Mixing of High Ductile Mortar (HDM) in Concrete Mixers

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Abstract

Plain concrete is strong in compression, but very weak in tension. Tensile strength of plain concrete is about10 to 15% of the compressive strength depending upon the grade of concrete. Another limitation of plain concrete is that it is brittle in failure. Fiber-reinforced concrete (FRC) is the concrete made primarily of hydraulic cements, aggregates, and discrete reinforcing fibers. Fibers suitable for reinforcing concrete are produced from steel, glass, and organic polymers (synthetic fibers). Author hereby has attempted to develop the High Ductile Mortar (HDM) using Poly Vinyl Alcohol (PVA) fibers. HDM may replace the steel fibers to increase the flexural strength and deflection. It also lightens the structure than steel fiber reinforced concrete (SFRC). This paper gives the brief history of HDM development results which were mixed in small mortar mixer of 10 liter capacity. Then, it presents the results of HDM mixed in two different concrete mixers of 100 liter capacity using different PVA fibers and sands.

Keywords: *PolyVinyl Alcohol (PVA), High Ductile Mortar (HDM),Flexural Strength,Deflection, Mortar Mixer, Concrete Mixer*

Introduction

Concrete consists of different ingredients ranging from very big size particles, like coarse aggregates, to very small size particles, like cement or other fine powders. Plain concrete is strong in compression, but very weak in tension. Tensile strength of plain concrete is considered as 10 to 15% of the compressive strength depending upon the grade of concrete. Another limitation of plain concrete is that it is brittle in nature. Fiber-reinforced concrete (FRC) is concrete made primarily of hydraulic cements, aggregates, and discrete reinforcing fibers. Fibers suitable for reinforcing concrete have been produced from steel, glass, and organic polymers (synthetic fibers) (ACI).The fibers are useful in providing greater resistance to plastic shrinkage cracking and service-related cracking. Fibers are not intended as primary reinforcing. The fibers are added during concrete production. They are useful in shotcrete and in thin overlays that are not sufficiently thick to accommodate reinforcing bars, and they have good resistance to impact, vibration, and blasts. The disadvantages of fiber-reinforced concrete are the reduced workability and the possibility of corrosion stains if the fibers are exposed at the surface (ACI, 2017). The main purpose of adding fibers to the concrete is to enhance the tensile strength and impact resistance and reduce the brittleness of the concrete (BMCE, 2011).

With advancement on the requirement of structural performance like in flexural strength and ductility requirement, different types of fibres have been developed to be mixed with cement paste, mortar or concrete. In this respect, many investigative works are required to increase the flexural and ductility behaviour of structural elements so that we may increase the strength, serviceability and durability of such structural elements like permanent formwork, tunnel segments, bridge girders and many structural and non-structural parts required lightweight elements in buildings. Fiber reinforced cements and concrete (FRC) are firmly established as construction materials. The extensive research and developments of FRC have been carried out since the early 1960 with FRC materials leading to a wide range of practical applications (Barr, 1992. In 1982, American Concrete Institute pointed out 5 methods of adding fiber materials in concrete (ACI, 1982). Later, American Concrete Institute, ACI 6.44-3R (1993), recommended that the fibers should be added either with aggregates or after the concrete is fully mixed (ACI, 1993).

The effect of mixing procedure on the properties of fiber reinforced concrete and especially with the feeding sequence of ingredients into the mixer was studied by many researchers (Bartos et al. 1996; Hoy, 1998; Hoy and Bartos, 1997).Some researchers have made the most significant forecasts that ordinary mixers, recently used in construction practice, may not satisfy the requirements to obtain better quality of mixed FRC (Hoy, 1998;Hoy and Bartos, 1997). Japan Concrete Institute has recommended the detailed mixing procedure for FRC (JCI-SF, 1983). The most difficult part of producing FRC in normal practice is to make the even distribution of fibers and avoid the clumps while mixing.In recent years, many types of synthetic fibers have been developed to replace the steel fiber. It is because of the fact that these fibers can provide inexpensive reinforcement for concrete and if the fibers are further optimized; greater improvements can be gained without increasing the reinforcement costs (Victor et al., 1998). Such fibers may also overcome the problems of corrosions which may generally occur in FRC.

Victor Li., in early 1990s, first developed the concept of Engineered Cementitious Composites (ECC) (Victor et al. 1998, Victor et al. 2001). Kuraray,a Japanese company, was first to develop Poly Vinyl Alcohol (PVA) fibers. PVA fibers have high tenacity, high modulus, low elongation, light weight, good resistance against chemicals (alkaline), good adhesion to cement matrix (Kuraray, 1993). PVA fibers act greatly in a cement based matrix with no coarse aggregates due to their surface formation and high strength. PVA fibers were used to develop the composite, which exhibited the pseudo ductile behavior, was named as ECC (Victor et al. 1998, Victor et al. 2001). The research work was also carried out on the effect of PVA fiber diameter on the crack resistance property of ECC (Gong et al., 2008).

The influence of matrix strength (water-binder ratio) on the bending resistance property of ECC was also studied (Zhang, 2010). Pang et. al. (2009) studiedwith the effect of fly ash amount, cement-sand ratio, and the like on the mechanical properties of ECC. Li and Xu carried out the research work on the bending resistance property and flexural toughness evaluation method of ultra-high toughness cementitious composite (UHTCC) (Li et al., 2010)..The fracture and impact property of short, discrete jute fiber reinforced cementitious composites (JFRCC) was studied by Zhou et al. (2013) with various matrices for developing low-cost natural fiber reinforced concretes and mortars. Wang et al. carried out the experimental and numerical studies on the performance of seven high-performance fiber-reinforced cement-based composites against high velocity projectile impact (Wang et al., 2016). Zhang et al. studied the dynamic characteristics and the constitutive relationship of polypropylene fiber reinforced mortar (PFRM) materials under compressive impact loading (Zhang et al., 2016).

With the development of such PVA fibers, many researches have been carried out to study the mechanical behavior of hardened PVA fibers reinforced mortar depending upon the types and percentage of PVA fibers. However, any research work has not been noticed to investigate the method to enhance the flexural strength and deflection behavior of PVA fiber reinforced mortar. In order to overcome this problem, the author has made the hypothetical prediction that since PVA fiber has more tensile strength and ductility behavior than steel fiber, its proper use in mortar should give better flexural strength and deflection than SFRC. In order to achieve this hypothetical prediction, the author has named the product as High Ductile Mortar (HDM) and has carried out series of experimental investigations considering all possible affecting parameters.

Objective

The main aim of this research paper is to provide the brief background of the development series of HDM with consideration of different affecting parameters. Its specific objectives are:

(1) to explore the background study about the development series of HDM carried out in the mortar mixer (10 liter capacity)

(2) to checkthe flexural strength of HDM mixed in two different types of concrete mixers with different types of sand and PVA fibers

Development Series of HDM

As we know that the concrete and mortar are brittle materials due to very weak transitional zone in-between the phases of the matrix. All experimental results have shown that all failures in ordinary concrete or mortar is initiated from the transition zone; and due to this reason, the structural elements are failing before providing any ductility. However, in modern construction industries we have badly needed ductile structural elements which may not only be capable to bear the high compressive stress but also the tensile and flexural strength. Now a day, fiber reinforced concrete (FRC) is extensively used in civil engineering in order to reduce or substitute reinforcement bars. It was first applied in pavement (Falkner H. 1995) and then in other precast structural elements with complete removal of reinforcement meshes (Di and Toniolo, 2000; Failla et al., 2002;Minelli et al., 2006]. After the development of Tunnel Boring Machine (TBM), SFRC tunne) segments are becoming popular in the world (Plizzari and Tiberti, 2006).

SFRC is also used in permanent formwork. After the adjustment of all reinforcement bars, permanent formwork is set and the concrete is poured. After the RCC is hardened, then the permanent formwork acts as the monolithic part of the structural element as covering to the reinforcement bars. Japanese National Association of Concrete Products, from research and meetings, decided that the flexural strength requirement for multi-crack panel and the permanent formwork (called as SEED form)should be as given in the **Table 1**(NACP, 2017).

Table 1: Flexural Strength requirement of multi-crack panel and SEED form (NACP, 2017)

Requirement	Multi-crack panel	SEED form
Maximum flexural strength (MPa)	10.6	12.0
Flexural strength for formwork (MPa)	6.4	8.0
Safety factor	1.2	1.5
Design strength for formwork (MPa)	5.3	

The author has targeted to achieve the specified value given in the Table 1 for the development of HDM.

In all series of investigation works, three types of PVA fibers were used as given in the **Table 2**.

Table 2: Properties of PVA fibers used in experimental investigation[1]

Parameters	Characteristics		
Fiber Type	RMH182	REC15	RECS100
Diameter (mm)	0.014	0.04	0.1
Length (mm)	6	12	12
Specific gravity	1.3	1.3	1.3
Tensile strength (MPa)	1900	1600	1200
Young's modulus (GPa)	43	41	28
Fiber Elongation (%)	5	6	6

Basic criteria adopted for the development of HDM was based upon 3 major points:

- Each thin and short PVA fiber should be uniformly distributed without forming any fiber clumps.
- Mortar should be viscous to be attached and firmly coated around the smooth surface of each PVA fiber.
- Final product of fresh PVA mortar should have good workability for placing, compaction and finishing.

Pre-dispersion of Thin and Short PVA Fibers and Different Mixing Methods

REC 15 type PVA fiber was used in this experimental work.PVA fibers were pre-distributed with air pressure, ESG mixer, juice mixer and chopper. PVA fibers dispersed with air pressure were found the most effective and it was chosen as parameter for the different mixing methods. Other dispersion methods were rejected. Then mixing of PVA fiber was carried out in both conventional mortar mixer and the chopper. For mixing in chopper, pre-distributed fibers with air pressure were also used (Gyawali, 2018).

The use of developed prototype chopper mixer for mixing PVA paste increased flexural strength and compressive strength by 27% and 8% respectively. Use of pre-dispersed PVA fibers for mixing in chopper mixer gave further increment of 34% and 11% respectively. The most important conclusion drawn from this research was that the dispersing and coating conditions of each PVA fiber is vitally important to enhance the flexural behavior of PVA fiber paste.Although mixing in the chopper gave the comparatively best result, this method was not considered as practical to produce PVA mortar in real practice.

[1] Kurary, Fibers and Industrial Materials Division, "Characteristics of KURALON™ (PVA fiber)", http://www.kuraray.co.jp/en/.

Development of High Ductile Mortar (HDM) Mixing Method (Gyawali, 2019)

In the conventional mixing method, dry materials (cement and sand) were first mixed in the dry state. Then water was added and wet mixing was carried. Then mixing was continued with charging of PVA fiber part by part. After the finish of charging PVA fibers, further mixing was carried out to produce the final fresh PVA mortar.While mixing PVA mortar with the conventional mixing method, fibers were not distributed uniformly and many lumps of fibers were noticed inside the mixed PVA mortar.The conventional mixing method did not enhance the workability, finish ability and mechanical properties of mortar, and then a special type of the new mixing method was thought to be investigated.

In the new developed mixing method, water was divided into 2 parts. At first, viscous mortar was prepared with the first part of the water. Then PVA fibers were introduced part by part in order to make them uniformly distributed and be firmly coated with viscous mortar. Finally, the PVA mortar was again mixed with remaining second part of water to increase the workability of PVA mortar without disturbing the coating condition of PFA fiber. This method produces the better workable PVA mortar with uniform distribution and firmly coated fibers. No any clumps of fibers were noted inside the mixed PVA mortar. The workability of each PVA mortar mixed with HDM mixing method was sufficient for placing, compaction and finishing (table flow > 150 mm).

Maximum flexural strength was noticed 7.5 MPa for the specimens mixed with conventional method. While mixing with HDM method, it was increased up to 10.1 MPa, which is about 35% above than conventional mixing method. The deflection of about 0.75mm was noticed at the maximum flexural stress of the specimens mixed with conventional method. Interestingly, the deflection was about 1.25mm in case of specimens mixed with HDM method, which is about a 67% rise. More plastic behavior of specimens, than of those mixed with conventional methods, was noticed (Gyawali, 2019).

From the observation of the stress-strain curve, plasticity of the specimen mixed with HDM mixing method was significantly more than those of the conventional mixing method. Specimens with conventional mixing method were failed with single crack, but numerous micro cracks were developed in those from the HDM mixing method.

Effect of Different Sizes and Contents of Thin and Short Fibers(Gyawali, 2019)

For this investigative experimental work, main two types of PVA fibers, REC15 (φ40μm×12mm) and RECS100 (φ100μm×12mm) were chosen. In this attempt, quite thick and long fibers were chosen, assuming that they could be well dispersed and properly coated mixing in big mixers at batching plant.In order to study their effect (with single or in combination) on flexural behaviour of HDM, different matrices of mix proportions was prepared for the experiment. In some cases, fly ash was also added to increase the matrices of paste in the mix with consideration that the fibers might be coated well with the sufficient available paste in the mix. In order to enhance the workability and viscosity of base mortar, super plasticizer and viscosity agent were used.

The second investigative point was to determine the appropriate size and content of PVA fiber. For this purpose, thinner and shorter RMH182 (φ14μm×6mm) type PVA fiber was used. From the result of first phase experiments, it was known that the use of mineral admixtures enhances the flexural behavior of HDM. It was also known that increase of fiber content is not the solution to enhance the flexural behavior of HDM. It was concluded from study of first phase experimental data that single size PVA fiber is better to use in HDM rather than in combination (Gyawali, 2019).

The workability of HDM was found inversely proportional to the percentage of fiber in mortar. Use of thicker and longer PVA fiber increased the workability, but decreased the flexural strength. Flexural strength of 1.5% RHS182 type thinner and shorter fiber was higher (9.01 MPa) than those from thicker and longer (8.65 MPa for REC40 and 8.01 MPa for RECS 100) fibers(Gyawali, 2019). Thus, from a whole series of this experimental and investigative work, the conclusion was drawn that the single size thinner and shorter PVA fiber is better to use in HDM due to high flexural strength in lower percentage and developing hair like multi cracks before the failure as well as reducing overall production cost (Gyawali, 2019).

Effect of Different Types of Sand and Mixing Process (Gyawali, 2019)

In all series of theses investigative works, REC 15 (diameter of 40 µm and a length of 12 mm) type PVA fiber was used. Two types of mixing process as Pre-mixed Mortar Method and Pre-mixed Paste Method were adopted for the comparison. Pre-mixed mortar method was similar to that used in the HDM mixing method. In pre-mixed paste method, first cement paste was prepared with the first part of the water. Then, PVA paste was prepared by introducing PVA fibers to the viscous paste and mixing followed by the addition of sand and then mixing. Finally, the remaining water was added and mixed to prepare the PVA mortar. And, another parameter taken for the comparison was the type of sand as crushed sand and river sand.

Table flow values of PVA mortar of all types satisfied the minimum level of workability requirement (≥150mm). Three beam specimens were prepared for each type of mix and bending test was carried out with the 3rd point loading method.It was understood from an overall investigation that with an appropriate balance of workability (use of chemical admixture) and viscosity (viscosity agent), pre-mixed mortar mixing method enhances the flexural and ductility behaviour of HDM. Moreover, it is better to use smaller particle size sand to produce HDM for the development of multi-cracks panel to be used for formwork (Gyawali, 2019).

Mixingof PVA Mortar in Concrete Mixers with Different Types of Sand and PVA Fibers

The main objective of this experimental work was to check if PVA fibers can be mixed in big size concrete mixers for practical application. For this purpose, two types of double shaft and pan type mixers were chosen for mixing.

Mix Proportion

RECS 100 and REC 15 types of PVA fibers were chosen for the parameter of fiber types. Crushed sand of maximum aggregate size of 5 mm and river sand of 1.2 mm was taken for the comparison. **Table 3** gives the detail of mix proportion with different types and content of fibers, different types of sand and types of mixers. In order to make the mortar base mix more viscous in initial wet mixing (to disperse the thin and short fibers uniformly and coating firmly) and more workable in the final step of wet mixing, viscosity agent and super plasticizer were also added. The content of the viscosity was 0.4% by weight of water and that of super plasticizer was 1.0% by weight of cement.

Table 3: Detail of mix proportions of PVA mortar

Mixer Type	Mix Name	Mix Proportion Condition				Unit Content (Kg/m^3)					
		Fiber (%)		Sand Type	W/C (%)	W	C	S	G	Fiber	
		RECS 100	REC 15							RECS 100	REC 15
Forced Action	N-1	0	2	Crushed (5 mm)	32	345	700	300	734	0	26
	N-2	0	2			400	875	325	408	0	26
	N-3	3	0			400	875	325	395	39	0
Pan Type	O-1	0	2			345	700	300	734	0	26
	O-2	0	2			400	875	325	408	0	26
	O-3	3	0			400	875	325	395	39	0
	OS-1	0	2	River (1.2mm)		345	700	300	734	0	26
	OS-2	0	2			400	875	325	408	0	26
	OS-3	3	0			400	875	325	395	39	0

Mixing Procedure

The HDM mixing method was adopted in all series of mixing procedures. Mixing was carried out in 100 liters capacity of both type mixers. Since viscosity agent was used in powder form, it was pre-mixed with cement in bucket by small scoop. The super plasticizer was pre-mixed with the first part of water in the bucket. At first, sand and cement were charged into mortar mixer and dry mixing was carried out for 30 seconds. Then part of the water was poured into the mixer and wet mixing was carried out for 2 minutes. Then PVA fibers were charged into the mixer while mixing. After finishing of the charging of fibers, then further wet mixing was done in one minute. Finally,the remaining water was added and then mixing was done for further one minute.

Workability Tests and Test Specimens Casting

In visual check, PVA fibers were found uniformly distributed, without any clumps, and firmly coated by the mortar. The average table flow values of each series of mixing were more than 150mm, which was sufficient for the casting.After visual check and the workability test,3 specimens of small beams (10 cm × 10 cm × 40 cm) were produced in all series of experiments. All prepared specimens were first maintained in air curing for 24 hours, followed by moist curing in the water tank. Since the test results were for the comparison study, bending tests, with 4 point loading method, were carried out at 15 days of age.

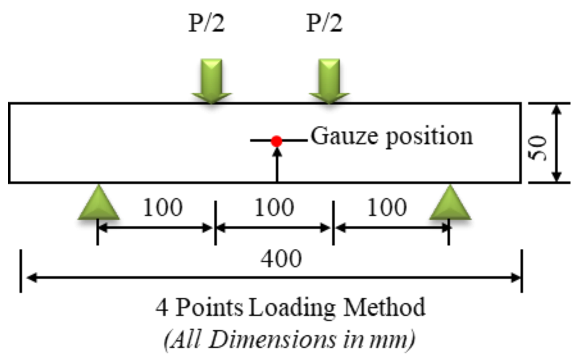

Fig. 1: Bending test method

Test Results and Analysis

Flexural stress- deflection relation data were obtained from bending test of each specimen. From the test results, the average flexural strengths were analyzed for the comparison. Table 4 gives the summarized results of average flexural strengths and variation coefficients for each parameter selected.

Table 4: Summarized result of average flexural strengths and variation coefficients

Mixer Type	Mix Name	Flexural Strength (MPa)	Variation Coefficient (%)
Double Shaft	N-1	9.0	10.6
	N-2	10.0	8.8
	N-3	9.0	8.5
Pan Type	O-1	7.7	10.1
	O-2	8.2	13.2
	O-3	7.2	5.9
	OS-1	6.6	2.1
	OS-2	7.8	10.6
	OS-3	11.0	9.0

From the test result, it is verified that the flexural strengths of PVA mortar mixed in the double shaft mixer (9.0 MPa, 10.0 MPa and 9.0 MPa for mixes N-1, N-2 and N-3 respectively) are higher than those mixed with pan type mixer (7.7 MPa, 8.2 MPa and 7.2 MPa for mixes O-1, O-2 and O-3 respectively). The flexural strength of PVA mortar with more cement paste is found relatively higher, i.e. flexural strengths of N-2, O-2 and OS-2 are more than those of N-1, O-1 and OS-1respectively. The most interesting result, the flexural strength of OS-3 (11.0 MPa) is the highest which should be considered as the base for the next series of experimental investigation. In general, it is experimentally verified that PVA mortar can be mixed in concrete mixers to achieve the required level of flexural strength depending upon other parameters.

Conclusion

The developed new mixing method "HDM mixing method" made possible to mix PVA mortar mixer increasing the flexural strength and deflection. It was also proved that single, thin and short PVA fiber gives more flexural strength and deflection than the combination of two different fibers. Sand of small particle size of 1.2 mm (river sand) has given a better performance than from crushed sand (5.0 mm).In this new experimental investigation, it was verified that PVA mortar can also be mixed satisfactorily in the concrete mixers, whereas the performance of double axis shaft mixer was found better than that in pan type mixer. The PVA mortar mixed in pan type mixer with 3% RECS 100 Fiber and river sand has given the highest flexural strength (11.0 MPa). It should be compared with that mixed in the double shaft mixer with the crushed sand.

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Conflict of Interests:*The author hereby declares that there is no any conflict of interest.*

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