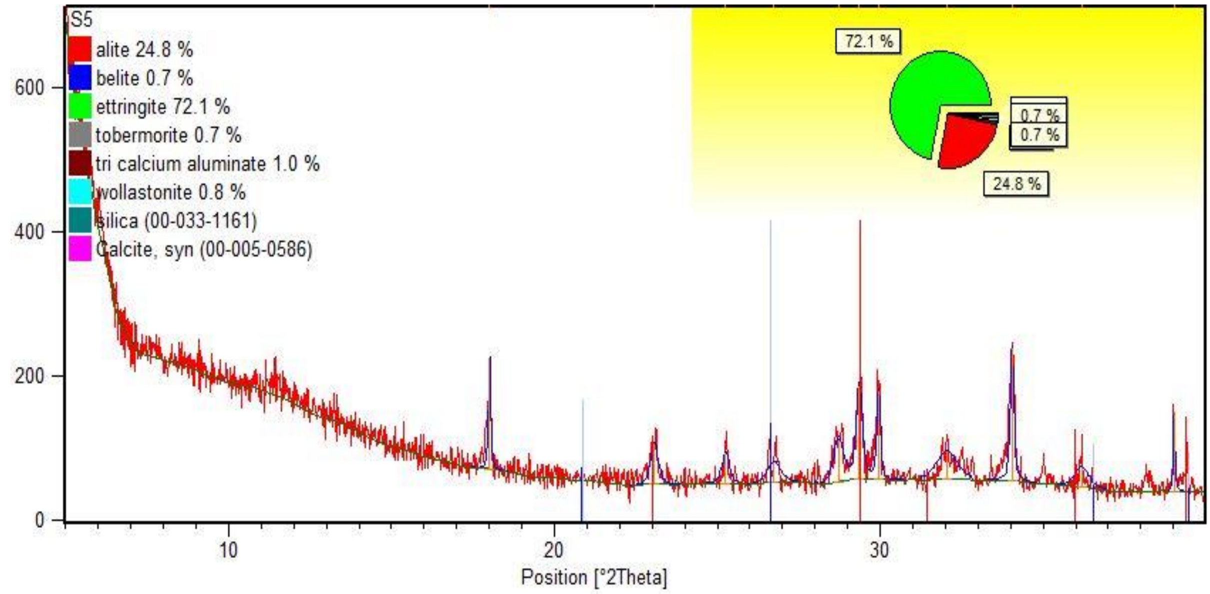

Fig. 8. XRD pattern for S5

It was found that presence of ettringites and tri-calcium aluminates was more pronounced for specimens representing S0 mix (i.e. without Wollastonite micro-fiber). Wollastonite, a fine particulate micro-fiber prominently consisting of calcium and silica when incorporated in concrete contributed to more hydration products which is also visible as peaks of Wollastonite and tobermorite in mixes with Wollastonite micro-fiber. This increase in hydration products is also reflected in better compressive and flexural strength of mix with Wollastonite micro-fiber.

5.2. Pavement Rehabilitation Study

The pavement rehabilitation study was carried out on prototypes of special sized specimens (700×300×200 mm^3) casted with conventional M40 grade pavement quality concrete to represent the concrete slabs being casted in concrete pavements. Special moulds (shown in Figure 9) were prepared to cast the required sized prototypes. In order to create an effect of transverse joint of the pavements in the prototypes, a partition up to mid depth was made in the prototypes. These partitions in the moulds were provided with the groove to be used for placement of dowel bars.

The specimens to be repaired were coated with Multi-Surface Bonding Primer (MPB bonding agent) to achieve proper bonding amongst existing and fresh concrete. A total of 16 specimens were prepared for 8 sets of prototypes. One set of prototype was repaired with conventional M40 mix i.e. RC, one set of prototype were prepared of SCC mix alone and designated as SS0, one set of prototypes each for repairing with SCC mixes S1, S2, S3, S4 and S5 defined as RS1, RS2, RS3, RS4 and RS5 respectively. These specimens were investigated for their flexural behavior at age 7 and 14 days. Figure 9 shows the schematic representation of rehabilitation and testing of pavement prototypes in the study.

The flexural strength parameters recorded for different prototypes till failure at 7 days and 14 days of moist curing are summarized in Table 3. Figure 10 illustrates strength pattern depicted by tested prototypes. It could be interpreted from the pattern that flexural strength improved when the prototypes were repaired with SCC. During the study of prototypes repaired with different concrete mixes it was observed that the flexural strength of prototypes repaired with Wollastonite micro-fibre replacing fine aggregates at levels 10%, 20% and 30% were more in comparison to those of repaired with conventional concrete or with referral self-compacting concrete mix.

Fig. 9. Schematic representation of rehabilitation and testing of pavement prototypes

Table 3. Strength parameters for repaired pavement prototypes

Repaired prototypes	Prototype designation	Load at 7 days (tonnes)		7 days Strength (Mpa)	Load at 14 days (tonnes)		14 days Strength (Mpa)
		1st crack	Failure load		1st crack	Failure load	
Conventional C1	RC	10	13	4.25	14.2	14.4	4.70
SCC Slab S0	SS0	8.1	10	3.27	7.9	10.3	3.36
Repaired with S0	RS0	12	13.5	4.41	14	15.2	4.97
Repaired with S1	RS1	11.4	13.9	4.54	14.6	16.4	5.36
Repaired with S2	RS2	10.8	14.23	4.65	14.1	15.1	4.93
Repaired with S3	RS3	9.8	14.14	4.62	15.4	17.3	5.65
Repaired with S4	RS4	9.3	13.86	4.53	15.2	16.1	5.26
Repaired with S5	RS5	9	12.84	4.19	12.7	14.3	4.67

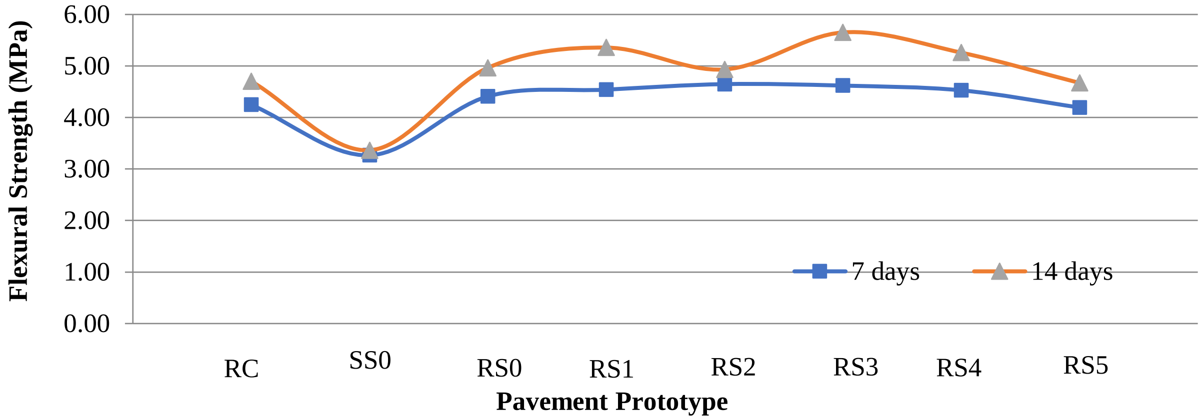

Fig. 10. Flexural strength of repaired prototypes

6. Conclusions

The conclusions made from study are as follows:

a) The mix incorporating Wollastonite micro-fiber depicted improved compressive and flexural strength parameters which is attributed to its fine particulate behavior that led to densification of matrix visible in XRD results thereby resulting in better strength.

b) The results obtained from investigations of fresh SCC mix showed comparable parameters for flow related properties such as slump flow rate, V-funnel and segregation behavior by probe test thereby indicating the suitability of admixing Wollastonite micro-fiber for preparation of SCC.
c) The flexural strength of prototypes repaired with Wollastonite micro-fibre replacing fine aggregates at levels 10%, 20% and 30% were more in comparison to those of repaired with conventional concrete or with referral self-compacting concrete mix.
d) Thus, it could be concluded that SCC incorporating Wollastonite micro-fibre up to 30% could be suitably used for repair/rehabilitation of concrete pavements.

7. Recommendations

From the present laboratory investigations, it is concluded that inclusion of Wollastonite micro-fibre on a partial basis for replacement of fine aggregates leads to improvement in flexural strength of SCC. Also, up to 30% replacement levels provides added advantage of better flowability and cohesiveness of the mix. Also, better finishing of the specimens was observed for SCC with Wollastonite micro-fibre. Hence, Wollastonite in fibrous form could be considered as a beneficial material for inclusion in SCC to be used for repair and rehabilitation of PQC slabs.

7. Abbreviations

SCC: Self-Compacting Concrete, OPC: Ordinary Portland Cement, PCC: Plain Cement Concrete, SEM: Scanning Electron Microscopy, IRC: Indian Road Congress, IS: Indian Standards, MPB: Multi-Surface Bonding Primer, ITZ: Interfacial Transition Zone, XRD: X-Ray Diffraction.

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