

Effect of Steel Fiber on Ultrasonic Pulse Velocity and Mechanical Properties of Self-Compact Concrete

Dr.Ahmed S. D. AL-Ridha¹, Ali F. Atshan², Ali A. Abbood³, Eng. Layth Sahib Dheyab⁴

Assistant Professor, Department of Civil Engineering College of Engineering, Al-Mustansiriya University, Iraq¹

Lecturer, Department of Environmental, College of Engineering, Al-Mustansiriya University, Iraq²

Assistant Lecturer, Department of Civil Engineering College of Engineering, Al-Mustansiriya University, Iraq³

Consultant Engineer, Baghdad, Iraq⁴

ABSTRACT: In this research , an attempt has been made to study the velocity of ultra-sonic pulse wave (UPV) transmitted through self-compacting concrete with and without steel fibers for different specimen lengths (i.e. 100mm cubes and 200mm cylinders) .Two volume fractions of steel fibers "0.4%" and "0.8%"(as an indication to steel fibers content) were also studied to explore their contributor role .

It was found that, for the (100mm) cubic specimens and the (200mm) cylindrical specimens , the (UPV) increases with the increase of steel fiber content , but the percentage of increase is higher in cylinders than in cubes .

It was also found that , for the same volume fraction of steel fiber , the Ultrasonic Pulse Velocity (UPV) in the self-compact concrete , increases with the decreasing of specimen length , from (200mm) cylinders to (100mm) cubes . The percentage of this increase , decreases with the increase of steel fiber content .

The effect of steel fibers on three mechanical properties of the self-compacting concrete (namely : the compressive strength , the splitting tensile strength , and the bulk density) was also studied . It was found that the three mentioned properties are increased with the increase of steel fiber content, but this increase is moderately in compressive strength , extremely in splitting tensile strength , and slightly in bulk density .

KEYWORDS: Self-Compact Concrete, Ultrasonic Pulse Velocity, steel fiber, mechanical properties.

I. INTRODUCTION

The Self compacting concrete (S.C.C.) is a concrete which has a good ability to flow by its own weight and attain an adequate compaction without external vibration. Furthermore, S.C.C. has a quite good resistance to bleeding and segregation because of its consistency characteristics [1].

Self-compacting concrete(S.C.C.) is familiar to be brittle and can easily crack under low levels of tensile force. Naturally, Plain (i.e. unreinforced) concrete is a brittle material , with a low tensile strength and a limited strain capacity. This brittleness behavior can be overcome by using small separated randomly oriented steel fibers. Fibers, not only restrain the formation of cracks, but also recede their growth and propagation [2] .

Fiber reinforced concrete becomes a considerable option whenever safety or durability considerations are a design criteria. They improve the performance (i.e. strength and toughness) and efficiency of brittle cement-based materials by bridging cracks, conveying stress across a crack, and restraining the crack growth [3].

Several researches and investigation works have been carried out for improving the self-compact concrete by adding steel fibers to it [4, 5, 6] .

The non-destructive ultrasonic pulse velocity method has been widely used for examining the mechanical properties and safety of concrete structures [7, 8, 9, 10, 11, 12, 13].

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Scientists have examined the application validity of the (UPV) to the evaluation of the concrete quality for decades. These sorts of measurements have proved to be of real importance as a useful achievement for evaluating the mechanical properties and concrete quality in concrete structures. The most likable side of this method is that the concrete remains undamaged while being tested, besides the quickness and simplicity in using it , in addition to the availability of the test results on the site and the less expensive equipments that can be used for this purpose [14, 15, 16, 17, 18].

Pulse velocity is affected , however , by many variables , including : w/c ratio[19, 20] , mixture proportions , aggregate type , age of concrete , moisture content , and others[21] .

2-Experimental Work

2-1-Materials

2-1-1-Cement :

In this research local ordinary Portland cement from "Tasluja" factory was used in all mixes.

2-1-2-Normal Fine Aggregate:

The fine aggregate (sand) which has been selected for the present work was taken from "Al-Ukhaidhir" territory field. Fine aggregate particles have (4.75) mm maximum size and (2.6) Specific gravity. The chemical and physical tests made for this fine aggregate were executed by The National Center for Research and Construction Laboratories. The obtained results indicate that the grading of fine aggregate and the sulfate content were within the acceptable range of the Iraqi Specification No. 45/1984[22]. In all concrete batches the sand was dried by exposure in air before being used.

2-1-3-Normal Coarse Aggregate :

Normal weight gravel (of rounded shape particles) with (10mm) maximum size and (2.63) Specific gravity was used as coarse aggregate in this work. It was obtained from "AL-Nibaai" zone field. The chemical and physical tests of coarse aggregate were executed also by the National Center for Research and Construction Laboratories . The obtained results indicate that the grading of coarse aggregate within the acceptable limits specified by ASTM C33[23] . The grading is found to be acceptable with this specification limits, and it has also been found that the sulfate content was within the acceptable limits of the Iraqi Specification No. 45/1984[22].

2-1-4-Admixtures (Superplasticizer) :

In this work, a suitable superplasticizer called "Sika ViscoCete-PC 20" was used with a dosage of 3.5 L per 100 kg of cement, this dosage had been settled on after many trial mixes. This admixture improves the workability (i.e. flowability) of the mix as:-

- Considerably powerful water reduction, leading to high density, high strength and reduced permeability for water.
- Very good plasticizing effect, leading to improved flowability , casting and compacting behavior.
- Especially appropriate for the production of Self Compacting Concrete (S.C.C.) .

The properties of the superplasticizer used are presented in Table (1).

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Table (1) Properties of the superplasticizer*

No.	property	The description
1	Commercial name	SikaViscoCete-PC 20
2	Chemical Base	Modified polycarboxylates based polymer
3	Form	liquid
4	Color	Light brown
5	Relative density	1.09-1.13 kg/l @ 20° C
6	pH	3 - 7
7	Chlorides	Free from chlorides

*Supplied by the manufacturer.

2-1-5-Steel Fibers :

In this research, hooked end steel fibers (which are known commercially as:"Dramix-Type ZC") were used. These fibers are (50mm) long and of (0.5mm) diameter (i.e. their aspect ratio: $l/d = 100$). The properties of steel fibers used are presented in Table (2).

Table (2) Steel fibers properties*

Commercial name	Configuration	Property	Specifications
Dramix ZC 50/0.5	 <p style="text-align: center;">Hooked ends</p>	Density	7860 kg/m ³
		Ultimate strength	1130 MPa
		Modulus of Elasticity	200x10 ³ MPa
		Strain at proportion limit	5650 x10 ⁻⁶
		Poisson's ratio	0.28
		Average length	50 mm
		Nominal diameter	0.5 mm
		Aspect ratio (L_f/D_f)	100

*Supplied by the manufacturer

2-1-6-Limestone Powder (LSP):

This material is a filler named locally as :“Al-Ghubra” . It is a white lime stone grinding material excavated from various regions in Iraq, and frequently used in many construction aspects.

2-2-Concrete Mix :

In this work , many types of mixes were produced , the difference between them is according to their steel fiber content (Mix1 , Mix2 , and Mix3) having a volume fraction of steel fiber : 0.0% , 0.4% , and 0.8% respectively.

In order to produce a non-fibrous concrete , the following mixing proportions (by weight) were used: [cement : 1 , Limestone Powder : 0.05 , sand : 1.95 , gravel : 2] , the water/cement ratio used was (0.44) and the superplasticizer was 3.5% by weight of cement. This mix was decided after several trial mixes made in order to obtain the most suitable one . It was found that the mixture mentioned above ,produces a self-compact concrete without segregation. This mixing proportions have tended to follow the British practice which has generally trends to use high sand content (approximately equal to gravel content) with (10mm) maximum size to ensure better spread of steel fiber in the mix [24].

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Steel Fiber Reinforced Concrete was obtained by adding steel fibers with volume fractions of (0.8%) to the fresh plain concrete, then the mixture is remixed. In this research two mixes of fibrous concrete are used depending on the volume fraction of steel fiber (0.4% and 0.8%). The workability of the mix and the uniform dispersion of the steel fibers are the two important factors that affect the quality of fibrous concrete.

2-3-Mixing Procedure :

The mixing procedure is an important factor for obtaining the self-compacting concrete which satisfies criteria of filling ability, passing ability and segregation resistance. The good dispersion of fibers prevents fiber agglomeration. All concrete batches was done by weight and mixed manually by using a pan. The interior surface of the pan is cleaned and moistened before placing the materials. The fresh concrete was mixed until a homogeneous fresh concrete is obtained. To avoid agglomeration and to distribute the steel fibers uniformly, the required amount of steel fibers was uniformly added to the mix by hand sprinkling. The fresh concrete was then mixed until a good spread of the fiber is obtained. This procedure is briefly stated in the following points:

- 1- In the beginning, the filler, the fine, and the coarse aggregates were poured in the pan and mixed for several minutes, then the cement was added to the mix and they are all mixed until a uniform combination is obtained.
- 2- Since; $w/c = 0.44$, then, the total quantity of water : $w = 0.44c$. In order to have an efficient mixing process , this total quantity was divided into four parts: $w_1 = 0.2c$, $w_2 = 0.08c$, $w_3 = 0.12c$, $w_4 = 0.04c$.
- 3- The quantity (w_1) was first poured on the mix in the pan and all components were remixed for a few minutes.
- 4- The quantity (w_2) was added to the quantity of the superplasticizer and they both were added to the mix and remixed again, then left for about five minutes.
- 5- Next , the quantity (w_3) was added and remixed until a homogeneous fresh concrete is obtained.
- 6- At last, the remaining quantity (w_4) was added and the whole components were remixed to be prepared for the casting .
- 7- For the mixes that contain steel fiber, to avoid agglomeration and to distribute the steel fibers uniformly, the required amount of steel fibers was uniformly added to the mix by hand sprinkling. The fresh concrete was then mixed until a good dispersion of the fiber was obtained.

2-4-Casting and Curing:

When the mixing process was finished, the fresh concrete was then poured into the molds as shown in Figure (1), and vibrated by hammering at sides and base of the specimens until the casting is completed. Then the specimens were covered with a plastic sheet to prevent evaporation of water. After (24) hours, the specimens were stripped out from the molds and cured in a water bath. To keep the bath temperature constant at about 25° to 30°, two heaters (which were taken from ornamental fish ponds and modified for our work) were used, a water pump was also used to distributed the heat over the entire bath water. After about one month the control specimens were taken out from the water bath and tested . The following paragraphs contain the result of the standard tests that were carried out on the fresh and the hardened concrete.



Fig 1: Details of Wooden Cubic Forms and Cylinders

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2-5-Testing of Fresh Concrete .

2-5-1-Slump Flow Test and T-50 Test :

The slump flow test is the most commonly used test to assess the horizontal free flow of self-compacting concrete which gives a good assessment of its flowability. It may give some indication of the resistance to segregation. T-50 test is also a measure of the speed of flow and hence the viscosity of S.C.C. [25]. This test (which was developed in Japan) was originally used to measure the viscosity of underwater concrete and has also been used to assess highly flowable concretes [26].

The slump flow test is used to determine the flowability and can indicate segregation resistance of S.C.C. by an experienced user [26]. Table (3) shows the results of slump flow tests. The values of (D) column represent the maximum spread (slump flow final diameter) , while the values of (T50) column represent the time required for the concrete flow to reach a circle with 50 cm diameter) , (see Figure 2). This table (3) also shows that the results were acceptable with criteria for Self-Compacting Concrete [27], and illustrates that the flowability was decreased when adding steel fibers to the concrete .

Table (3) Slump Flow Test and Acceptance criteria for Self-compacting Concrete

V _f %	T50 (Sec.)	D (mm)	Acceptance criteria for Self-compacting Concrete			
0.0	6	630	Typical range of values			
			Slump flow by Abrams cone		T50cm slump flow	
0.4	7	620	Max. (mm)	Min. (mm)	Max. (Sec.)	Min. (Sec.)
			D=800	D=600	T50= 25	T50=3
0.8	9	610	Max. (mm)	Min. (mm)	Max. (Sec.)	Min. (Sec.)
			D=800	D=600	T50= 25	T50=3



Fig (2) Slump flow test

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2-6-Testing of Hardened Concrete

2-6-1-Ultrasonic Pulse Velocity Test:

The principle of ultrasonic pulse velocity measurement involves sending a wave pulse into concrete and measuring the travel time for the pulse to transmit through the concrete. In this method an ultra-sonic pulse is generated by a pulse generator and transmitted to the surface of concrete through the transmitter transducer. The time traveled by the pulse through the concrete is measured by the receiver transducer on the opposite side. In order to ensure effective transfer of the wave between concrete and transducer, a thin grease layer is applied to the surface of transducer.

The ultra-sonic pulse velocity test was carried out according to ASTM C597-02 [28], using L = 100mm (cube), and L = 200mm (cylinder). (See Fig. 3).

The pulse velocity is given by the following expression:-

$$v = (L / t) \times 1000 \dots\dots\dots [1]$$

Where:-

v = pulse velocity, (m/s).

L = distance between the center of transducers faces, (mm).

t = trans. time traveled, (μs).



Fig (3) ultrasonic pulse velocity measurement for concrete cubes and cylinders

2-6-2-Compressive Strength test:

The compressive strength test was executed according to (BS 1881: part 116:1989)[29]. This test was carried out on 100 mm cubic specimens using electrical testing machine with capacity of (2000 KN). The test was conducted for specimens at ages of about 28 days for non-fibrous concrete, and about 34 days for fibrous concrete. (Fig. 4a).

2-6-3- Splitting Tensile Strength test:

The splitting tensile strength test was performed according to ASTM C496-86 [30].(100×200) mm cylindrical concrete specimens were tested. The test was achieved using an electrical testing machine with capacity of (2000 kN). (Fig.4b).

2-6-4-Unit weight (density):

The unit weights of steel compact concrete (with three steel fiber contents) were measured using the following equation:-

$$Density = \frac{W_A}{(W_A - W_W) / \gamma_w} \dots\dots\dots [2]$$

Where: W_A = weight in air, W_W = weight in water, γ_w = mass density of water. (Fig. 4c)



(Fig. 4a) Compressive strength test



(Fig. 4b) Splitting tensile strength test



(Fig. 4c) Unit weight (density) test

III. Results and discussion

3-1-Effect of steel fiber on Ultrasonic Pulse Velocity (UPV) of Self-Compact Concrete for different specimen lengths:

Table (4) and Figure (5) show that the (UPV) is increased with the increasing of steel fiber content. This behavior may be interpreted through the fact that the (UPV) is faster in minerals than in non-metallic materials and it is axiomatically that as the steel fiber content increase the specimen environment approaches metallic materials, therefore the UPV increases. It is also obvious from the table and figure (mentioned above) that the percentage of increase of UPV is higher in cylindrical specimens than in cubic ones. The reason behind this result may be attributed to:-

- (1)-In (100mm) cubic specimens, because of the smallness in distance between sender and receiver of ultrasonic testing device, the probable number of internal voids and cracks (in concrete) that are crossing ultrasonic wave path is small, so that their effect on the (UPV) is limited. On the other hand because of the small distance between sender and receiver, the number of steel fibers crossing the ultrasonic wave path is small, therefore their effect on (UPV) will be limited.
- (2)-In (200mm) cylindrical specimens, the distance between sender and receiver of ultrasonic testing device is larger, so the probable number of internal voids, cracks, and steel fiber crossing the ultrasonic wave path is larger, therefore their effect on the (UPV) is obvious.

Table (4) Effect of steel fiber on Ultrasonic Pulse Velocity (UPV) of Self-Compact Concrete for different specimen lengths

Length of spacemen (mm)	Mix No.	V _f %	Ultrasonic Pulse Velocity UPV (m/s)	Percentage of increase
100 cube	Mix1	0.0	4333.78	-----
	Mix2	0.4	4355.26	0.49
	Mix3	0.8	4364.42	0.70
200 cylinder	Mix1	0.0	4132.87	-----
	Mix2	0.4	4187.13	1.31
	Mix1	0.8	4271.22	3.34

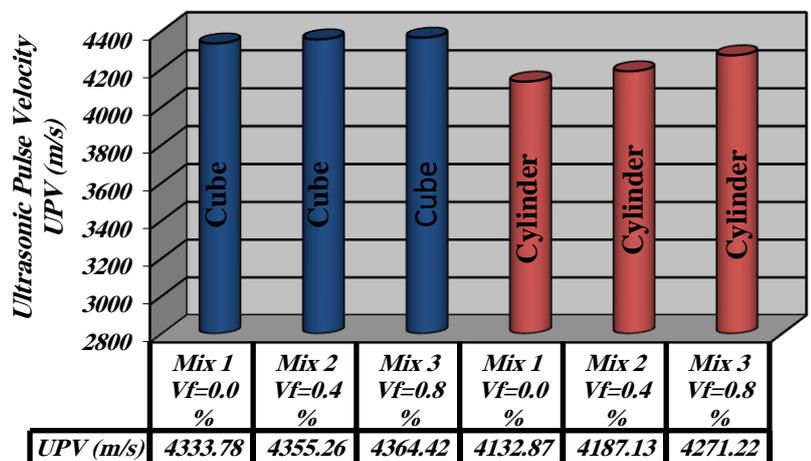


Fig (5) Effect of steel fiber on Ultrasonic Pulse Velocity (UPV) of Self-Compact Concrete for different specimen lengths

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3-2-Effect of specimen Length on Ultrasonic Pulse Velocity (UPV) of Self-Compact Concrete for different steel fiber content:

The Table (5) and Figure (6) shows the results of the (UPV) in (100mm) concrete cubes and (200mm) concrete cylinders for the same steel fiber content. The results reveal that the (UPV) is higher in cube than in cylinder for the same steel fiber content. The results also indicate that the percentage of increase in the (UPV) between cube and cylinder decreases with increasing steel fiber content .

This behavior in non-fibrous concrete might be due to the probable number of internal voids and cracks (crossing the ultrasonic wave path) which is higher in (200mm) cylinders than in (100mm) cubes.

In fibrous concrete the reason behind this behavior may be attributed to the fact that the steel fibers create an environment approaching to the metallic one and hence reduce the bad effect of voids and cracks in the concrete which leads to reduce the difference in (UPV) between cubes and cylinders.

Table (5) Effect of specimen Length on Ultrasonic Pulse Velocity (UPV) of Self-Compact Concrete for different steel fiber content.

Mix No.	V _f %	Length of spacemen (mm)	Ultrasonic Pulse Velocity UPV (m/s)	Percentage of increase
Mix1	0.0	100 cube	4333.78	4.86
Mix1	0.0	200 cylinder	4132.87	-----
Mix2	0.4	100 cube	4355.26	4.01
Mix2	0.4	200 cylinder	4187.13	-----
Mix3	0.8	100 cube	4364.42	2.18
Mix3	0.8	200 cylinder	4271.22	-----

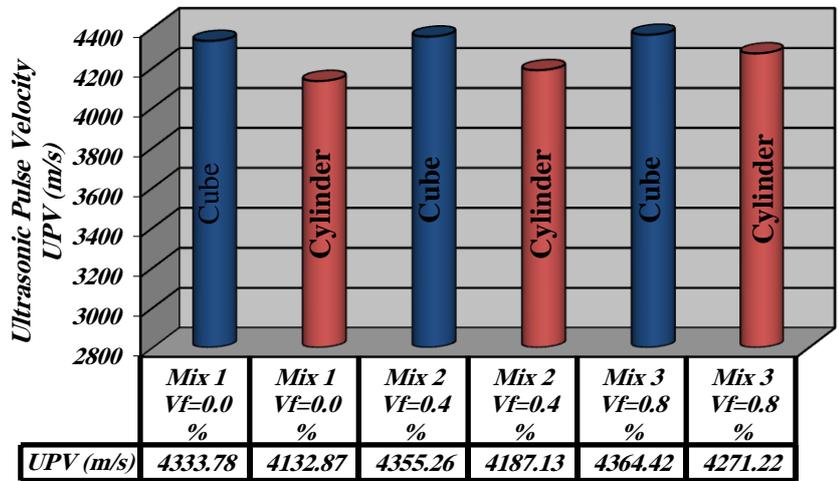


Fig (6)Effect of specimen Length on Ultrasonic Pulse Velocity (UPV) of Self-Compact Concrete for different steel fiber content.

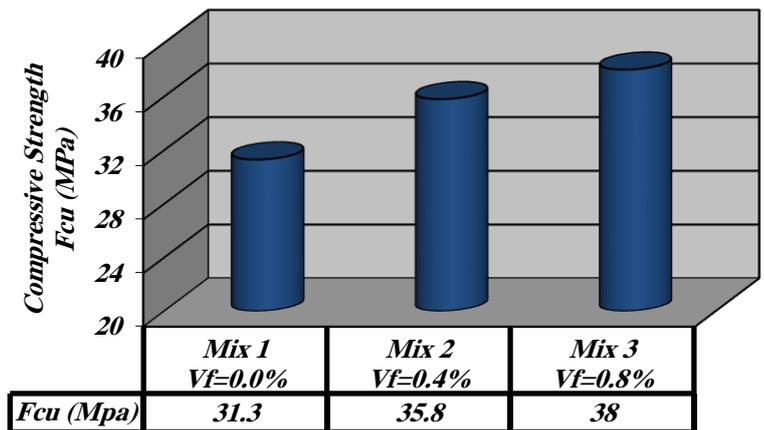
3-3-Effect of steel fiber on Compressive Strength of self-compact concrete:

Fig (7) and table (6) show the effect of steel fiber content on the compressive strength of self-compact concrete. The results illustrate that the compressive strength of self-compact concrete moderately increases with increasing steel fiber content.

The increase in compressive strength may be correlated with the uniform spread of fine fibers throughout self-compacting concrete of high flowability, leading to consistent internal integrity. Moreover, this improvement in the compressive strength of the steel fibrous self- compacting concrete refers to the cracking control and the failure mode via post cracking ductility. However, steel fibers cause crack closing forces which lead to increase the compressive strength. [31].

Table (6) Effect of increasing steel fiber –volume fraction (V_f) % on compressive strength of self-compact concrete

Mix No.	Volume fraction of steel fiber V_f %	Compression strength f_{cu} (MPa)	Percentage of increase
Mix 1	0.0	31.3	-----
Mix 2	0.4	35.8	14.37
Mix 3	0.8	38	21.40



Fig(7) Effect of increasing steel fiber –volume fraction (V_f) % on compressive strength of self-compact concrete

3-4-Effect of steel fiber on Splitting Tensile Strength of self-compact concrete :

Fig (8) and table (7) display the results for the effect of steel fiber on splitting tensile Strength of self-compact concrete. These results reveal that the Splitting Tensile Strength of self-compact concrete extremely increases with increasing of steel fiber content.

The tensile strength increase due to the presence of steel fibers is attributed to the mechanism of steel fibers in restraining crack propagation. Where, the existence of fibers in concrete ceases the progression of internal micro (hair) cracks and thus participates in the increase of tensile strength. Accordingly, the increase in fiber content leads to an increase in the tensile strength of concrete. Furthermore , the improved bonding of fiber-matrix that is provided by the steel fiber shape and its hooked ends , promote strength , and thus, yield to high increment in tensile strength due to inclusion of fibers [32,33].

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Table (7) Effect of increasing steel fiber –volume fraction (V_f) % on Splitting Tensile Strength of self-compact concrete

Mix No.	Volume fraction of steel fiber V_f %	Splitting tensile strength f_t (MPa)	Percentage of increase
Mix 1	0.0	3.34	-----
Mix 2	0.4	4.43	32.63
Mix 3	0.8	5.34	59.88

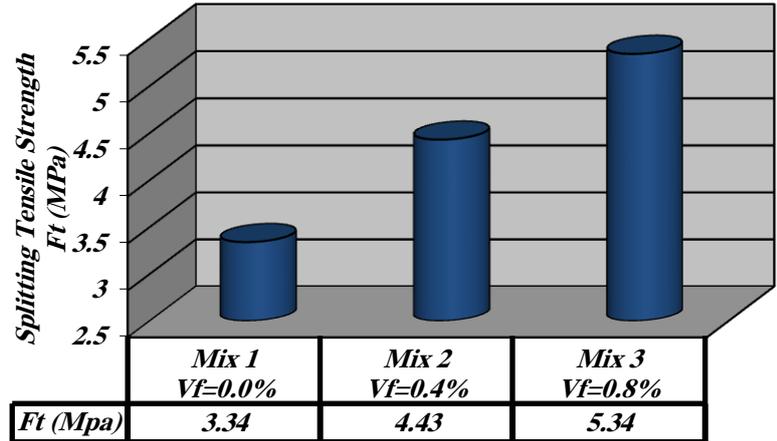


Fig (8) Effect of increasing steel fiber –volume fraction (V_f) % on Splitting Tensile Strength of self-compact concrete

3-5-Effect of steel fiber on density of Self-Compact concrete :

Fig (9) and table (8) displays the density results of the self-compact concrete. These results show that the density increases slightly with the increasing of volume fraction of steel fiber.

Table (8) Effect of increasing steel fiber –volume fraction (V_f) % on bulk density of self-compact concrete

Mix No.	Volume fraction of steel fiber V_f %	Density Kg/m^3	Percentage of increase
Mix 1	0.0	2357	-----
Mix 2	0.4	2388	1.31
Mix 3	0.8	2405	2.03

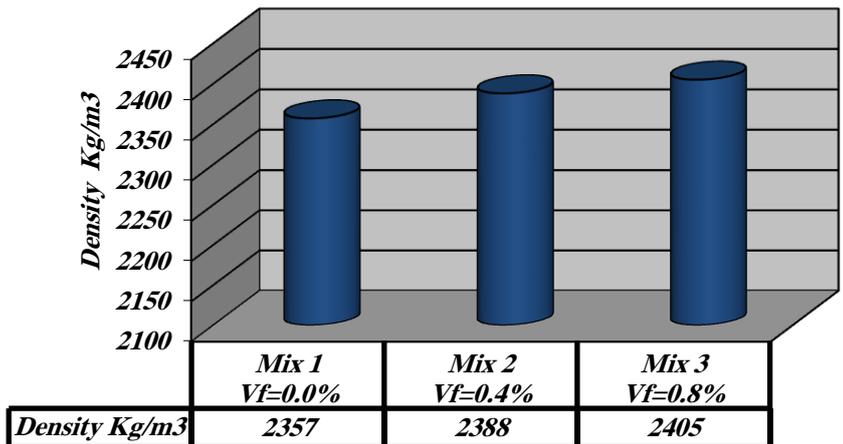


Fig (9) Effect of increasing steel fiber –volume fraction (V_f) % on density of self-compact concrete

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IV. CONCLUSIONS

- 1- The Ultrasonic Pulse Velocity (UPV) in the self-compact concrete increases with the increase of steel fiber content, and the percentage of this increase is higher in cylinders than in cubes.
- 2- For the same volume fraction of steel fiber, the Ultrasonic Pulse Velocity (UPV) in the self-compact concrete increases with the decreasing of specimen length, from (200mm) cylinders to (100mm) cubes. The percentage of this increase decreases with the increase of steel fiber content.
- 3- The compressive strength of self-compact concrete increases moderately with the increasing of steel fiber content.
- 4- The splitting tensile strength of self-compact concrete extremely increases with increasing of steel fiber content.
- 5- The density of self-compact concrete was slightly increases with the increasing of steel fiber content.

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