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Properties of High Strength Flowable Mortar Reinforced With Different Fibers.

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Abstract

An experimental study was conducted on the high-strength flowable mortar (HSFM) reinforced by the different percentages of palm Fiber (0, 0.5& 1%), steel fiber (0, 0.5, 1.0& 2%), and the hybridization of these two fibers with 2% volumetric fractions. Different tests have been done to determine some aspects namely the density, compressive strength, splitting tensile strength, static modulus of elasticity, flexural strength, toughness and ultrasonic pulse velocity. The results show that the use of hybridization of steel fiber with palm fiber gives an unambiguous improvement in these properties and thus the optimum percentages for these two fibers have been taken into consideration. The use of low volume fraction of palm fiber in hybrid fiber mixes was found to be a promising concept in HSFM mixes.

Keywords: Steel fiber; Palm fiber; High strength mortar; Toughness; Ultrasonic pulse velocity.

1. Introduction

The use of fibers in cement-based materials may considerably enhance the toughness, impact resistance, durability and reduce the cracking in concrete [1]. The main weaknesses of incorporating the fibers, are the loss of workability and the increased difficulty of casting. This status may lead to an insufficient workability and high volumes of entrapped air in mortar, which cause reduction in its strength and durability [2]. The modern concrete can be designed to have the high flowability, whereby the term 'flowability' suggests that the concrete is able to flow in the congested reinforcement areas and fill complicated formwork without segregation [2, 3]. Additionally, the repaired mortar applied to concrete is usually hard to consolidate well; therefore, the said mortar with high flowability may bring considerable advantages to the narrow mould system [4].

Natural fibers have the potential to serve as a reinforcement to overcome the inherent deficiencies in cementitious materials. In recent years, there has been a sustained interest in utilizing natural fibers in cement composites and in manufacturing products based on these fibers with a view that alternative building materials which are energy-efficient, economical and eco-friendly can be made. This is of course, with the condition that the function of natural fibres in a relatively brittle cement matrix is to achieve and maintain toughness and ductility of the composite [5-7].

By far the best advantage of using natural fibers is that they offer significant cost reduction and benefits associated with processing as compared to synthetic fibers [8]. However, the primary problem with the use of natural fibers in concrete is their tendency to disintegrate in an alkali environment. Efforts are being made to improve the durability of these fibers in concrete or mortar by using admixtures to make concrete less alkaline and by subjecting the fibers to special treatment[5,8].

Steel fiber has a considerably higher Young's modulus, in comparison to the other fiber-types. This leads to an improved potential for crack control, although the volumetric density is high. As a result, the steel fiber content has to be reduced to a certain level. Optimizations of mechanical and conductivity properties can be achieved by combining different types and sizes of fibers, such as in the case of Palm and steel fiber [9, 10].

The research concentrates on highlighting some properties of high strength flowable mortar (HSFM) reinforced with different volume fractions of the single- palm fiber as well as the single - steel fiber and then the hybridization of these two fibers.

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2. Materials and mixed proportions

2.1 Materials

The cement used in mortar mixtures was the ordinary Portland cement type I from Tasek Corporation Berhad. Silica fume was obtained from Scancem Materials Sdn. Bhd. and used as partial replacement of cement. The chemical compositions of Ordinary Portland and silica fume are given in Table (1).

TABLE 1: CHEMICAL COMPOSITION OF ORDINARY PORTLAND CEMENT AND SILICA FUME

Constituent	Ordinary Portland Cement	Silica fume
	% by weight	% by weight
Lime (CaO)	64.64	1.0% (max)
Silica (SiO_2)	21.28	90% (max)
Alumina(Al_2O_3)	5.60	1.2 % (max)
Iron Oxide(Fe_2O_3)	3.36	2.0% (max)
Magnesia(MgO)	2.06	0.6%(max)
Sulphur Trioxode (SO_3)	2.14	0.5%(max)
N_2O	0.05	0.8%(max)
Loss of Ignition	0.64	6% (max)
Lime saturation factor	0.92	-----
C_3S	52.82	-----
C_2S	21.45	-----
C_3A	9.16	-----
C_4AF	10.2	-----

The superplasticizer (SP) is Conplast SP1000 obtained from Fosroc Sdn. Bhd. It's according to ASTM C494 type F. It was used to establish the desired flowability of mixes. The fine aggregate was natural sand, with a fineness modulus of 2.86 and maximum size of less than 5 mm. The palm fiber was supplied by Fiber-X (M) Sdn. Bhd, and their characteristics are shown in Table (2). The steel fiber used in this study is hooked ends low carbon cold drawn produced by Hunan Sunshine Steel Fiber Co. Ltd, and its characteristics are presented in Table (3).

TABLE 2: CHARACTERISTICS OF PALM FIBER

Fiber Properties	Quantity
Average fiber length,(mm)	30
Average fiber width ,micron	21
Tensile strength(MPa)	21.2
Specific gravity	1.24
Water absorption%, 24/48 hrs.	0.6

TABLE 3: CHARACTERISTICS OF STEEL FIBER

Fiber Properties	Quantity
Average fiber length,(mm)	30
Average fiber width,(mm)	0.56
Aspect ratio(l/d)	54
Tensile strength (MPa)	> 1100
Ultimate elongation (%)	< 2
Specific gravity	7.85

2.2 Mix proportions and mixing method

The design of Mortar compositions is shown in Table (4). Ten mortar mixes were prepared using the water-binder (Cement+ Silica fume) ratio as 0.43 and silica fume replacement of 10%. The amount of cement, silica fume, sand and free water were kept constant. The amount of superplasticizer (SP) varied from 1.8% to 2.2% by weight of binder materials content to maintain the required flowability for all mixes. The mix design of the control mix (MF0) was carried out according to the absolute volume method given by the ACI 211.1 [11] to achieve the criteria of flowing high strength mortar. The palm fiber of the volumetric fractions 0.5 & 1.0% were used to prepare mixes: MF1& MF2, respectively. The steel fiber of the volumetric fractions 0.5, 1.0 & 2.0 % were used to prepare mixes: MF3, MF4 & MF5, respectively. The hybrid fiber of 2% was also used but with different amounts from each of palm fiber and steel fiber in the mortar mixes"MF6-MF9".

TABLE 4: MORTAR MIX PROPORTIONS

Index	Cement Kg./m^3	Silica fume Kg./m^3	Water Kg./m^3	Sand Kg./m^3	SP %	W+SP/B	*Steel fiber %	*Palm fiber %	Flow (mm)
MF0	550	55	260	1410	1.8	0.43	0	--	160
MF1					1.8	0.43	--	0.50	150
MF2					2.0	0.43	--	1.0	145
MF3					1.8	0.43	0.50	--	145
MF4					2.0	0.43	1.0	--	145
MF5					2.2	0.43	2.00	--	140
MF6					2.2	0.43	1.75	0.25	140
MF7					2.2	0.43	1.50	0.50	145
MF8					2.2	0.43	1.25	0.75	145
MF9					2.2	0.43	1.0	1.0	150

* Volumetric percentages are given in this Table; weight/volume of fibers should be used to calculate the mortar components per cubic meter.

Each batch of mortar was produced in a pan mixer. At first, cement, sand, water and SP were added to the mixer and mixed for 3 minutes. Then the silica fume was added and the mixture was further mixed for 2 minutes. Finally, the steel fiber or/and palm fiber was disseminated to prevent any agglomerates of fibers and the mixture was further mixed for other 3 minutes.

3. Test methods

Three cube samples of 50 mm were used for each mix to test the density and compressive strength at 28 days, after undergoing water curing. The Flow test for the mixes was performed according to ASTM C230 [12] with a targeted flow of 150 ±10mm. The cube specimens were left in the moulds for 24 hours at 20 °C. After demoulding, the specimens were transferred into the water for curing until the age of test. Saturated surface dry specimens were used to determine the density, and this test was carried out according to ASTM C642 [13]. The compressive strength test was done immediately after determining the density test specimens according to ASTM C109 [14] for each test age. The splitting tensile strength test was achieved using the average of three cylindrical specimens (D=100 mm × H=200mm) according to ASTM C496 [15]. On the other hand, the average of three cylinders (D=150 × H=300 mm) was used to determine the static modulus of elasticity test according to ASTM C469 [16]. The flexural strength and the toughness indices of the specimens were performed by using 40× 40 × 160 mm samples (the average of three specimens) at similar ages according to ASTM C348[17], and ASTM C1018[18], respectively. Finally, the test of ultra sonic pulse velocity was carried out according to BS EN 12504-4:2004[19].

4. Results and Discussion

4.1 Effect of fibers on flowability

The effect of fibers on the flow of the ten mortar mixes is highlighted in Table (4). It is easy to note that the inclusion of steel fiber in HSFM reduces the flowing ability and thus higher dosage of SP is needed to achieve the required workability. On the other hand, in mortar mixes with hybrid fibers, a higher amount of palm fibers makes better flowability. In summary, the effect of palm fiber on either the flowing or working capacity is much less than that of the steel fiber.

4.2 Saturated surface dry density

Table (5) shows the results of the saturated surface dry density for all mixes. The saturated surface dry density results at 28 days for the mixes of palm fiber (MF1& MF2), show that the density reduced uniformly with the increase of palm fiber content: The behavior is probably due to the specific gravity of palm fiber which reduces the overall density of mortar. On the other hand, the saturated surface dry density at 28 days for the different mixes of steel fiber (MF3-MF5) show that there is a rise in the density level as the volume fraction of steel fiber increases and again this is resulted from the specific gravity of steel fiber which increases the overall density of mortar. Continuously, the hybrid fiber results (MF6-MF9) also illustrate that the use of palm fiber as a partial replacement of steel fiber reduces the overall density of HSFM.

4.3 Compressive strength

From Table (5), when a single type of fibers was used, the increase in the compressive strength of the high strength flowable mortar (HSFM) reinforced with palm fiber was up to 14.4 % compared with that of the reference mortar. This result was obtained from the low volume fraction of palm fiber up to 0.5% used in the mix (MF1). The use of 1.0% of palm fiber reduces the compressive strength and this is probably due to air voids and disintegration when the excessive fiber content was used in the mortar mixes [20]. Alternatively, the compressive strength of the high strength flowable mortar (HSFM) with steel fibers volume fraction increased significantly compared to the reference mortar. It is observable that the increase of the compressive strength by using 1.0% volume fraction of steel fiber (MF4) would increase the compressive strength up to 12.1%, as opposed to the reference mortar. This condition can be rooted from the improvement in the mechanical bond strength when the fibers allow the ability to delay the micro-crack formation and arrest their propagation afterwards up to a certain extent [20-22]. The comparison between control mortar mix (MF0) with the highest volume fraction of steel fiber (2%) used in this study (MF5) shows that there is no significant enhancement of compressive strength. This is again due to the increase of air voids and disintegration when the excessive fibers were used in the mortar mixes [20]. The results of hybrid fiber (MF6-MF9) in the HSFM also indicate that the use of low volume fraction of palm fiber (0.25% & 0.5%) improves the compressive strength of the HSFM as observed from mixes MF6 & MF7. This is due to the fact that hybrid fibers with different sizes and types are contributed to different restraints [23].

TABLE 5: MECHANICAL PROPERTIES OF MORTAR MIXES

Index	Density Kg./m^3 (28days)	Compressive strength (MPa) (28days)	Splitting Tensile strength (MPa) (28days)	Static modulus of elasticity (GPa) (28 days)	Ultra sonic pulse velocity (m/s) 90 days
MF0	2300	54.3	2.1	33.1	3770
MF1	2280	62.1	2.15	36.8	4170
MF2	2265	52.4	2.0	33.5	4050
MF3	2340	58.9	2.23	37.9	3920
MF4	2360	60.9	2.53	40.4	4070
MF5	2400	55.7	2.62	45.1	4110
MF6	2325	57.8	2.71	47.8	4140
MF7	2305	58.4	2.89	44.9	4100
MF8	2285	54.9	2.35	42.7	4080
MF9	2280	54.4	2.25	41.8	4060

4.4 Splitting Tensile strength

The splitting tensile strength results of the HSFM mixes are shown in Table (5). It is important to note that the incorporation of single-palm fiber may not improve the splitting tensile when 1% of palm fiber was used. In contrast to that, the influence of steel fiber on the splitting tensile strength is much effective. The increase of splitting tensile strength was recorded with the increase of steel fiber inclusion in the mix. The splitting tensile strength was increased by using 2% of steel fiber as 29% higher than that of the control mix [24]. On the other hand, the hybrid fiber results indicated that the use of 1.5% steel fiber with the 0.5% palm fiber increases the splitting tensile strength by about 38% higher than that of control mix. This is because the mortar with the ability of two different types of fibers to bridge the major crack and thus, the micro-mechanical feature of crack bridging is operative from the stage of damage evolution to beyond ultimate loading [25].

4.5 *Static modulus of elasticity E_c*

The modulus of elasticity results for all HSFM mixes are presented in Table (5). The comparison between MF0 with MF1 indicates that the use of 0.5% palm fiber leads to an increase in static modulus of elasticity of HSFM. On the other hand, the use of steel fiber in HSFM, enhances the static modulus of elasticity. It can be concluded that the higher percentage of the steel fiber gives the higher the modulus of elasticity. This is probably due to high stiffness of steel fiber, which leads to a higher modulus of elasticity for HSFM [25-27]. The hybrid fiber results show that the use of 0.25% of palm fiber with 1.75% steel fiber, gives the higher improvement for the static modulus of elasticity of HSFM. This is probably due to the optimization of these percentages of fibers to produce the higher bond strength behavior and thus a higher modulus of elasticity [25-28].

4.6 Flexural strength

The flexural strength results of HSFM mixes are shown in Table 6. The results of mortar mixes containing the single palm fiber indicate that the increase of the flexural strength using 0.5% volume fraction (MF1) is 16.4% higher than that of the control mix (MF0). On the other hand, the use of single steel fiber up to 2.0% for the mix (MF5) increases the flexural strength of 109% higher than the control mix (MF0) and this could be due to better compactness and homogeneity of fiber distribution in HSFM [20,23,25]. The hybrid fibers results are also given the limelight in Table 5. The mortar mix MF7 (1.5% steel fiber + 0.5% palm fiber) exhibits the highest increment, which is up to 132.5% higher than that of the control mix (MF0). Fig. (1) summarizes the mechanical properties that utilize the different percentages of fibers.

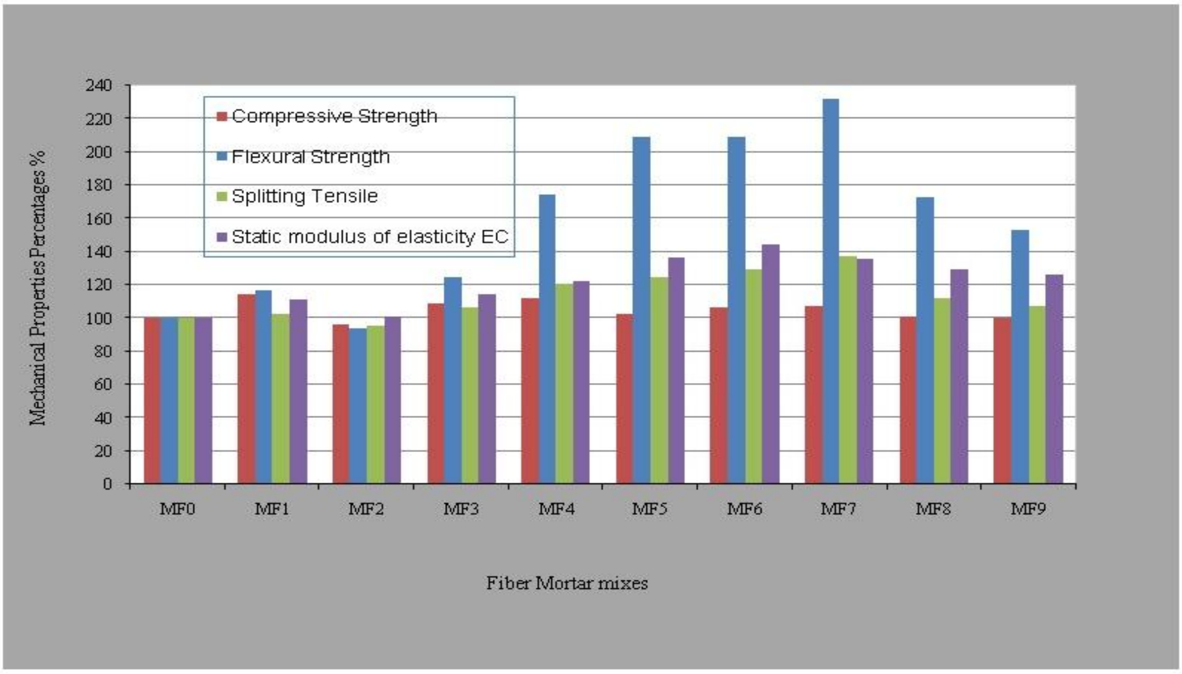

Figure 1: Relationship between fiber mortar mixes with mechanical properties percentage.

4.7 Toughness Indices

The Toughness Indices were determined according to ASTM C1018. The indices I-5 and I-10 can be gained from this test. Table 6 illustrates the results of the I-5 & I-10 for 28 days. It can be observed that the mono palm fiber fraction up to 0.5% has no effect on the toughness indices, while the use of 1% of this fiber was found to give a slight improvement in the toughness concerns. Fig. (2), illustrates the load-deflection curves for mortar containing different percentages of palm fiber. On the other hand, the use of single steel fiber has a clear effect when the volume fraction used is 0.5% and more. The toughness indices increase with the increasing content of fibers, the reason being the ability of fibers in arresting cracks at both micro-and macro–levels. At micro-level, fibers inhibit the initiation of cracks, while at macro-cracks, fibers provide effective bridging and impart sources of toughness and ductility [24, 25]. These findings are also supported by other researchers [20, 29], whereby it is added that the flexural toughness can be increased as the fiber volume fraction is increased and similarly higher values of the toughness indices can be obtained at higher fiber volume fractions. However, the use of 2% of steel fiber can be utilised in HSFM to give the significant improvement for the toughness indices. Figure 3 shows the load-deflection curve of mortar mixes with different percentages of steel fiber. The hybrid fiber results show that the use of hybrid fiber as: 1.5% steel fiber + 0.5% palm fiber (MF7) was found to show the highest improvement for the toughness indices. Figure 4 illustrates the load-deflection curve of hybrid fiber mortar mixes. By viewing the Figs (2, 3 & 4), it can be seen that the stronger and stiffer steel fibers enhance the first crack and ultimate strength, whereas the more flexible and ductile fibers palm fibers improve the toughness and strain capacity in the post- crack zone [30-32]. Fig. (5) summarizes the respective effects of using different volume fractions of palm fiber, steel fiber and the combination between these fibers on the toughness indices at 28 days of normal water curing.

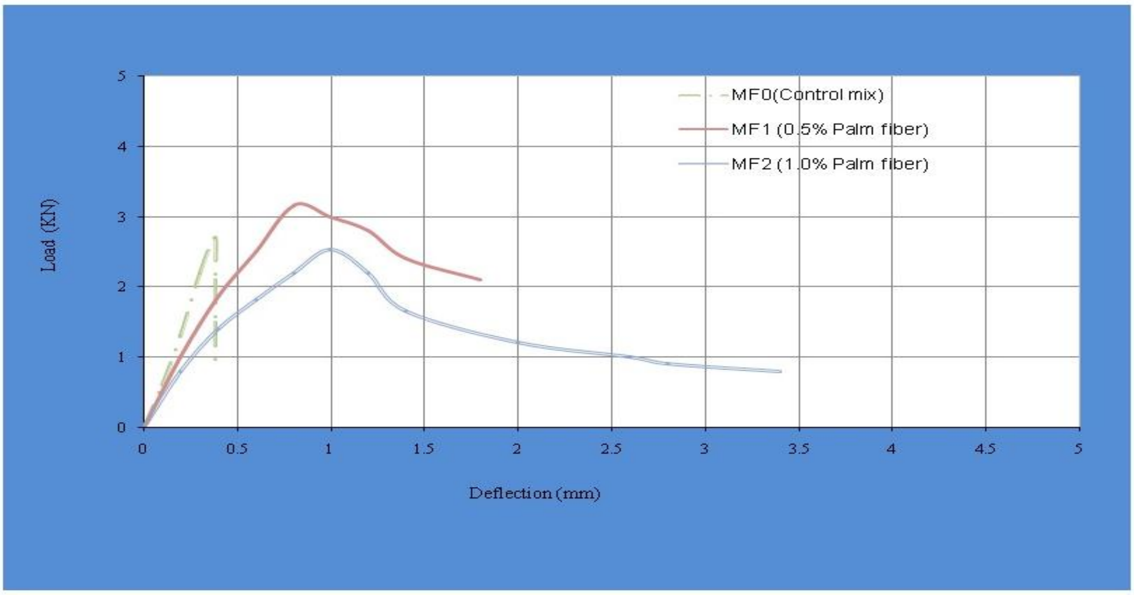

Figure 2: Load-deflection curves for high strength flowable mortar (HSFM) reinforced by different percentages of palm fiber.

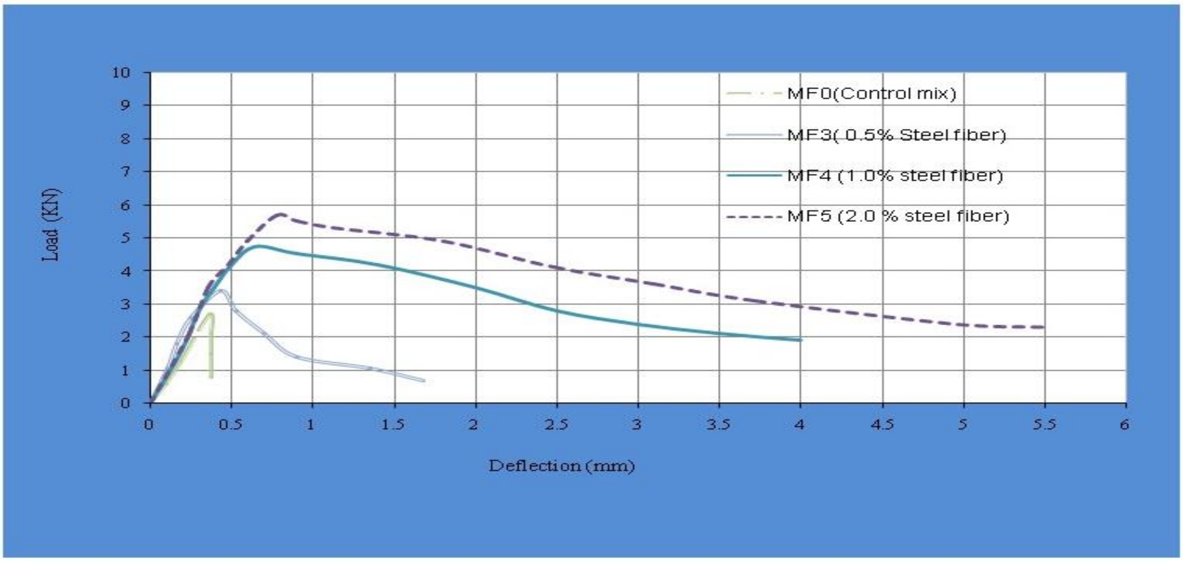

Figure 3: Load-deflection curves for high strength flowable mortar (HSFM) reinforced by different percentages of steel fiber.

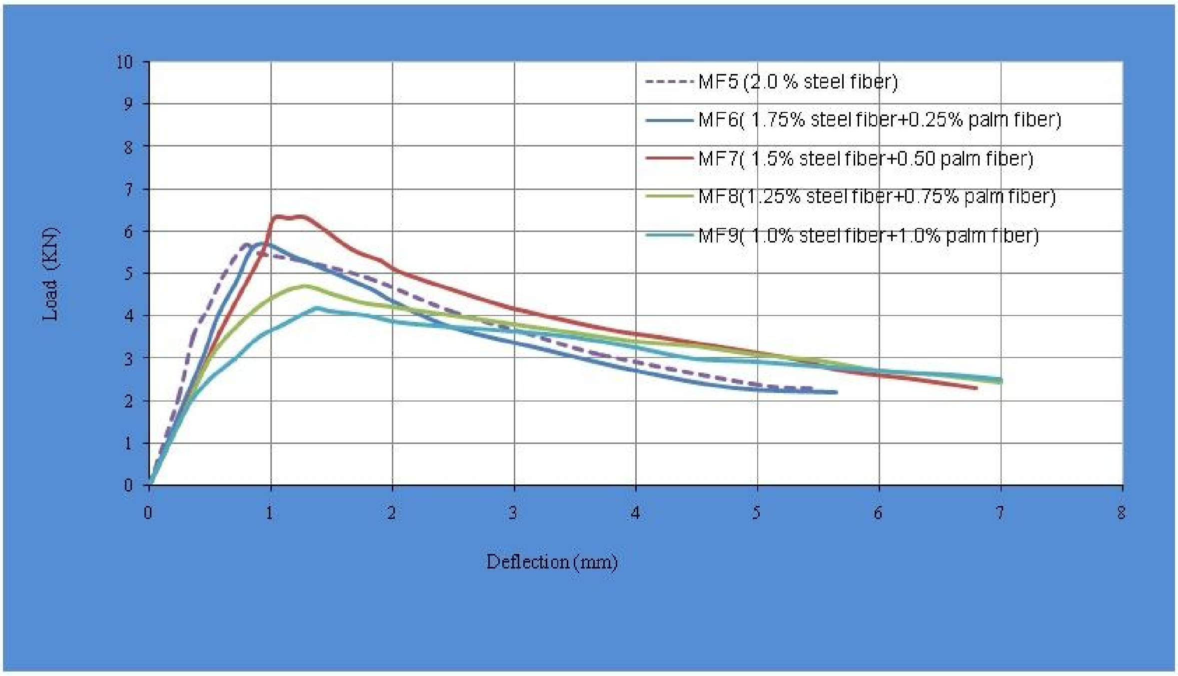

Figure 4: Load-deflection curves for high strength flowable mortar (HSFM) reinforced by hybird fibers.

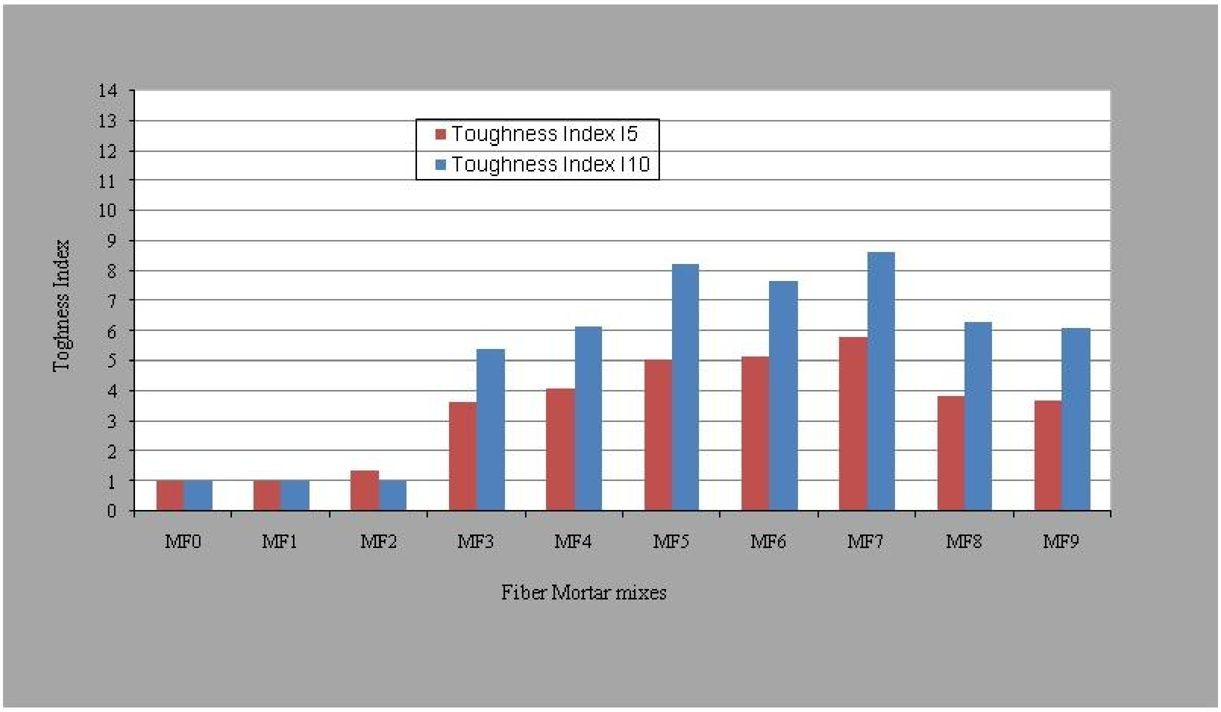

Figure 5: Relationship between fiber mortar mixes with toughness index.

TABLE 6: TOUGHNESS INDICES FOR MORTAR MIXES

Index	Flexural strength (MPa) (28days)	Toughness Index (I 5) (28 days)	Toughness Index (I 10) (28 days)
MF0	7.60	---	---
MF1	8.85	---	---
MF2	7.10	1.88	---
MF3	9.49	3.64	5.42
MF4	13.25	4.10	6.16
MF5	15.90	5.05	8.22
MF6	15.92	5.15	7.67
MF7	17.67	5.82	8.62
MF8	13.12	3.84	6.32
MF9	11.65	3.66	6.12

4.8 Ultrasonic pulse velocity test

The ultrasonic test for all HSFM was implemented at age of 90 days. The highest value of ultrasonic velocity (4170 m/s) was obtained by the inclusion of 0.5% palm fibers in HSFM mixes. On the other hand, the results showed that the steel fibers enhanced the results for the velocity of ultrasonic test. Therefore, the inclusion of 2% vol. of steel fibres in HSFM mixes increased the ultrasonic velocity from 3770 m/s to 4110 m/s. The greatest value of ultrasonic pulse velocity test (4110 m/s) was obtained when 2% vol. of steel fibers was used

The results for all hybrid fibres also show that the ultrasonic results increases with the fibers inclusions. The highest value of hybrid fibers for HSFM was 4160 m/s which was obtained in mortar mix (MF6) using 1.75 % of steel fiber + 0.25 % palm fiber. However, for HSFM mixes reinforced with hybrid fibers, it was found that the ultrasonic pulse velocity is related to compressive strength.

5. Conclusions

The results of an experimental study on the high strength flowable mortar (HSFM), reinforced with various volume fractions of palm fiber and/ or steel fiber reveal the following conclusions:

1. The compressive strength results show that the use of 0.5% mono- palm fiber increases the compressive strength by about 14.4%, while the use of 1.0% mono -steel fiber increases the compressive strength by about 12.1%.
2. The splitting tensile strength, flexural strength and the toughness indices of mortar mixes containing mono-steel fibers increase with the increasing of volume fraction.
3. The static modulus of elasticity for steel fiber high strength flowable mortar has increased through the inclusions of steel fiber. However, the highest increase of modulus of elasticity has been obtained when the hybridization of steel fiber and palm fiber are applied as much as 1.75% and 0.25%, respectively.
4. The flexural strength and the toughness indices results show that the use of hybrid fibers as:1.5 %steel fiber + 0.5% palm fiber fraction betters the performance of HSFM compared with other mixes when the single-steel fiber or palm fiber were used, and this further indicates that the use of hybrid fiber combinations in mortar would boost their overall performance.
5. The ultrasonic pulse velocity was found to be related to the compressive strength of high strength flowable mortar reinforced with hybrid fibers.

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