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Investigation on Performance of High Ductile Mortar With Different Types of Sand and Mixing Process

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Abstract

The performance of High Ductile Mortar (HDM) with Poly-Vinyl Alcohol (PVA) fiberwas evaluated with two different types of sand and two different mixing methods. Parameters on sand were taken as crushed sand of 5 mm maximum size, i.e. Gmax = 5mm, and river sand ofgmax = 1.2 mm. Parameters for the mixing procedure were taken as pre-mixed mortar and pre-mixed paste. The use of the river sand gave the higher flexural strength (12.15 mpa in pre-mixed mortar and 11.05 mpa in pre-mixed paste) than that of crushed sand (11.25 mpa in pre-mixed mortar and 10.40 mpa in pre-mixed paste). Deflection values were also found higher in HDM with river sand (3.20 mm in pre-mixed mortar and 2.78 mm in pre-mixed paste) than in with crushed sand (2.15 mm in pre-mixed mortar and 1.89 mm in pre-mixed paste). In the stage of flexural strength of 6.4 mpa, cracks in the specimens were not visible. The result satisfied the requirement of multi-crack panels to be used for formwork.

Keywords: High Ductile Mortar (HDM); Poly-Vinyl Alcohol (PVA) fibers; pre-mixed mortar; pre-mixed paste; Flexural strength; Deformation

Introduction

Fiber reinforced cements and concrete (FRC) are firmly established as construction materials. Since the early 1960's extensive research and developments have been carried out with FRC materials leading to a wide range of practical applications [1]. With regard to the production of FRC, many trials had been carried out, especially with the timing of adding fiber materials when mixing and other materials as well. American Concrete Institute had listed the following 5 methods of adding fiber materials in 1982 [2].

1) Feed the fibers with the aggregate and cement on the central conveyor belt.
2) Blend fibers and aggregate before charging into the mixer and then use standard mixing procedure.
3) Blend fine and coarse aggregate. Add fibers to the mixer operating at mixing speed, then add water and cement.
4) Add fibers to previously charged aggregate as the water. Finally, add cement and remaining water.
5) Add fibers as the last step to mixed concrete.

However, American Concrete Institute, ACI 6.44-3R (1993), has indicated that the fibers should be added to a fluid mix, either as the last stage of mixing or added to the mixer with the aggregates [3]. Both documents of ACI indicated that care should be taken to avoid fiber balling. Many recommendations were made such as to avoid the clumps of fiber adding and slow rate of adding to allow dispersion.

Bartos and Hoy [4], [5], [6] had studied about the effect of mixing procedure on the properties of fiber reinforced concrete and especially with the feeding sequence of ingredients into the mixer. Its methods and descriptions are shown in Table 1.

Table 1: Method and descriptions of SFRC mixing methods

Method no.	Description
1	Coarse aggregates, cement, pfa and fines are layered in the mixer. The mixer is starte and the water and super plasticizer are added. After two minutes mixing fibers are added and mixing continues for 30 seconds.
2	Mix coarse and fine aggregates, cement and half water for 1 minute, add remaining water and mix for a further minute. Add fibers and mix for 30 seconds.
3	Mix fines, cement and half water for one minute, add remaining water and mix for one minute. Add fibers and coarse aggregate and mix for a further 30 seconds.
4	Mix fine aggregate, fibers, cement and half water for one minute, add remaining water and mix for one minute. Add coarse aggregate and mix for a further 30 seconds.
5	Mix the cement, water and super plasticizer for 90 seconds, and then add aggregates and fibers. Mix for a further minute.

The method of adding water and the time of adding fibers affected different properties of concrete in different ways. The best charging sequence may therefore depend on the performance criteria adopted, which depends upon the specific application

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requirements. The mixer used should be designed to prevent any fibers becoming lodged in gaps between the mixing blades or the mixing container. One of the most significant forecasts they made in their research was that ordinary mixers, recently used in construction practice may not satisfy the above mentioned requirement to obtain better quality of mixed FRC [5], [6].

Japan Concrete Institute [7] has recommended the mixing of concrete should be followed by feeding of fiber materials. The mixing volume of one batch should be less than 80% of the total volume capacity of the mixer. Mixing time is dependent upon the volume, type of mixer and concrete type as well. In general, more than 3 minutes is recommended for tilting type mixer and more than 2 minutes for the forced action mixer. Feeding of fibers should be carried consequently by running mixers and it should be done in such a way that all fibers should be dispersed uniformly. Feeding time for fibers depend upon the mixing volume and content of fibers. Generally, it should be 1~2 minutes. After all feeding of fibers, further mixing should be carried out for about one minute. The use of dispenser and vibrated chute or sieve is also recommended for feeding fiber materials.

Existing Problems with SFRC

In normal practice, the mixing of steel fiber reinforced concrete (SFRC) is carried out with the first method, described in Table 1, which is also recommended in most of the standards worldwide, i.e. ACI, JCI etc. However, it is noticed still difficult to make the even distribution of fiber materials in mixed concrete with this method in almost all types of existing mixers ever developed. Moreover, fibers may clump or form balls if more than 2% (by volume) of steel fibers are mixed with concrete. It is needless to say that the increase in the content of fiber means the increase in the requirement of external energy to make the fibers well distributed throughout the concrete. It means electric consumption of the mixer is more for the concrete with higher amount of fibers. In the forced type double axis mixer of 1.5m3 capacity [8], when mixing steel fiber reinforced concrete (SFRC) of slump about 10 cm, load becomes double than that of ordinary concrete. This becomes 4 times in the case of slump 5cm. From this result, it can be understood that the load becomes extremely large when mixing the dry consistency SFRC with its slump of 2~3 cm. In order to avoid the balling of the fibers within a short time of introducing, dispensers are being used. These dispensers help the fibers to be introduced into the concrete in the dispersed form, which minimize the chance for balling. However, when using one dispenser with its capacity of 40kg/min, it takes about 4 minutes to introduce all fibers into the mixer for mixing SFRC with 2% fibers. It means it requires more than 5 minutes mixing SFRC with 2% SF in 1.5m3 mixer. Therefore, the main reason to limit the fiber content from 0.5% to 2% in the existing mixer should be due to the electric load and the mixing time.

Development of Thin, Short and Light Fibers

Synthetic fibers have become more attractive in recent years as reinforcements for cementitious materials. This is due to the fact that they can provide inexpensive reinforcement for concrete and if the fibers are further optimized; greater improvements can be gained without increasing the reinforcement costs [9]. Moreover, unlike the steel fiber, which is highly corrosive in nature, there is no corrosion concern regarding synthetic fibers in concrete.

Victor Li., in early 1990s, first introduced that inclusion of small and thin synthetic fibers in cementitious material enhances toughness and increases crack resistance capacity as well as damage resistance capacity. His purposed product was known as Engineered Cementitious Composites (ECC) [9], [10]. By the time, Kuraray was the first Japanese company 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. [1a]. PVA fibers act greatly in a cement based matrix with no coarse aggregates due to their surface formation and high strength. The resulting composite, which exhibits a pseudo ductile behavior, is called ECC [9], [10]. Gong and Zhang carried out the research work on the effect of PVA fiber diameter on the crack resistance property of ECC [12].

Zhang et al. investigated the influence of matrix strength (water-binder ratio) on the bending resistance property of ECC [13]. Pang et al. did the research work on the effect of fly ash amount, cement-sand ratio, and the like on the mechanical properties of ECC [14]. Li and Xu studied the bending resistance property and flexural toughness evaluation method of ultra-high toughness cementitious composite (UHTCC) [15]. Zhou et al. conducted research on fracture and impact properties of short discrete jute fiber reinforced cementitious composites (JFRCC) with various matrix for developing low-cost natural fiber reinforced concretes and mortars [16]. Wang et al. performed experimental and numerical studies on the performance of seven high-performance fiber-reinforced cement-based composites against high velocity projectile impact [17]. Zhang et al. investigated the dynamic characteristics and the constitutive relationship of polypropylene fiber reinforced mortar (PFRM) materials under compressive impact loading [18].

With the development of such PVA fibers, many researchers 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 works have not been noticed to investigate the dispersing method of such thin and short fibers one by one inside the mortar and coating firmly by mortar. This paper has attempted many trials to investigate the appropriate method of dispersing and mixing of PVA reinforced cement paste to set the base for the development of High Ductile Mortar (HDM) with significant high flexural strength and high ductility.

Theoretically, we know that if small and thin fibers are uniformly distributed and if each individual fiber is well coated with mortar, then it is possible to increase the strength and ductility of mortar by strengthening the transition zone in between paste and aggregate as each well coated fiber plays the important role of structural bridging the phases. For this, small and thin fibers were pre- distributed before mixing with mortar.

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Moreover, sequence and timing of charging each ingredient were modified while mixing fiber mortar. The result was obtained:

1. Pre-distribution of PVA fibers in air pressure gave the best result of the distribution. [19]
2. Mixing of fiber mortar in chopper mixer gave the better result than in a mortar mixer. [19]

With development of new mixing procedure, namely High Ductile Mortar (HDM) mixing method, it significantly enhanced the strength and ductility behaviour of the High Ductile Mortar. It was because this method made possible to disperse thin and short PVA fibers within the viscous mortar, prepared with the first portion of water, and fine coating around each fiber; then, its required workability was achieved with the addition of the second portion of water without disturbing distribution and coating condition of PVA fibers [20].

With development of new HDM mixing method, the author, in this paper, investigated the effect of the type of sand and comparison of premixed mortar and paste on the flexural and ductility behaviour of HDM.

Objective

The main aim of this experimental and investigative work is to identify the type of sand and the appropriate mixing procedure to enhance the flexural and deflectionbehaviour of HDM. Its specific objectives are:

(1) Use of crushed sand (5mm) and river sand (1.2 mm) to check the flexural strength and deflection of HDM.

(2) Use of pre-mixed mortar and pre-mixed paste mixing to check the flexural and deflectionbehaviour of HDM.

The author believes both above investigative work may create the logistic base for the development of HDM.

Necessity of this Research Work

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 deflection. 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 flexural tensile stress.

Experimental Procedure

Main parameters used in this study were types of sand and two different mixing procedures. Two types of sand as crushed sand (maximum size of 5mm) and river sand (maximum size of 1.2 mm) were used in this experiment.

Type of PVA Fiber and Mix Proportion

In all series of theses investigative works, REC 15 (diameter of 40 µm and a length of 12 mm) type PVA fiber was used. Their details are given in Table 2.

Table 2: Properties of PVA fiber used in experimental investigation

Parameters	Characteristics
Fiber Type	REC15
Diameter (mm)	0.04
Length (mm)	12
Specific gravity	1.3
Tensile strength (MPa)	1600
Young's modulus (GPa)	41
Fiber Elongation (%)	6

Table 3: Mix proportion for ranging percentage of RHS182 and 2% of REC40 and RECS100 type fibers

Mix Proportion Content									
W/C (%)	Fiber Content (%)	SP	VA	W	C	S	Fiber	S	VA
		(% by C)	(% by W)						
32	2.0	1.0	0.4	400	1250	489(476)	16	12.5	1.6

W = Water, C = Cement, S = Sand, SP = Super plasticizer, VA = Viscosity agent
The unit content of sand indicated in parentheses is river sand

Table 3 gives the mix proportion of the HDM used in the experiment.

Mixing Procedure

HDM mixing procedure [21] was the basic mixing procedure. In addition, two different mixing procedures were used as pre-mixed mortar mixing method and pre-mixed paste mixing method. Before mixing with both methods in the mortar mixer, viscosity powder was first tentatively mixed with cement with a spoon in the bucket and the super plasticizer was mixed in water.

Pre-mixed Mortar Mixing Method

Cement and sand were introduced into the mortar mixer and dry mixing was carried out for 30 seconds with low speed. Then, the first part of water was poured and the wet mixing was done in 90 seconds with high speed. After then, mixing was done with low speed for a further 90 seconds by pouring PVA fibers part by part. After finishing of introducing fibers, mixing was done with high speed for 90 seconds. Finally, the second part of water was poured and mixing was done with high speed for 120 seconds. Total mixing time, in this method, was adopted as 7 minutes.

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Pre-mixed Paste Mixing Method

Cement was introduced into the mortar mixer and dry mixing, with low speed, was carried out for 30 seconds in order to mix the viscosity powder inside the cement uniformly. First part of water was poured and wet mixing was carried out for 120 seconds with high speed. Further 90 seconds mixing was done with low speed by pouring PVA fibers part by part followed by 90 seconds mixing of high speed. Then, sand was added and a further 90 seconds mixing was done with high speed. Finally, the second part of was added and mixing with high speed was done for 90 seconds. Total mixing time, in this method, was adopted as 8.5 minutes.

Workability Evaluation and Strength Tests Method

The first investigative evaluation of the prepared mortar was just the visual check with an eye and touched by hand. The second was flowing table test followed by mechanical properties tests. Visual check was almost similar in all series of mixed fiber mortar. No any fiber lump was noticed throughout the mixed mortar. Each fiber was found uniformly distributed and well coated with mortar/paste. Moreover, it was found with the tentative check of the viscosity by hand, high ductile was found to be easier for placing, compaction and finishing. All table flow values of fiber mortar were obtained greater than 150 mm.

After visual check and the workability test, 3 small beams with sizes of 400mm × 100mm × 50mm (length × width × depth) were produced in all series of experiments for 28 days tests.

Bending test was carried out with 3rd point loading method, as shown in Fig. 1. Strain gauge was set at the exact centre of the depth to measure the deflection (strain) while increasing load (stress) momentously Fig. 1

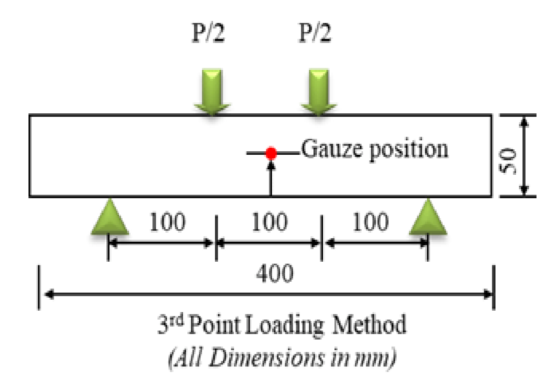

Figure 1: Bending test method

Test Results and Analysis

Fig. 2 and Fig.3 show the results on the relationship of flexural stress and deflection curvewith pre-mixed mortar mixing method and pre-mixed paste mixing method respectively. Fig. 2 and Fig.3

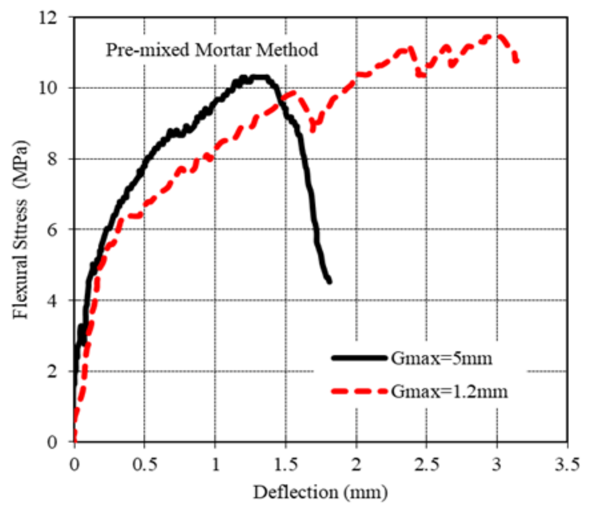

Figure 2: Flexural stress- deflection relationship of pre-mixed mortar mixing method

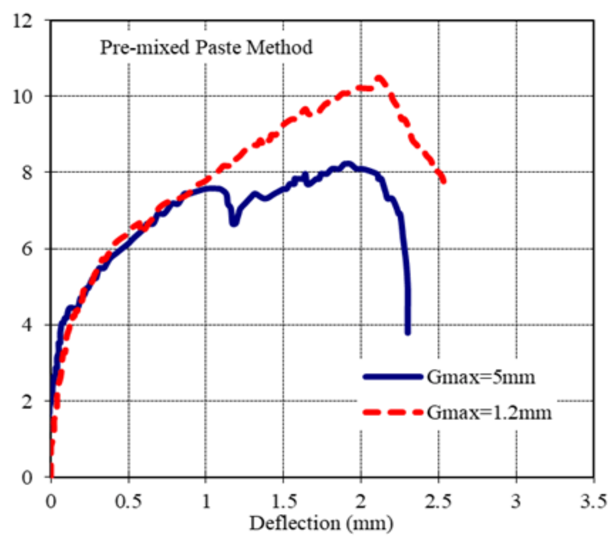

Figure 3: Flexural stress- deflection relationship of pre-mixed mortar mixing method

In the pre-mixed mortar mixing method, average flexural strength of 12.15 MPa was obtained for river sand of Gmax = 1.2 mm and 11.25 MPa was obtained for the crushed sand of Gmax = 5mm. And in the pre-mixed paste mixing method, average flexural strength of 11.05 MPa was obtained for river sand and 10.40 MPa was obtained for the crushed sand. The respective deflection values in pre-mixed mortar mixing method were 3.20 mm for river sand and 2.15mm for crushed sand, And in pre-mixed paste mixing method, values were 2.78 mm for river sand and 1.89 mm for crushed sand.

Fig. 4 and Fig. 5show the result on the close-up relationship of flexural stress and deflection relationship up to the flexural stress of 4.5 MPa for pre-mixed mortar mixing method and pre-mixed paste mixing method. Fig. 4 and Fig. 5

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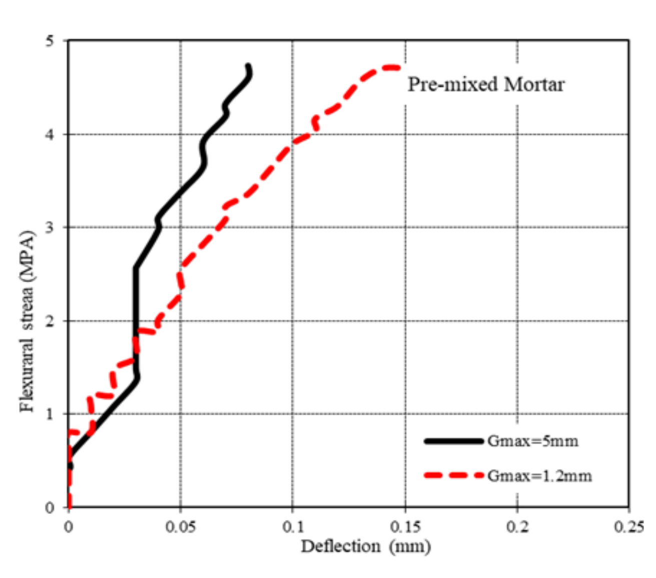

Figure 4: Close-up flexural stress- deflection relationship of pre-mixed mortar method up to 4.5 MPa

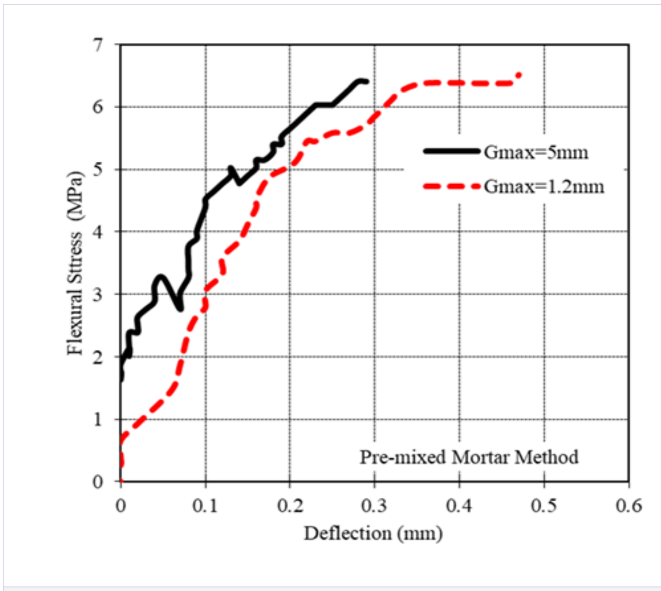

Figure 6: Close-up flexural stress- deflection relationship of pre-mixed mortar method up to 6.4 MPa

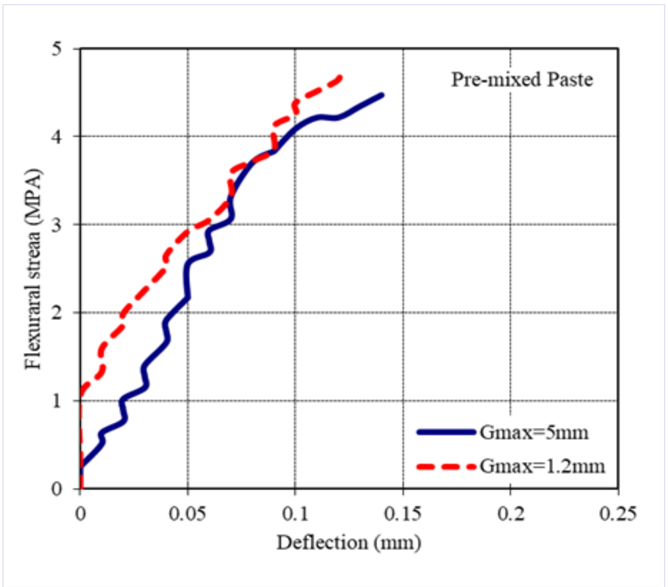

Figure 5: Close-up flexural stress- deflection relationship of pre-mixed paste mixing method up to 4.5 MPa

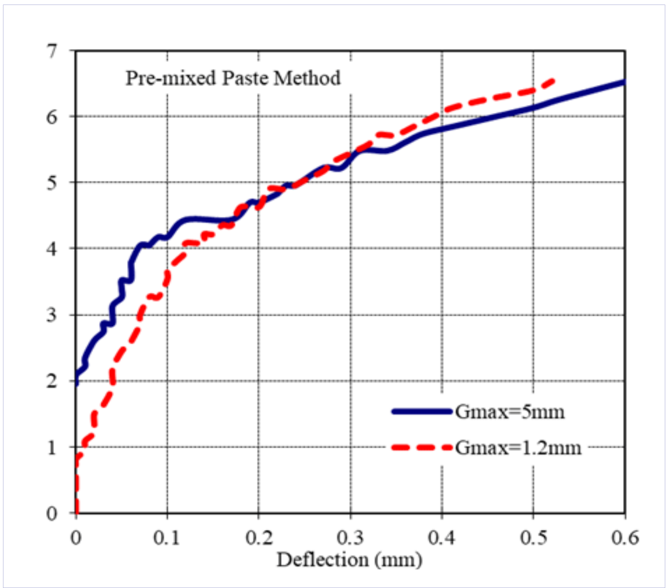

Figure 7: Close-up flexural stress- deflection relationship of pre-mixed paste mixing method up to 6.4 MPa

As per Japanese standard, flexural strength of the multi-crack panel should be more than 10.6 MPa. When it is used as formwork, its flexural strength should be more than 6.4 MPa without formation of any cracks. With consideration the partial factor as 1.5, 5.3MPa is taken as the design flexural strength of such multi-crack panes to use as formwork. Fig. 6 and Fig. 7.

Fig. 6 and Fig. 7show the result on the close-up relationship of flexural stress and deflection relationship up to the flexural stress of 6.4 MPa for pre-mixed mortar mixing method and pre-mixed paste mixing method.

In the pre-mixed mortar mixing method, average deflection values were 0.46 mm for Gmax = 1.2 mm and 0.29 mm for Gmax = 5.0 mm. And, in the pre-mixed paste mixing method, those values were 0.52 mm and 0.6 mm respectively. Moreover, no any micro-cracks were noticed, in all specimens, at this stage of loading.

Fig. 8 shows the condition of the bottom surface of the specimens, with river sand and mixed with premixed mortar method, after the completion of bending test. It has clearly seen the numbers of multi-cracks on the surface.Fig .8

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Figure 8: Condition of multi-cracks on bottom surface of specimen after completion of bending test

Figure 9: Condition of the bottom surface after flexural stress reached to 6.4 Mpa in bending test

Fig. 9 shows the condition of the bottom surface of the specimens, with river sand and mixed with premixed mortar method, while the flexural stress reached at 6.4 Mpa in the bending test. It has clearly seen the numbers of multi-cracks on the surface. No any single crack was seen on the surface and the condition of the surface was similar to that observed before the bending test. Fig.9

The summarized data of all test results are listed in Table 4. C: Crushed Sand; R: River Sand

Table 4: Summarized data of all test results

Mixing Method	Sand Type	Deflection at 4.5Mpa(mm)	Deflection at 6.4 Mpa(mm)	Flexural Strength(Mpa)	Deflection at Max Strength (mm)
Pre-mixed Mortar	C: Gmax=5.0 mm	0.075	0.29	10.3	1.35
	R: Gmax=1.2mm	0.125	0.46	11.4	3.02
Pre-mixed Paste	C: Gmax=5.0 mm	0.15	0.6	8.2	1.93
	R: Gmax=1.2mm	0.11	0.52	10.5	2.12

After analysing all important data of all tests, the following major points were drawn:

- It was made possible to increase the flexural strength of 50 mm depth specimen with distribution of hair like multi-cracks before the failure.
- Elastic yield limit, at flexural stress – strain curve, was obtained about at 4.5 Mpa in pre-mixed paste mixing method; whereas, that limit was increased up to about 5.0 Mpa in pre-mixed mortar mixing method. In each mixing method, the elastic yield limit was similar for both types of sand.
- No any crack was visible while the flexural stress reached at the level of 6.4 Mpa.
- The deflection was higher of the HDM with smaller size river sand than with the crushed sand with larger size at maximum flexural strength.
- Flexural and deflectionbehaviour of HDM was enhanced while using river sand than the crushed sand. This difference was more significant in pre-mixed mortar mixing method than in pre-mixed paste mixing method.
- The target of flexural strength required for the multi-cracks panel was obtained only in the HDM of river sand (11.4 Mpa) mixed with pre-mixed mortar mixing 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 deflectionbehaviour 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.

Conclusions

The maximum particle size of sand and the mixing procedure were investigated to enhance the flexural behaviour of HDM. Crushed sand (Gmax=5.0 mm) and river sand (Gmax=1.2 mm) was used as parameters for types of sands. Pre-mixed mortar and pre-mixed paste method was used as the parameter for mixing procedure. No any cracks were observed at the level of flexural stress of 6.4 MPa, which is one of therequirements of multi-cracks panel for formwork. Flexural and deflectionbehaviour of HDM was enhanced while using river sand than the crushed

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sand. This difference was more significant in pre-mixed mortar mixing method than in pre-mixed paste mixing method. The target of flexural strength required for the multi-cracks panel was obtained only in the HDM of river sand (11.4 MPa) mixed with pre-mixed mortar mixing 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 deflectionbehaviour 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.

Future Scope

The author has focused on developing High Ductile Mortar (HDM) with a target of the flexural strength more than 12 MPa, required for tunnel pre-cast segments, replacing steel fibers with short and thin synthetic fibers in order to overcome the problems on mixing as well as to enhance the flexural strength and deflectionbehaviour. Since, it is very preliminary investigative work; the focus was given on different parameters to identify qualitatively rather than quantitatively.

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Conflict of Interest

The author hereby states that there is no conflict of interest.

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