EFFECT OF RE-VIBRATION TIME AND STEEL FIBER CONTENT ON THE PROPERTIES OF CRUSHED CEMENT-SAND MORTAR CONCRETE

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Abstract

The investigation aims to study the effect of re-vibration time and amount of steel fiber on the properties of concrete made with crushed cement-sand mortar as coarse aggregate. Three mixes were prepared with 0.00, 50 and 100 percent replacement of natural gravel by crushed cement-sand mortar aggregates. Mix proportions of concrete were 1: 2: 3 by weight. The water cement ratio of 0.50 to 0.60 was used to obtain the same workability for all mixes throughout the research. The specimens were cast to investigate compressive and splitting tensile strength of concrete.

The results showed that concrete made of crushed cement-sand mortar as coarse aggregate had lower workability than concrete made with natural gravel aggregate for the same water cement ratio. This reduction in workability is reduced for the richer mixes and the influence of coarse aggregate on the workability decreases with an increase in the amount of cement in the mixture. Concrete compressive and splitting tensile strength were improved due to re-vibration by about 19 percent at the peak value (about one hour after initial vibration) with volume fraction of steel fiber of about 0.5 percent. The steel fibers improve the compressive strength of concrete by about 8-11 percent and the splitting tensile strength by about 10.3 percent for the same period of re-vibration.

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Introduction

Investigations showed that some parts of the world suffer great shortage of natural gravel satisfying the requirements of the coarse aggregate to be used in concrete works.

In regions where natural aggregates are scarce, concrete made with crushed stone or crushed cement-sand mortar, as coarse aggregate may be an adequate alternative. It is well known that the quality of concrete is largely influenced by the properties of the aggregate which occupies about three quarters of its volume. So, special care must be taken in the investigations concerning aggregate[1,2].

Investigations showed that high strength concrete can be easily produced by using crushed brick as coarse aggregate[3], but few researches are available on using crushed cement-sand mortar as coarse aggregate. Husain H. M. [4] showed that concrete with compressive strength of about 60-65%. of that made with natural gravel can be obtained. He used concrete mix of 1:2:4 with w/c of 0.55 and cement- sand mortar mix of 1:3 and w/c of 0.4 by weight. Husain et al[5] concluded that good quality concrete can be made by using crushed cement-sand mortar as coarse aggregates. The compressive and splitting tensile strengths and modulus of elasticity of such concrete were found to be about 91%, 145% and 65% respectively of identical concrete made with natural gravel. The lower unit weight of concrete made with crushed cement- sand mortar aggregate (varied from 2100-2200 kg/m^3) added advantages to this type of concrete. Yousif A.R. [6] tested different mixes (mix A 1:2:4 with natural gravel, mix B 1:2:4 crushed cement-sand as coarse aggregate and mix C 1:2:4 in which coarse and some of other finer sizes are replaced by crushed cement-sand aggregate) are used at different ages (7,14 and 28 days). He concluded that mix B gives compressive strength more than mix A by about 9% while splitting tensile strength was smaller by about 33% at age of 28 days. Mix C gave higher compressive and splitting tensile strength than mix A by about 38% and 49% respectively at the age of about 28 days.

Fiber reinforced concrete is an ordinary concrete with randomly dispersed discrete fibers. Different types of fibers have been used to strengthen the concrete and the cement mortars in the field. These types are asbestos, steel, carbon, glass, and polypropylene and polyethylene fibers (7). It has been shown by researchers[7-10] that the addition of steel fibers improves the concrete properties in tension, compression, shear, flexure, ductility, impact resistance…etc.

Vibration of concrete plays an important role in placing high quality concrete especially in the zone adjacent to steel reinforcement and plays a major role in governing the bond strength between the two materials [11,12]. It is shown that internal re-vibration provides an increase in compressive strength of concrete ranging form (7-19)% depending on the concrete mixes[11,13] Palanjian et al [14] studied the effect of re-vibration time on the compressive, tensile and bond strength of fiber concrete, they found that the compressive and tensile strength of fiber concrete are improved due to re-vibration, the peak value of improvement is found to be at two hours after initial vibration.

The main objectives of this investigation are to study the effect of different amount of steel fiber and re-vibration time on the compressive and tensile strength of concrete made of crushed cement-sand mortar as coarse aggregate.

Experimental Program

1. Materials

1- Cement: type I Portland cement was used throughout the research. It is conforming with ASTM C150[1].

2- Sand: sand was river sand from Erbil region, which had black appearance, its grading was within ASTM C33[1] and measured bulk specific gravity based on saturated and surface dry basis was 2.60and fineness modulus of 2.63.

3- Natural coarse aggregate (gravel) Local river gravel from Erbil region was used and its grading was within ASTM C33 [1]. The bulk specific gravity based on saturated and surface dry basis was 2.70. Drinking water from Erbil water supply was used throughout the research.

4- Crushed cement-sand mortar: the cement- sand mortar had 1:2.75 mix proportion (dry basis) and w/c of 0.5 by weight. Mixing was done by tilting mixer. The mortar was cast in one layer in a form of dimensions 750x750x35 mm and compacted by means of a vibrating table. The mortar slabs were left 24 hours in the form then in water for the next 6 days.

The mortar slabs were crushed at the age of 7 days by a hammer. The crushed mortar particles were soaked in water for further 7 days then sieved into groups. The measured bulk specific gravity based on saturated and surface dry basis was 2.22.

5- Steel fiber: Duform steel fibers were used with tensile strength of 1150 MPa and aspect ratio of 80 (length of 40mm and diameter of 0.5mm).

2. Mix proportion

Three types of mixes were prepared mix A, B and C. The normal concrete with natural gravel (mixA), concrete with 50% of natural grave and 50% of crushed cement-sand mortar coarse aggregates (mix B), and concrete with 100% crushed cement-sand mortar coarse aggregate (mix C). All the mixes had mix proportions of about 1:2:3 (by weight) and w/c was changed from 0.5 to 0.6 to obtain the same workability. Table.1 summarize the details of the specimens.

3. Fabrication

All the specimens were cast in steel cylinders, diameter of 100mm and height of 200mm, the mixes have been batched in a tilting mixer of 0.08m^3 capacity. First the aggregate and cement were mixed dry for about one minute, then water was poured and fiber was dispersed by means of hand in order to achieve homogeneous mixes. Mixing process was continued until a uniform consistency was attained. Immediately slump tests were carried out according to ASTM standards[1] and the slump of the mixes was about 80 $\mp$ 10mm. Each cylinder was filled in approximately with two equal layers, each layer initially vibrated for ten seconds using vibrating table (Type WTN, width of 1.2m, length of 3m, height of 60cm, capacity of 20 kN and velocity of vibration is 3000 frequency/min). Specimens for studying the effect of re-vibration were re-vibrated after 0.5, 1.0 and 2 hours respectively for another ten seconds (at these times initial and approximately final setting times of the cement occurred) [12,13,14]. All specimens were stripped off their molds after 24 hours and submerged in water at temperature of 20 ±2 c^0 until date of testing.

4. Testing

All the specimens were tested immediately after removing from water at age of 28 days. Compressive and splitting tensile strengths of each group were carried out according to ASTM C192 & C496 [1] respectively. Results of the tested specimens are summarized in Table1.

Test Results and Discussion

The average bulk specific gravity (saturated surface dry) was 2.22 for crushed cement sand mortar aggregates and 2.70 for natural gravel. The value of specific gravity of aggregate is not a measure of its quality, but for material of a given petrologic character, variation in specific gravity would reflect the porosity of the particles.

The water absorption capacity of crushed cement-sand mortar aggregate is relatively high (2.6)% compared with 0.8% for natural gravel. Water absorption of aggregate in excess of 2 to 3% may indicate unsuitable aggregates. However aggregates which absorb up to 5 to 6% may still be suitable if the pore sizes are large[15], therefore, care should be taken when using the crushed stone and crushed cement-sand mortar aggregates in concrete.

Crushed cement-sand mortar aggregate mix showed lower workability than natural gravel mix. This behavior is attributed to the high water absorption of the crushed cement-sand aggregate used in making the concrete mixes which results in reducing the net water content required to provide workability. Furthermore crushed cement-sand mortar particles have rougher surface texture and contain higher percentage of flaky and elongated particles than natural gravel. Thus more work is needed to overcome the increased internal friction.

The difference in workability of the two types of concrete mixes is affected by the coarse aggregate/cement ratio. As coarse aggregate/cement ratio increases, the rate of loss of workability of concrete mixes is lowered. This reduction in workability might be due to the amount of mixing water that might affect to some extent. However the coarse particles become quickly coated with cement paste, particularly in a rich mix which prevents further ingress of water due to sealing or plugging of the surface pores. In lean mixes, ingression of water necessary to saturate the dry aggregate, results in lowering the effective water/cement ratio and workability, this means that the influence of aggregate on the workability decreases with an increase in the richness of the mix.

It is usual to vibrate concrete immediately after placing so that consolidation is generally completed before the concrete has stiffened. On the basis of the experimental results it appears that concrete can be successfully revibrated up to about 4 hours from the time of mixing[2]. Re-vibration improve concrete properties, the improvement is more pronounced at earlier ages and is greatest in concrete’s liable to high bleeding. For the same reason, re-vibration greatly improves bond between concrete and reinforcement[2].

1. Compressive strength of concrete

1.1 Effect of type of coarse aggregate

The results show that, concrete with crushed cement-sand mortar as coarse aggregate has higher compressive strength than the mix with natural gravel as coarse aggregate for the same volume fraction of steel fiber and degree of compaction (Table 1). This can be explained by the fact that crushed cement-sand mortar particles has less effective water/cement ratio, which results from the higher water absorption. Furthermore, crushed cement-sand mortar particles, which are porous and have rough surface texture, make better bond with cement paste when compared with natural river gravel. However, the gain in strength is small when compared with loss of workability of crushed cement-sand mortar mixes, i.e., to obtain a specified compressive strength and given workability, more cement is needed in mixes with crushed cement-sand mortar particles.

1.2 Effect of re-vibration time (R.V.T)

Compressive strength versus re-vibration time relationship for different volume fraction of steel fibers is shown in Fig.1. Compressive strength reached its maximum value when the concrete mixes re-vibrated at about (1-1.5) hours after initial vibration. The compressive strength of concrete mixes improved due to re-vibration by about 16.5%, 18.7% and 19% at the peak value (about 1 hour) and with volume fraction of steel fiber 0.5% for mixes A, B and C respectively. It is clear that all the mixes were affected by re-vibration time, but within an optimum time and for low amount of steel fibers. The mechanism which leads to strength improvement due to re-vibration is that the water in the pores comes out and the pores then filled by mortar.

1.3 Effect of Volume fraction of steel fibers(V_f)

The steel fibers change the mode of failure from brittle to ductile especially in higher strength concrete and delay the final failure (i.e. increase the area under the stress-strain curve). As shown in Fig.2, the steel fibers improve the compressive strength for all the mixes by about (8-11) % for the same period of re-vibration.

2. Splitting Tensile strength of concrete

2.1 Effect of type of coarse aggregate

It can be noticed that (from results), the crushed cement-sand mortar (as coarse aggregate) concrete exhibits higher splitting tensile strength than natural gravel concrete for the same mix proportion. The reasons for that are as mentioned for compressive strength.

The ratio of splitting tensile strength of crushed cement-sand mortar to the compressive strength is about 11.7 % (without steel fiber and without re-vibration), while it is about 10.5% for the natural gravel concrete.

2.2 Effect of Re-vibration time

The splitting tensile strength versus re-vibration time for different percentages of steel fibers is shown in Fig.3. As shown, the specimens have the same behavior as for compressive strength. The splitting tensile strength of concrete for different types of concrete was improved due to re-vibration by about 22.6%, 18.7% and 19% for the volume fraction of steel fiber of about 0.5%.

2.3 Effect of volume fraction of steel fibers

The splitting tensile strength improved by about 10.7%, 10.8 % and 10.3% for mix A, B and C respectively when the volume fraction of steel fiber increased from 0.00 to 1 % as shown in Fig.4.

Conclusions

From the results of the tested specimens, the following conclusions can be made:

1. Crushed cement-sand mortar as a coarse aggregate produces concrete of lower workability than natural gravel concrete.
2. Compressive and splitting tensile strength of concrete are improved by using steel fiber and re-vibration for the same type of coarse aggregate. Also the steel fibers change the mode of failure from brittle to ductile especially in higher strength concrete mixes and delay the final failure (i.e. increase the area under the stress-strain curve).
3. Compressive and splitting tensile strength of concrete made with crushed cement-sand mortar aggregate are higher when compared with concrete made with natural gravel and same water / cement ratio.

Finally the following recommendations can be suggest for the future works:

- More tests are required to show the effect of re-vibration time in full scale members.
- More tests are required to show the effect of steel fibers with high strength concrete for smaller time interval re-vibrations.
- More tests are required to use the crushed cement-sand mortar as a coarse aggregate to show their effect in regions bending, shear, …etc of reinforced concrete members.

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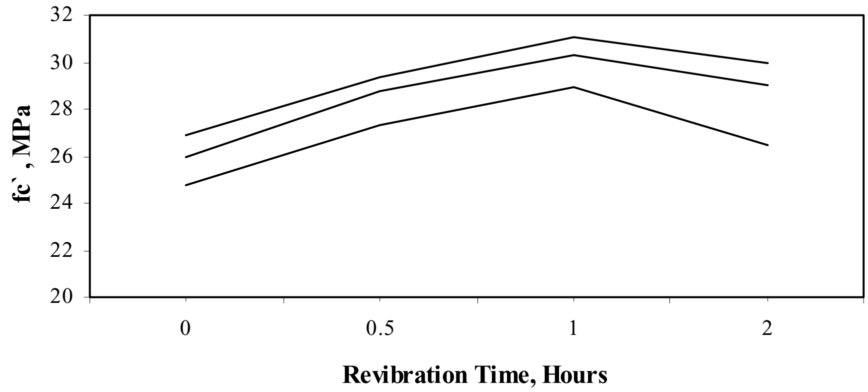
Table 1. Details and Properties of the Tested Specimens

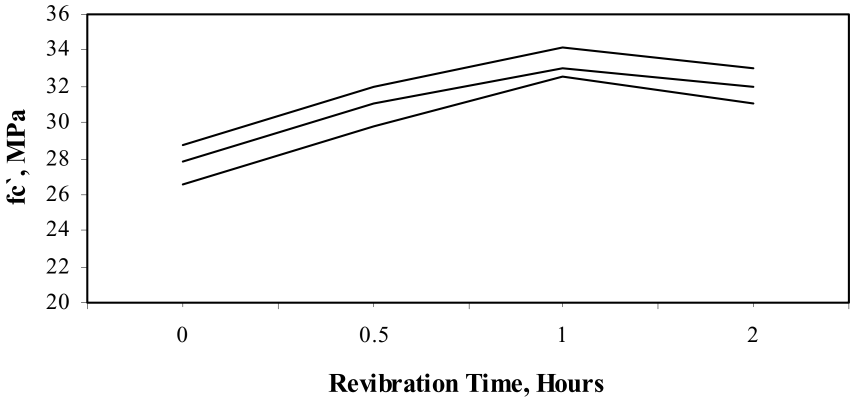
Sp. No.	V_f %	R.V.T. hours	fc` N/mm^2	ft N/mm^2	Remark
A00	0.00	0.0	24.80	2.60	Mix A, 1:2:3 Natural Gravel
A01	0.00	0.5	27.30	2.91	
A02	0.00	1.0	28.90	3.00	
A03	0.00	2.0	26.50	2.80	
A10	0.50	0.0	26.59	3.00	
A11	0.50	0.5	29.80	3.25	
A12	0.50	1.0	32.60	3.50	
A13	0.50	2.0	31.00	3.26	
A20	1.00	0.0	27.46	3.52	
A21	1.00	0.5	29.80	3.75	
A22	1.00	1.0	31.30	3.82	
A23	1.00	2.0	30.00	3.70	
B00	0.00	0.0	26.00	2.80	Mix B %50Natural Gravel %50Crushed Cement-Sand Mortar Aggregate
B01	0.00	0.5	28.80	3.16	
B02	0.00	1.0	30.30	3.25	
B03	0.00	2.0	29.00	3.10	
B10	0.50	0.0	27.80	3.30	
B11	0.50	0.5	31.00	3.55	
B12	0.50	1.0	33.00	3.76	
B13	0.50	2.0	32.00	3.62	
B20	1.00	0.0	28.80	3.80	
B21	1.00	0.5	31.30	4.10	
B22	1.00	1.0	32.90	4.20	
B23	1.00	2.0	31.80	4.00	
C00	0.00	0.0	26.90	3.16	Mix C %100Crushed Cement-Sand Mortar Aggregate
C01	0.00	0.5	29.40	3.45	
C02	0.00	1.0	31.10	3.67	
C03	0.00	2.0	30.0	3.45	
C10	0.50	0.0	28.73	3.60	
C11	0.50	0.5	32.0	3.95	
C12	0.50	1.0	34.20	4.12	
C13	0.50	2.0	33.00	3.90	
C20	1.00	0.0	29.68	4.25	
C21	1.00	0.5	32.30	4.60	
C22	1.00	1.0	34.00	4.70	
C23	1.00	2.0	33.00	4.62	

Notations:

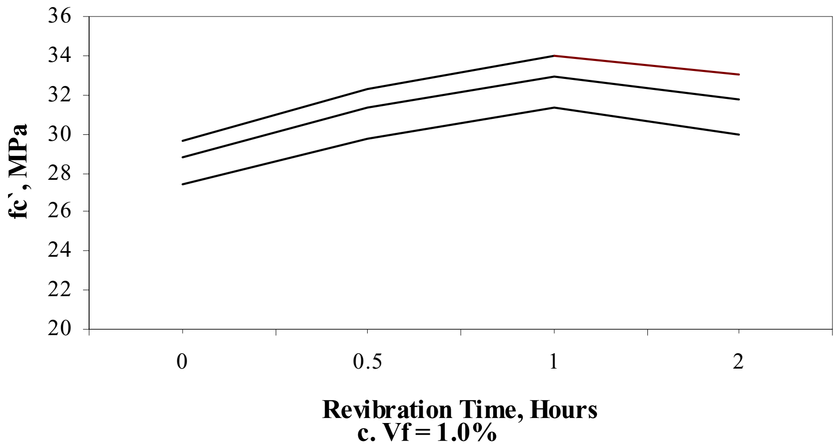
fc` Compressive strength of concrete based on ASTM specifications, MPa.
ft Splitting tensile strength of concrete, MPa.
R.V.T. Re-vibration time after initial vibration, Seconds.
V_f Volume fraction of steel fiber%.



a. Vf = 0.00 %

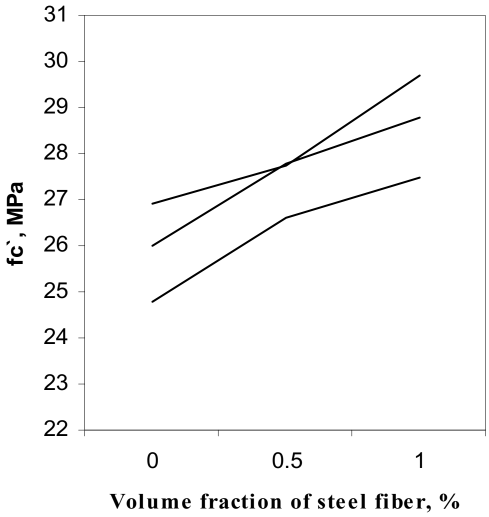


b. Vf = 0.50 %

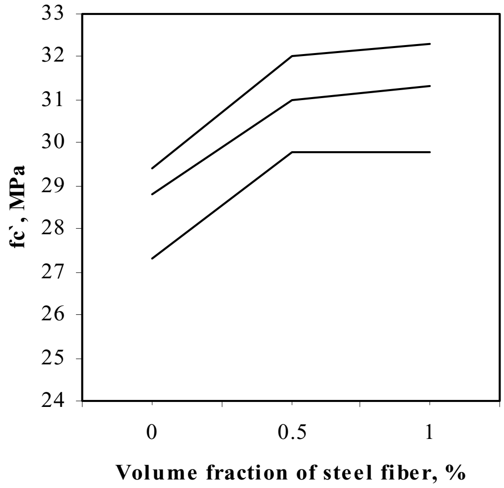


c. Vf = 1.0%

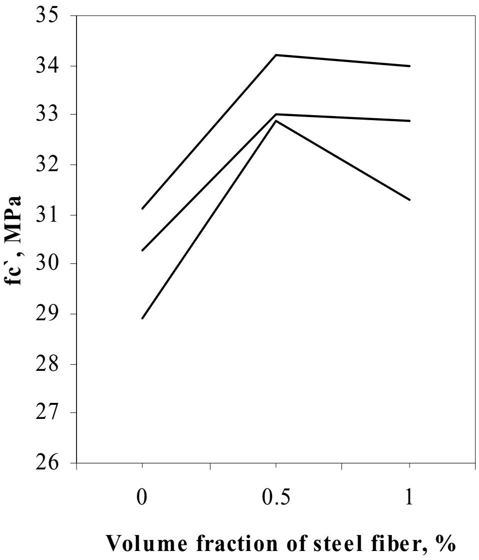
Fig. 1 Compressive strength versus re-vibration time



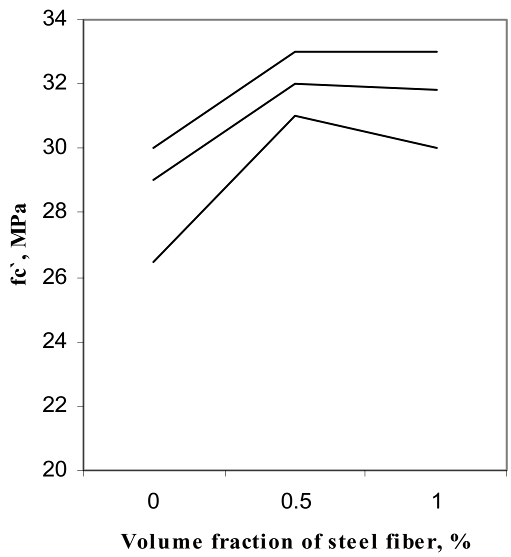
a. R.V.T. = 0.00 hours



b. R.V.T. = 0.50 hours

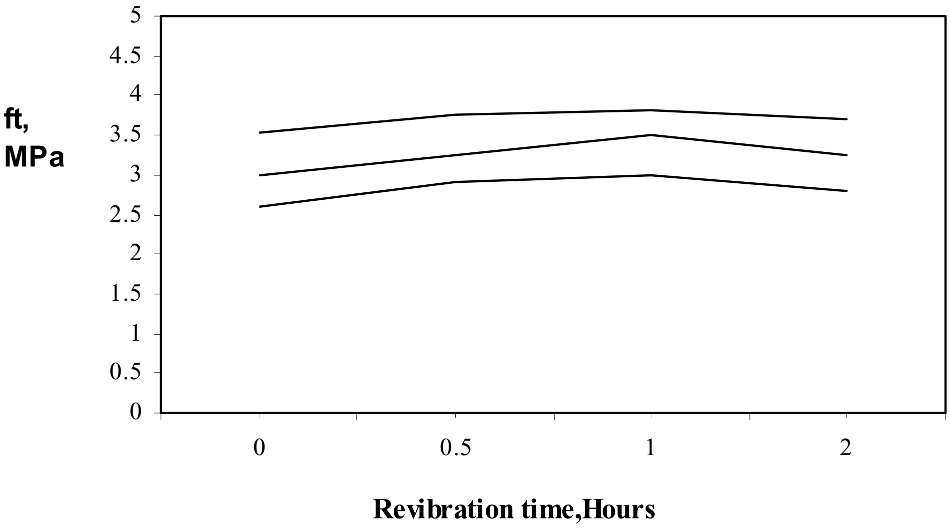


c. R.V.T. = 1.00 hours

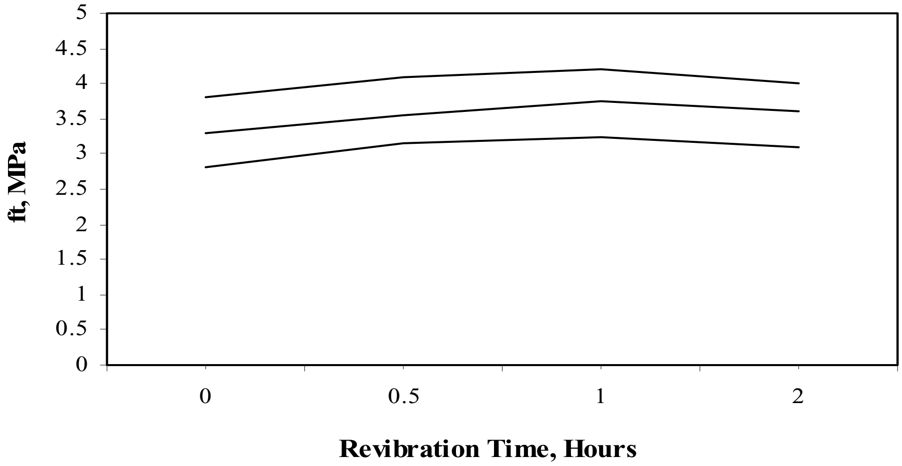


d. R.V.T. = 2.00 hours

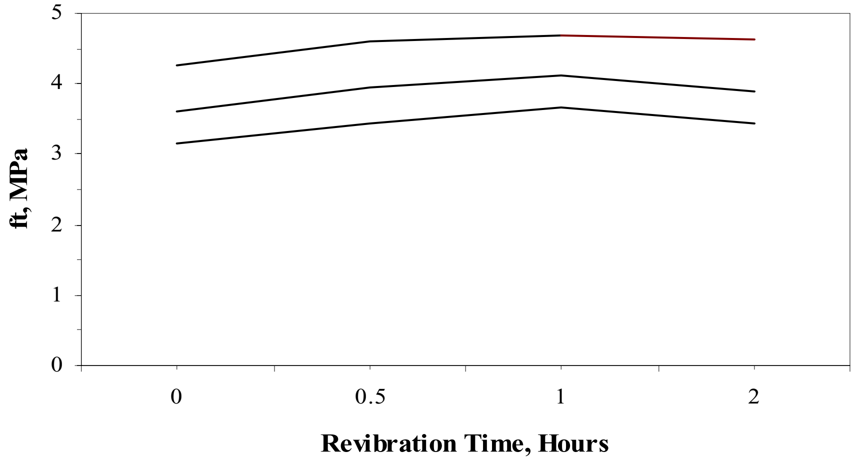
Fig. 2 Compressive strength versus volume fraction of steel fiber at different re-vibration times



a. Vf = 0.00 %

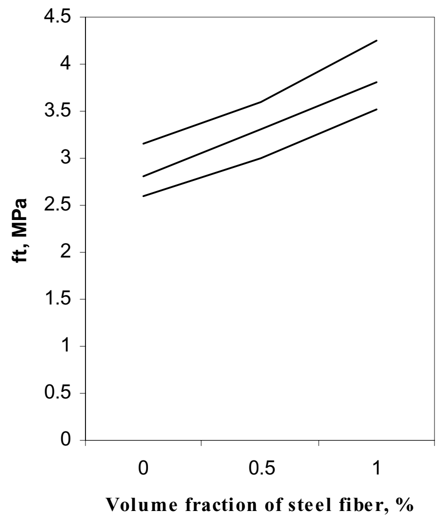


b. Vf = 0.50 %

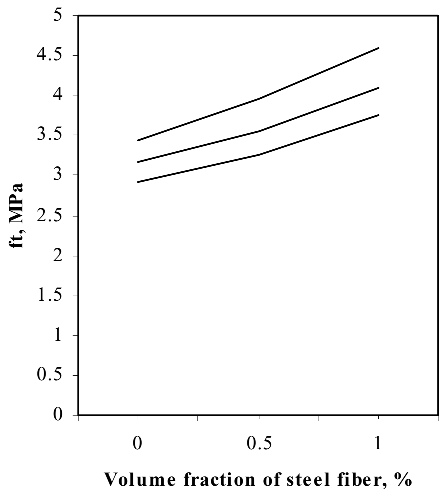


c. Vf = 1.0%

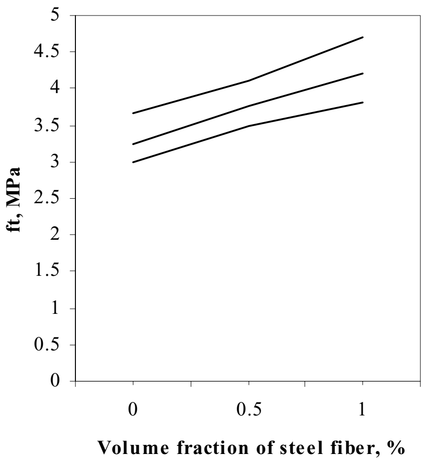
Fig. 3 Splitting tensile strength versus re-vibration time



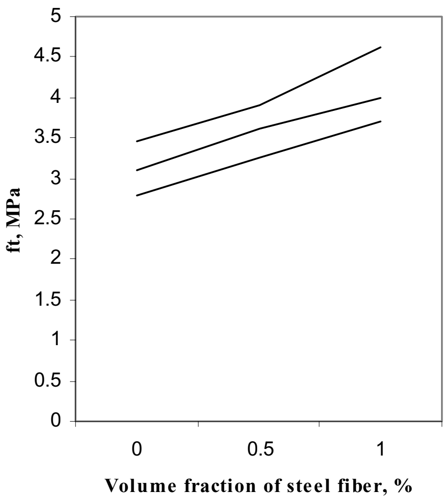
a. R.V.T. = 0.00 hours



b. R.V.T. = 0.50 hours



c. R.V.T. = 1.00 hours



d. R.V.T. = 2.00 hours

Fig. 4 Splitting tensile strength versus volume fraction of steel fiber at different re-vibration times