IMPACT RESISTANCE OF FLAX AND STEEL FIBER REINFORCED CONCRETE

Maher Behnam Alsamaani **Mahdi Saleh Essa** **Ali Hassoon Nahhab**
Engineering ,Babylon University

Abstract

An experimental study was conducted to investigate the impact resistance of concrete reinforced with steel fibers (SFRC) and waste flax fibers (WFFRC). The impact strength was measured by using a simple, portable and practical drop-weight test recommended by the ACI Committee 544. Other mechanical properties including compressive strength, splitting tensile strength and modulus of rupture were also examined. Variables incorporated in this research were fiber type, fiber content, compressive strength and age of testing. Steel fibers and waste flax fibers were added to concrete in various volume fractions of up to 1 and 4% respectively.

The fiber reinforced concrete (FRC) investigated is superior in impact strength to the plain control concrete. This property increases as the amount of fibers addition is increased. When the observed values are compared, the 4% volume fraction of waste flax fibers can produce impact strength comparable or higher than that obtained at 1% crimped steel fibers. For a given steel fiber content, the impact strength increases with matrix compressive strength up to a certain limit beyond which it starts to decrease. The capacity of WFFRC to absorb impact energy enhances as the compressive strength of the matrix and the age increase.

The analysis of the test results also shows that compressive strength, splitting tensile strength and modulus of rupture are improved by including crimped steel fibers, but insignificantly influenced by waste flax fibers.

Introduction

Concrete is an inherently brittle material with a relatively low tensile strength compared to compressive strength. Reinforcing by randomly distributed short fibers presents an effective approach to the stabilization of the crack system and improving the ductility and tensile strength of concrete. A variety of fibers, including steel, polypropylene, glass and natural fibers have been applied to concrete.

Fiber reinforcement of concrete is one of the most effective ways for improving its resistance to impact, blast, explosion and other forms of short duration dynamic loads. While the toughening mechanism is well understood in this composite under statically applied loads, unfortunately in the case of impact and other dynamic loads, our understanding is far from adequate and continued research is clearly needed [1,2]. The root cause of this lack of understanding is the absence of a standardized test technique for conducting impact tests on fiber reinforced concrete (FRC) [2].

A wide range of impact loading tests that are mostly complicated and expensive have been used in practice. However, the results arising from them are not comparable because the test methods, specimen sizes and support conditions used in these tests are arbitrary.

Fiber reinforced concrete can be an alternative for the use in slabs on grade, overlays, pavements and other such applications [3] .These applications require the concrete to be more resistant to impact. In such an environment the concrete is subjected to impact from falling objects, aircraft, or from motor vehicles.

The present work was conducted in two phases. In the first phase, the impact resistance of steel fiber reinforced concrete was investigated and measured by simplified and practical method. In the second phase, the use of waste flax fibers as a reinforcement in concrete was studied. The specimens were prepared and tested under impact, splitting tension, flexure and compression. To undertake the experiments of impact strength, a portable and economical test recommended by ACI Committee 544 (4) was adopted and used.

Four parameters were taken into account: mix proportion and hence compressive strength, type of fibers, namely, crimped steel fibers and waste flax fibers, volume fraction of fibers, and age of the specimens at test. The following reasons led to propose waste flax fibers in this investigation: (*i*) they are a type of natural fibers and can be used in applications where impact damage is likely (5), (*ii*) they are locally available during reclaiming process of rubber tires, and (*iii*) they are disposable and thus, no additional cost will be added for concrete construction, in addition to environmental advantages.

The present work is a part of the thesis of Al- Khafaji, A.H. (10).

Materials and Experimental Work

Materials

Cement

Ordinary portland cement manufactured by the New Cement Plant of Kufa was used throughout this study which conformed with IOS 5: 1984.The physical properties and chemical composition of the cement are given in Tables 1and 2.

Fine Aggregate

Al-Akhaidhur well graded natural sand was used. The physical and chemical properties of the sand are listed in Table 3. Its grading conformed with IOS 45: 1984, Zone 3.

Coarse Aggregate

The gravel used was brought from Al-Nebaee area. it was sieved on 9.5 mm sieve to exclude the large size particles in order to obtain good workability and uniform dispersion of fibers throughout the composite. Table 4 shows the physical and chemical properties of the gravel. The table also includes the limits specified by IOS 45: 1984.

Superplasticizer

The high – range water – reducing admixtures or superplasticizers available are relatively a new category of chemical admixtures and of considerably higher efficiency than those within the range of normal plasticizers.

In the present work, a commercially marketed superplasticizer Iraqi-admixture known as Melment L10 was used; chemically it is sulphonated melamine formaldehyde condensate composition (Type F according to ASTM C494).It was used to reduce the water content of some mixes while maintaining workability in order to produce concrete with high compressive strength. The technical description of this admixture is shown in Table 5.

Fibers

Two types of fibers were used: crimped steel fibers and waste flax fibers. The latter fibers were disposable during reclaiming process of rubber tires. The properties of fibers investigated are presented in Table 6.

Table 1: Physical properties of the cement

Physical Properties	Test results	IOS 5: 1984 Limits
Fineness, Blaine, cm^2/gm	3060	≥ 2300
Setting time, Vicat's method		
Initial hrs: min.	1:54	45
Final hrs: min.	3:35	≤ 10: 00
Compressive strength of 70.7 mm cube, MPa		
3 days	22	≥ 15
7 days	28	≥ 23

Table 2: Chemical composition of the cement

Oxide	(%)	IOS 5: 1984 Limits
CaO	61.26	
SiO_2	20.80	
Fe_2O_3	3.20	
Al_2O_3	6.12	
MgO	4.40	≤ 5.0
SO_3	2.33	≤ 2.8
Free lime	0.76	
L.O.I.	1.75	≤ 4.0
I.R.	0.61	≤ 1.5
Compound composition	**(%)**	**IOS 5: 1984 Limits**
C_3S	35.88	
C_2S	32.56	
C_3A	10.80	
C_4AF	9.73	
L.S.F.	0.88	0.66-1.02

Table 3: Properties of the sand

Sieve size (mm)	Percent passing	IOS 45: 1984 Limits, Zone 3
9.5	100	100
4.75	95	90-100
2.36	93	85-100
1.18	79	75-100
0.6	61	60-79
0.3	28	12-40
0.15	0	0-10
Properties	**Test results**	**IOS 45 : 1984 Limits**
Sulphate content, SO_3 (%)	0.27	≤ 0.5
Specific gravity	2.60	
Absorption (%)	1.6	

Table 4: Properties of the gravel

Sieve size (mm)	Percent passing	IOS 45 : 1984 Limits
14.0	100	100
9.5	100	85-100
4.75	16	0-25
2.36	0.9	0-5
Properties	**Test results**	**IOS 45: 1984 Limits**
Sulphate content, SO_3 (%)	0.08	≤ 0.1
Specific gravity	2.64	
Absorption (%)	0.8	

Table 5 : Technical description of superplasitcizer (Melment L10)

Main action	Concrete superplsticizer
Subsidiary effect	Hardening accelerator
Appearance	Clear to slightly milky
Solids in aqueous solution	Approximately 20%
Density	1.1 g /cm^3
Chloride content	Less than 0.005 %
Sugar content	None
pH value	7-9
Storage life	At least two years

Table 6: Properties of the fibers

Fiber type	Density (kg/m^3)	Tensile strength (MPa)	Length (mm)	Diameter (mm)	Aspect ratio
Crimped steel	7800	1050	30	0.4	75
Waste flax	825	260-320	20-70	0.8-1.0	20.0-87.5

Mix Proportions

The mix design of FRC is a matter of trial and error and there is no standard procedure which has been agreed upon so far. In addition, the fiber mixes require higher cement and sand contents compared to the plain mixes and so conventional procedure of mix design is not directly applicable [(3)].

Two basic mixes were used in the experimental work of the present study. The proportions by weight were 1: 2: 2 and 1: 1: 2 (cement: sand: gravel). Superplasticizer was also added to the second mix to produce a third one with less W/C ratio and same workability.

Concrete Mixes

Normal – strength and medium – strength plain concrete and FRC were investigated. Superplasticizer was also added to the medium – strength mixes in a dosage of 4% to attain the desired water reduction and hence further strength development. The details of the mixes are given in Table 7. Concrete mixes, therefore, can be divided into six series according to the strength level and type of fiber.

Twelve crimped steel fiber mixes were made using different fiber concentrations, 0.3, 0.5, 0.7 and 1.0% by volume. Twelve mixes were made with waste flax fiber of 1, 2, 3 and 4% volume percentages. To compare the properties of FRC with plain concrete, six plain concrete mixes were also prepared using the basic mix proportions.

Table 7: Details of plain concrete and FRC mixes

Series	Mix proportions cement: sand: gravel (by wt.)	W/C (by wt.)	Superplasticizer dosage (% by wt. of cement)	Fiber type	V_f(%)
ASF	1:2:2	0.52	0	No-fiber	0.0
				Steel	0.3 0.5 0.7 1.0
BSF	1:1:2	0.39	0	No-fiber	0.0
				Steel	0.3 0.5 0.7 1.0
CSFS	1:1:2	0.33	4	No-fiber	0.0
				Steel	0.3 0.5 0.7 1.0
DWF	1:2:2	0.57	0	No-fiber	0.0
				Waste flax	1.0 2.0 3.0 4.0
EWF	1:1:2	0.43	0	No-fiber	0.0
				Waste flax	1.0 2.0 3.0 4.0
FWFS	1:1:2	0.36	4	No-fiber	0.0
				Waste flax	1.0 2.0 3.0 4.0

Specimens Preparation

Mixing

Conventional and steel fiber concretes were mixed in a horizontal pan-type mixer of 0.1 m^3 capacity. The interior surface of the mixer was cleaned and moistened before it was used. The aggregate and cement were first mixed dry for 60 sec., then the water or the water with superplasticizer was added and mixed for another 30 sec. The steel fibers were then fed continuously to the mixer for a period of 2 to 6 min. depending upon the fiber content, using a 25 mm steel sieve to separate and prevent fiber clumps from entering the mixer.

Attempts of mixing the waste flax fiber concretes in the mixer failed due to the phenomenon of fibers balling when the fiber content is high, and thus they were manually mixed. The aggregate and cement were first mixed dry. Then the water or the water with superplasticizer was added and mixed until a homogeneous mix was obtained. The waste flax fibers were then added and mixed until a uniform distribution of fibers within the mixture was achieved.

Casting

After mixing, the concrete was poured into the moulds and compacted using a vibrating table. The specimens were left for about 30 min. before they were leveled by hand trowelling.

Curing and Age of Testing

The moulds of concrete specimens were covered with polyethylene sheets and left in the laboratory for 24 hrs. The specimens were then demoulded carefully and stored in a water tank until 4 days before testing date. The specimens of series ASF, BSF, CSFS and FWFS mixes were tested at ages 28 and 90 days. Series DWF and EWF tests were performed at only 28 days.

Testing Fresh and Hardened Concrete

Slump Test

The slump of fresh mixes was measured according to ASTM C143 test method. [11]

Compressive Strength Test

Compressive strength tests were carried out according to B.S. 1881: Part 116, using a digital testing machine of 2000 kN maximum capacity. Three cubes (152 mm) were tested for each mix at each age for determination of compressive strength. The load was applied without shock and increased continuously at a constant rate.

Modulus of Rupture Test

Three points flexure tests were performed on three (100×100×400mm) prisms with a span of 300 mm using the machine meeting the requirement of ASTM C293.

Splitting Tensile Strength Test

The splitting tensile strength was determined according to the procedure outlined in ASTM C496, using (100×200 mm) cylinders. Each strength value is the average of strength of three specimens.

Impact Resistance Test

A portable and economical impact test published by the ACI Committee 544 [4] was used.

Referring to Fig.1, the equipment for the drop-weight test consists of three main components:

1. A 4.54 kg standard , manually operated compacting hammer with a 457 mm drop (ASTM D 1557).
2. A 63.5 mm hardened steel ball.
3. A manufactured flat base plate with four positioning lugs and a bracket to position the steel ball on top of the test specimen.

Cylindrical steel moulds having the inside dimensions of 150 $\phi \times$ 64 mm were made to cast the disk specimens.

Testing Procedure

Prior to testing, the thickness of the specimen was recorded. The samples were then coated on the bottom with a heavy grease and placed on the base plate within the positioning lugs with the finished face up. The bracket with the cylindrical sleeve was bolted in place and the hardened steel ball placed on the top of the specimen within the bracket. The drop hammer was then placed with its base upon the steel ball and held vertically. The hammer was then dropped repeatedly, and the number of blows required for the first visible crack to form at the top surface and for ultimate failure was recorded. Ultimate failure is defined by the ACI Committee 544 in terms of the number of blows required to open the cracks in the specimen sufficiently to enable the fractured pieces to touch three of the four positioning lugs on the base plate.

To carry out the test satisfactorily, the base plate was held rigidly by securing it firmly on about (600×600×450 mm) concrete block.

Three test samples were used for each variable.

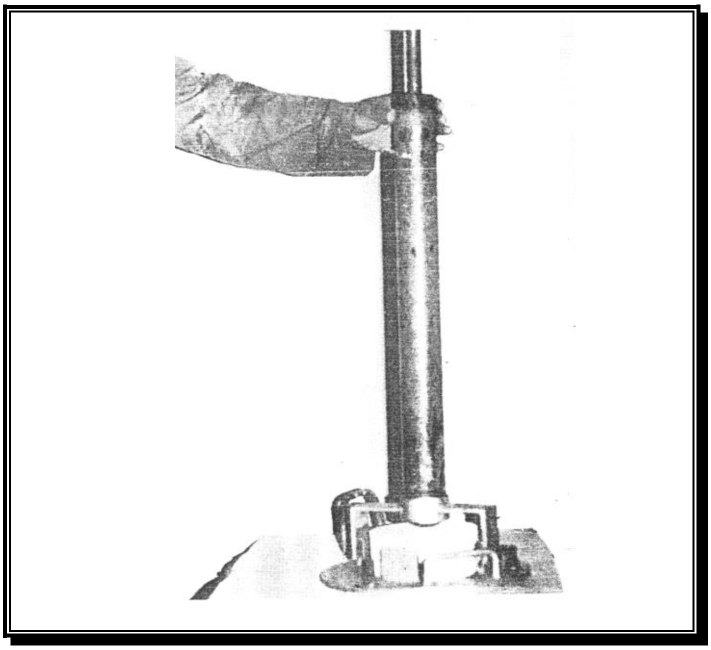


Fig.1: Impact resistance testing device

Results and Discussion

Compressive Strength Test Results

Figs.2 and 3 show the variation of compressive strength with volume percentage of steel fibers, for ages 28 and 90 days respectively. It is clear from the figures that the compressive strength increases due to the inclusion of crimped steel fibers, and as the fiber content is increased the compressive strength increases up to a limit beyond which the improvement achieved in strength goes down. This limit is 0.7% volume fraction of fibers for all SFRC mixes. The enhancement in compressive strength of concrete caused by incorporating steel fibers was also previously reported by **Ramakrishnan *et al.*** [(6)], **Abdul- Hameed** [(7)] .

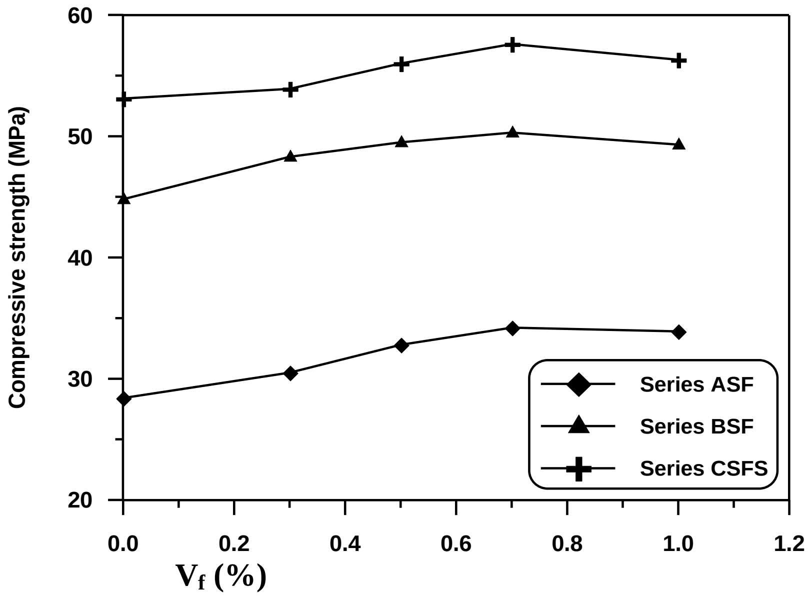


Fig.2: Variation of the 28 day cube compressive strength with volume fraction of steel fibers for different series

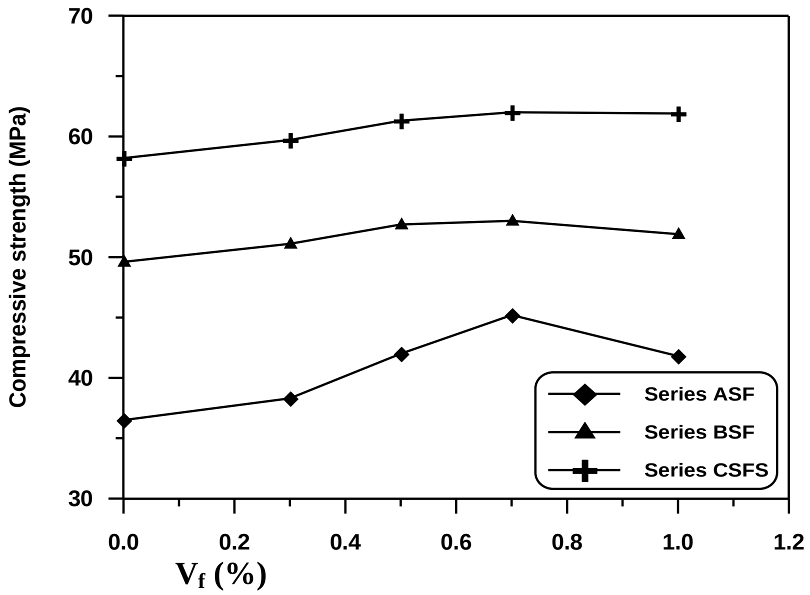
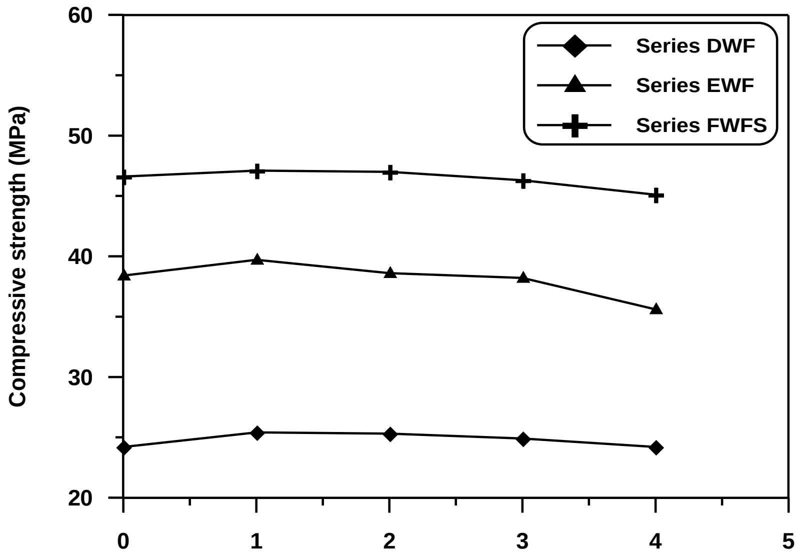


Fig.3 : Variation of the 90 day cube compressive strength with volume fraction of steel fibers for different series

The relation between compressive strength and waste flax fiber content is presented in Figs.4 and 5. It can be seen that the waste flax fibers do not affect the concrete strength appreciably. The fair reduction in strength at high fiber content mixes is attributed to the reduction in workability of these mixes and the presence of balling fibers during mixing which led to incomplete compaction and more voids.

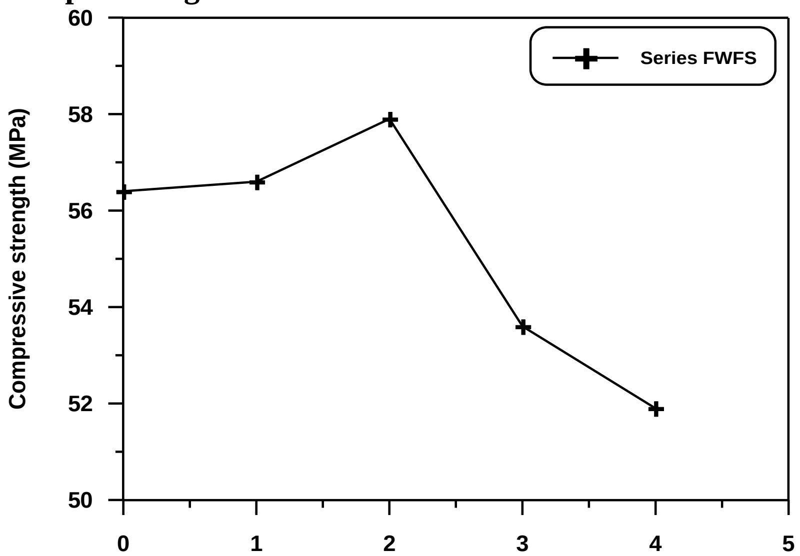
It is evident from the results that the effect of using a superplasticizer results in an increase in the strength of plain concrete and FRC with the decrease in W/C ratio.

The presence of steel and waste flax fibers enabled the cubes to keep their integrity even after failure, while plain concrete cubes disintegrated after the maximum load was reached.



V_f (%)

Fig.4: Variation of the 28 day cube compressive strength versus volume percentage of waste flax fibers for different series



V_f (%)

Fig.5 : Variation of the 90 day cube compressive strength with volume percentage of waste flax fibers

Splitting Tensile Strength Test Results

The influence of steel fiber content on the splitting tensile strength at ages 28 and 90 days is shown in Figs. 6 and 7 respectively. It is obvious from these figures that the indirect tensile strength increases with increasing the percentage of crimped steel fibers. This clearly confirms that the addition of steel fibers improves the concrete tensile strength which is due to the capacity of fibers to arrest cracks and prevent them from propagating until the composite ultimate stress is reached. The observed increases are anticipated and conform with the published data [(8)].

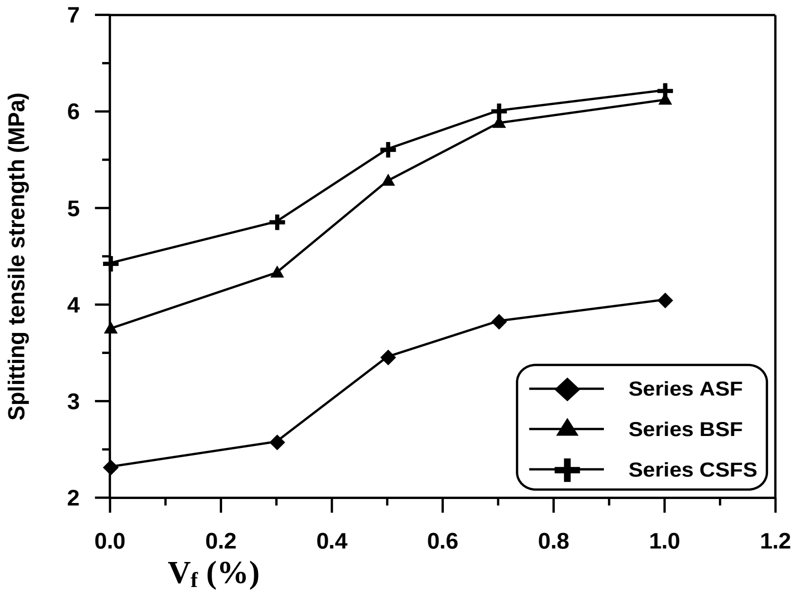


Fig.6 : Effect of volume fraction of steel fibers on 28 day splitting tensile strength for different series

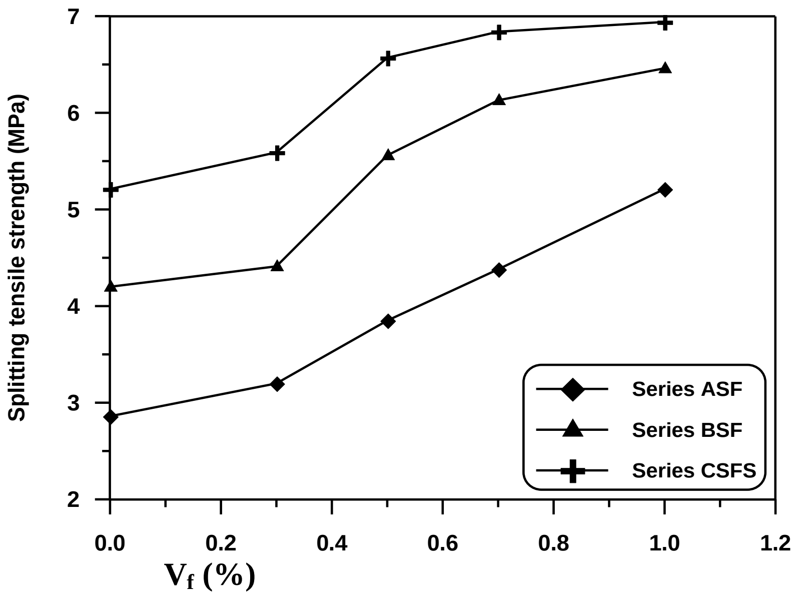


Fig.7: Effect of volume fraction of steel fibers on 90 day splitting tensile strength for different series

The results plotted in Figs.8 and 9 show the variation of splitting tensile strength with volume percentage of waste flax fibers. It can be observed that the inclusion of the waste flax fibers in concrete slightly improves the splitting tensile strength up to a certain point beyond which it starts to drop again. The maximum enhancement generally occurs with the initial inclusion of fiber content, at 1% by volume. The insignificant improvement in the tensile strength of concrete may be attributed to the high flexibility and low aspect ratio of the waste flax fibers. On the other hand, at higher volume fractions, fibers tended to cluster together resulting in an inadequate bond and reduction in strength.

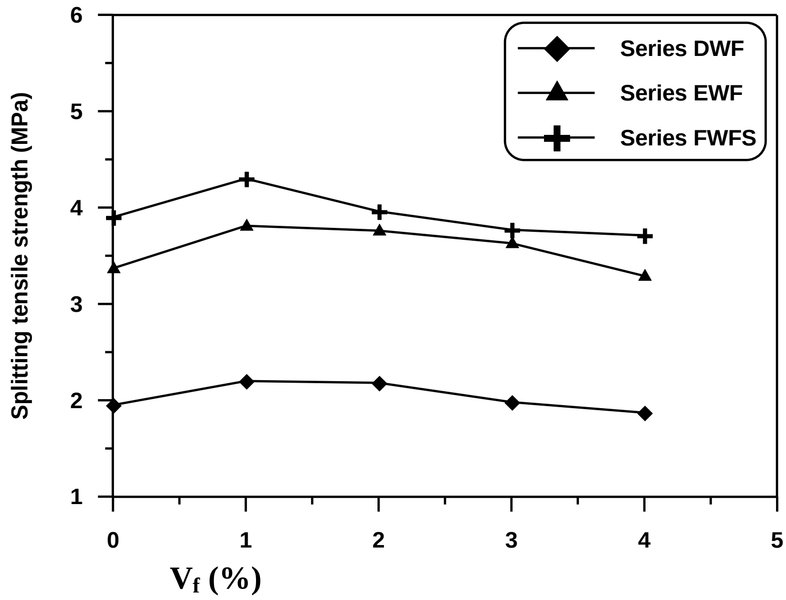


Fig.8: Influence of volume percentage of waste flax fibers on 28 day splitting tensile strength for various series

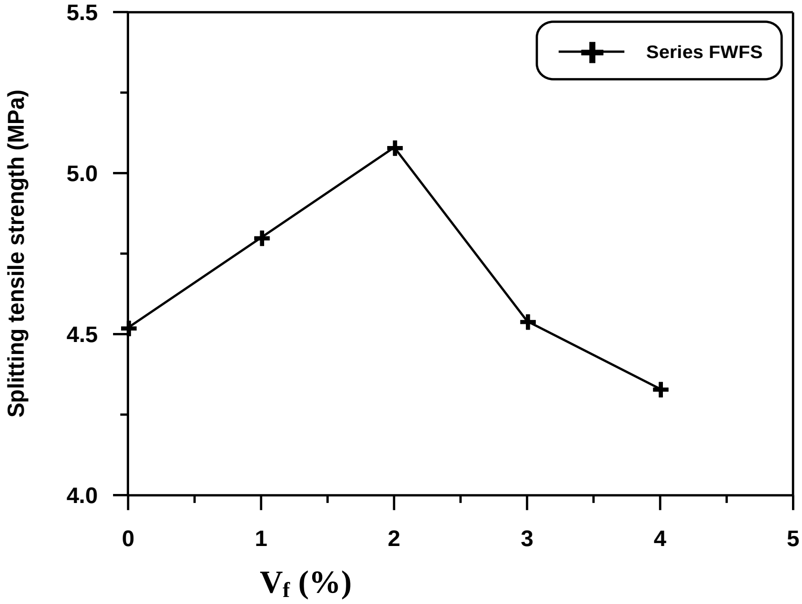


Fig.9: Influence of volume percentage of waste flax fibers on 90 day splitting tensile strength

Modulus of Rupture Test Results

The relation between 28 day and 90 day modulus of rupture (flexural strength) of specimens and volume of steel fibers is shown in Figs.10 and 11 respectively. The figures clearly show that there is an increase in the flexural strength as the volume fraction of fibers is increased. The reason could be that, the number of fibers that arrest microcracks and delay development of unstable crack system is increased. This note agrees with the conclusions of other authors [6,9] that the flexural strength increases linearly with steel fiber content. However, there is a variability in the amount of increase in the published work possibly due to the differences in the geometry, aspect ratio and orientation of fibers; coarse aggregate size and content; and the workability of mixes. This is also true for other mechanical properties of FRC.

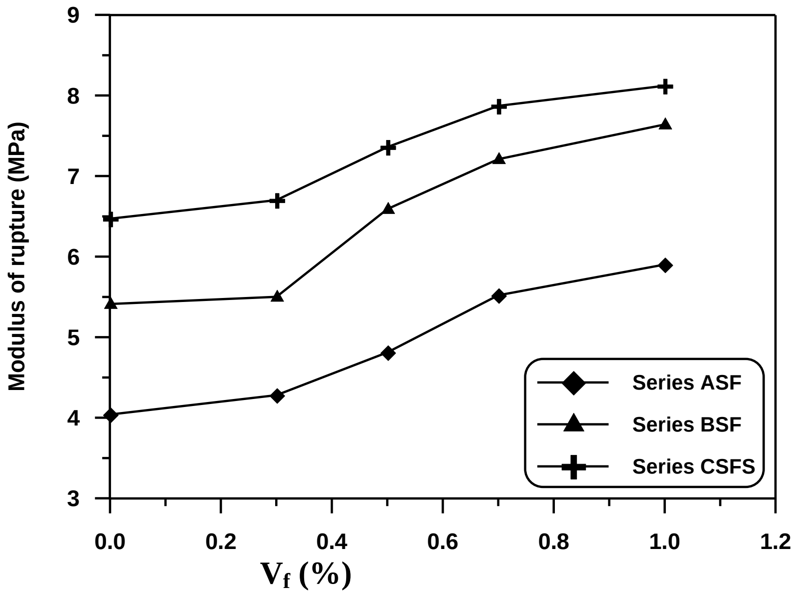


Fig.10: Effect of volume percentage of steel fibers on 28 day modulus of rupture for different series

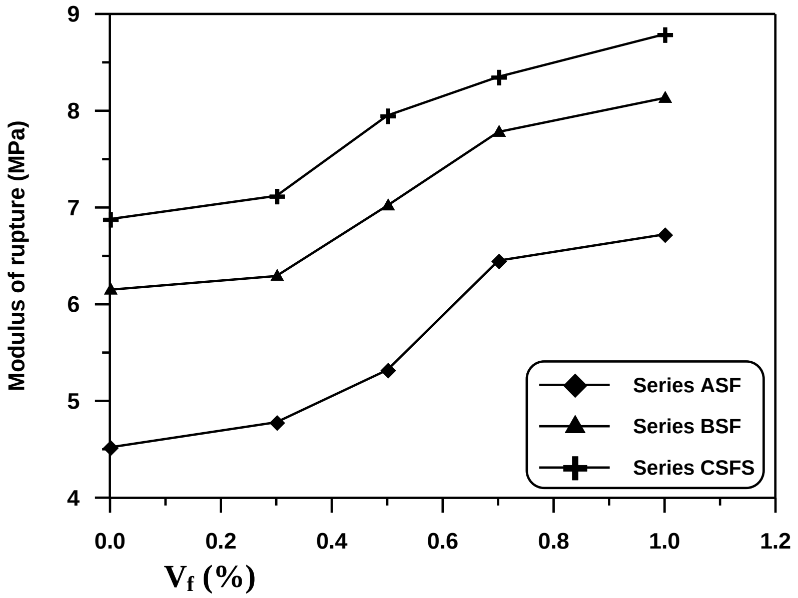


Fig.11: Effect of volume percentage of steel fibers on 90 day modulus of rupture for different series

The trend of modulus of rupture variation with waste flax fiber content is very similar to that of splitting tensile strength as can be seen from Figs12 and 13. There is a moderate change in modulus of rupture by including fibers and so it does not depend on the gravel content of mixes.

The failure of plain concrete prisms was always brittle and the crack passed through the section causing complete collapse. With fiber reinforcement, the specimens merely cracked at failure without separation.

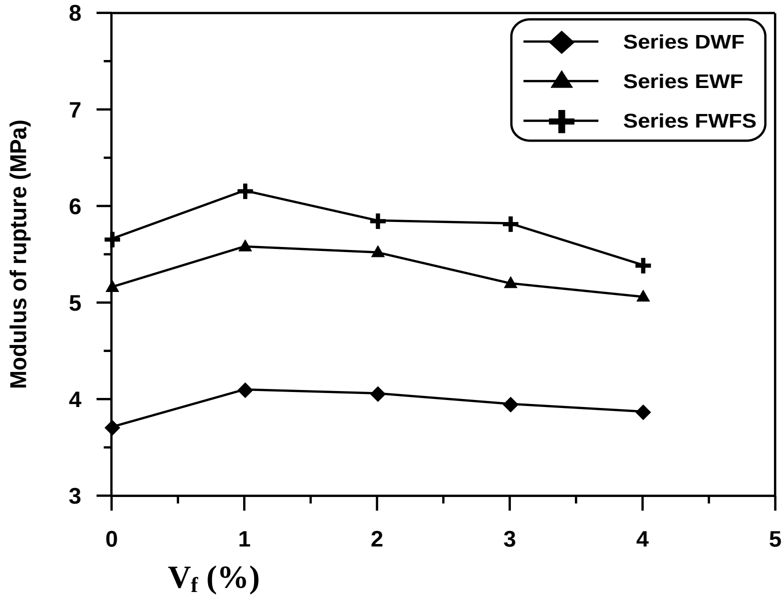
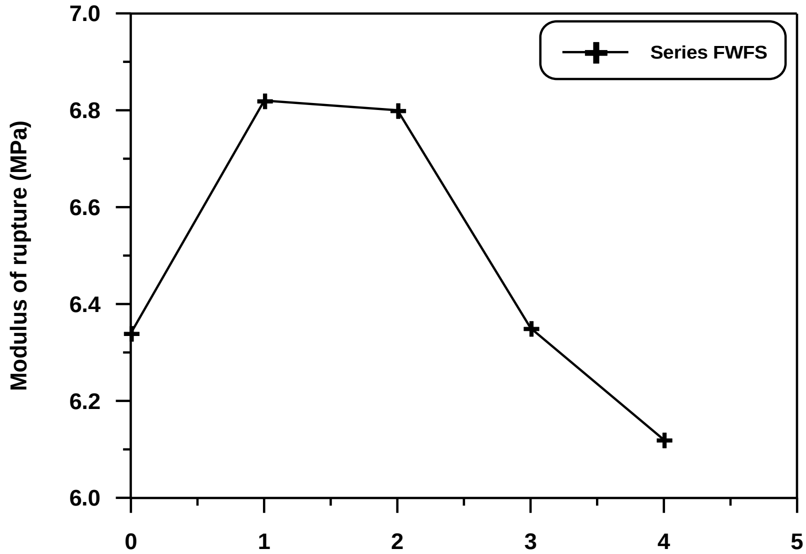


Fig.12: Effect of volume fraction of waste flax fibers on 28 day modulus of rupture for different series



V_f (%)Fig.13: Effect of volume fraction of waste flax fibers on 90 days modulus of rupture

Impact Resistance Test Results

The results of impact resistance for the 6 series are given in Table 6. The table includes measured thickness of the specimens and the impact behavior expressed by two indices: the number of blows required to cause the first visible crack, the number of blows required to cause the full failure.

Table 8: Impact resistance test results

Series	Fiber type	V_f (%)	Specimen thickness (mm)	Impact resistance (number of blows)			
				28 days		90 days	
				First crack	Complete failure	First crack	Complete failure
ASF	No-fiber	0.0	64.0	19	24	28	31
	Steel	0.3	64.5	32	86	72	105
		0.5	63.5	124	290	134	322
		0.7	63.5	182	472	176	654
		1.0	65.5	281	846	733	988
BSF	No-fiber	0.0	64.5	36	39	10	15
	Steel	0.3	63.5	52	95	29	53
		0.5	65.0	186	339	124	216
		0.7	64.0	226	708	165	295
		1.0	64.0	455	1125	102	511
CSFS	No-fiber	0.0	63.5	65	67	153	158
	Steel	0.3	63.0	31	96	164	192
		0.5	64.0	173	315	195	289
		0.7	64.0	261	469	362	453
		1.0	65.0	417	809	437	731
DWF	No-fiber	0.0	64.5	10	12	-	-
	Waste flax	1.0	63.5	15	95	-	-
		2.0	63.0	13	196	-	-
		3.0	64.5	10	576	-	-
		4.0	65.5	11	1018	-	-
EWF	No-fiber	0.0	64.5	17	18	-	-
	Waste flax	1.0	64.0	22	122	-	-
		2.0	64.0	21	293	-	-
		3.0	63.5	21	591	-	-
		4.0	63.0	19	1137	-	-
FWFS	No-fiber	0.0	65.5	38	42	76	82
	Waste flax	1.0	65.0	53	148	82	227
		2.0	63.5	45	356	80	328
		3.0	63.0	36	811	75	973
		4.0	63.5	25	1225	71	1262

Effects of Fiber Type and Content on Impact Resistance

The variation of impact resistance with volume percentage of fibers for SFRC series is shown in Figs. 14 to 17. It is obvious from these figures that the SFRC has a tremendous ability to absorb impact load. This ability increases as the steel fiber content is increased both at first crack (except for a few specimens of series BSF and CSFS) and at failure. The exceptions are related to the natural scatter of the results. The improvement in first crack resistance is achieved mainly through the arrest of microcracks by fibers. While, the substantial increase in impact resistance at failure could be due to the large energy required to de-bond and pull out or fracture the steel fibers when the cracks open at impact loading [1].

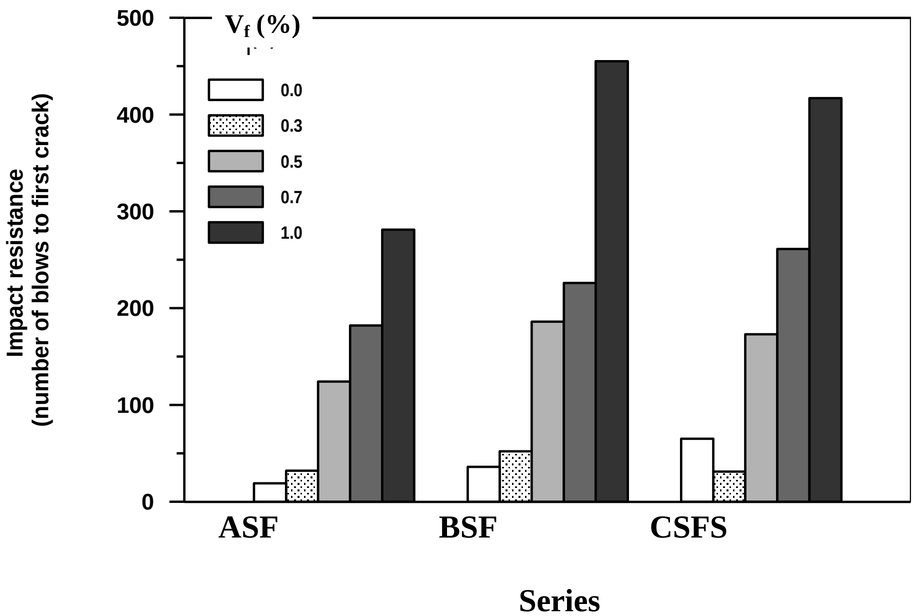


Fig.14: Variation of the 28 day impact resistance at first crack with volume percentage of steel fibers for different series

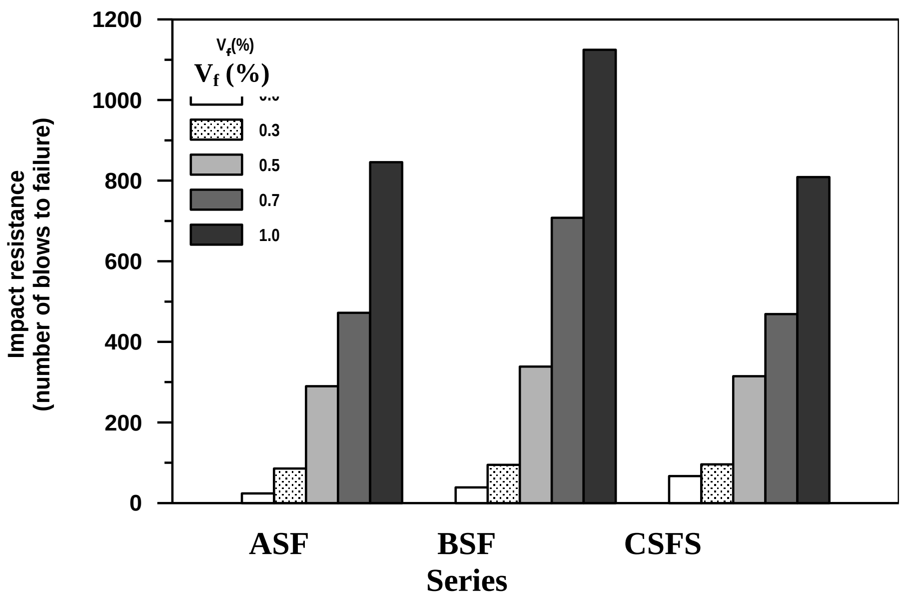


Fig.15: Variation of the 28 day impact resistance at failure with volume percentage of steel fibers for different series

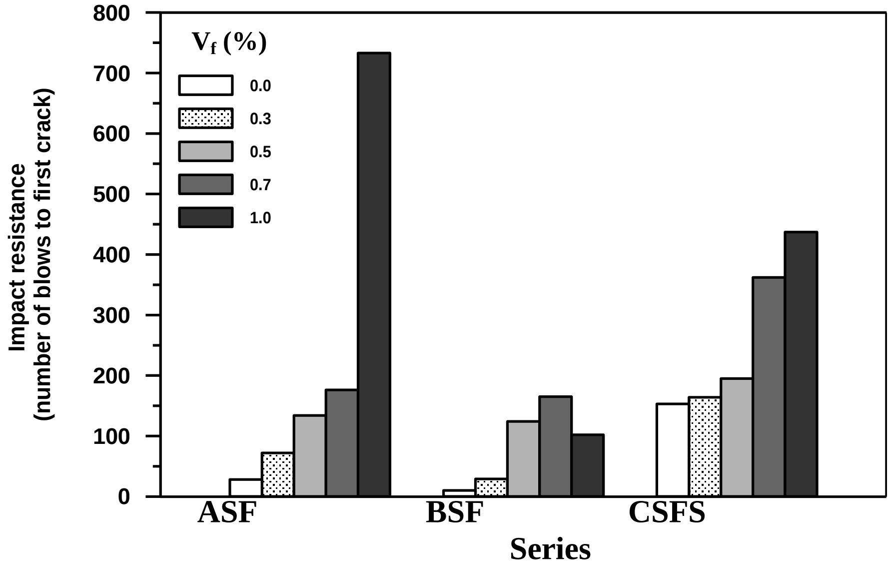


Fig.16: Variation of the 90 day impact resistance at first crack with volume percentage of steel fibers for different series

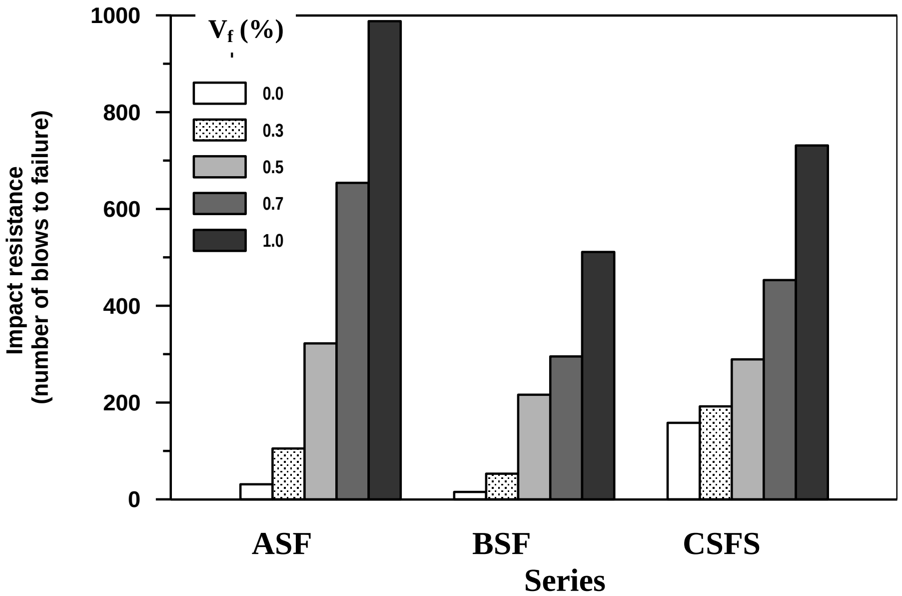


Fig.17: Variation of the 90 day impact resistance at failure with volume percentage of steel fibers for different series

The superior ability of SFRC to resist impact load has been also reported by other investigators [1,10] using totally different testing procedures. A direct comparison is not reliable due to the fact that the recorded value of impact is strongly dependent on many factors such as the energy and velocity of the impacting mass, the size of specimen, rigidity of supports, the type of test and even the definition of failure [1].

Figs.18 to 20 show the impact resistance against waste flax fiber content. It can be noticed that the waste flax fibers, in general, slightly delay the appearance of visual cracks regarding the fiber content. The reason is thought to be due to the significant flexibility of these fibers and thus their capacity to arrest microcracks is very small. On the other hand, the impact resistance or the impact energy at failure substantially improves as the percentage of waste flax fibers is increased. This enhancement could be related to the large amount of energy absorbed in debonding and pulling out the fibers which is required after the matrix has been cracked.

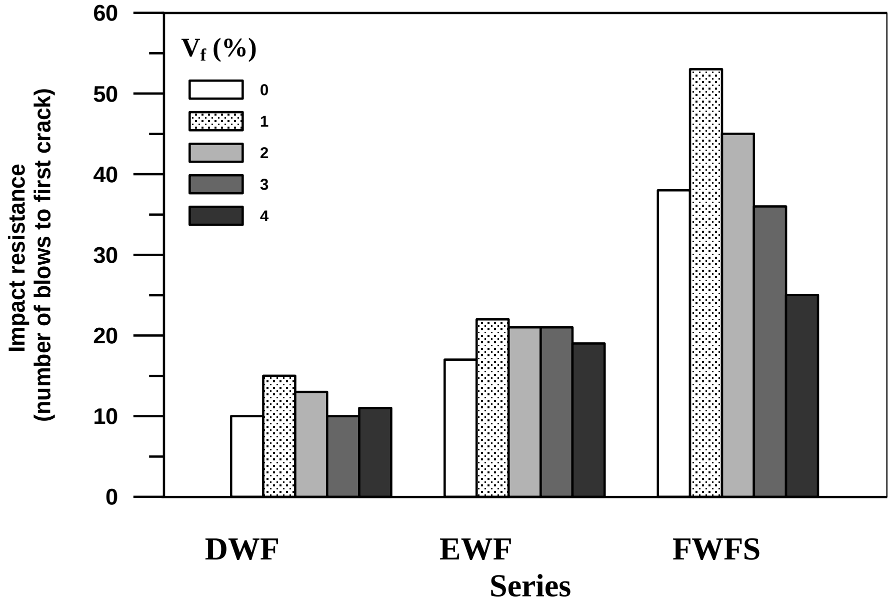


Fig.18: Variation of the 28 day impact resistance at first crack against volume fraction of waste flax fibers for different series

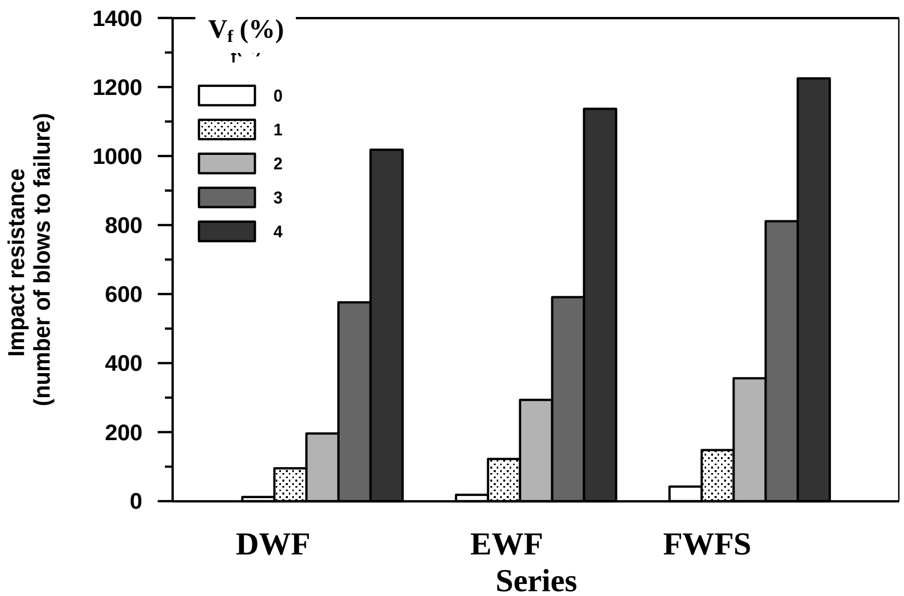


Fig.19: Variation of the 28 day impact resistance at failure against volume fraction of waste flax fibers for different series

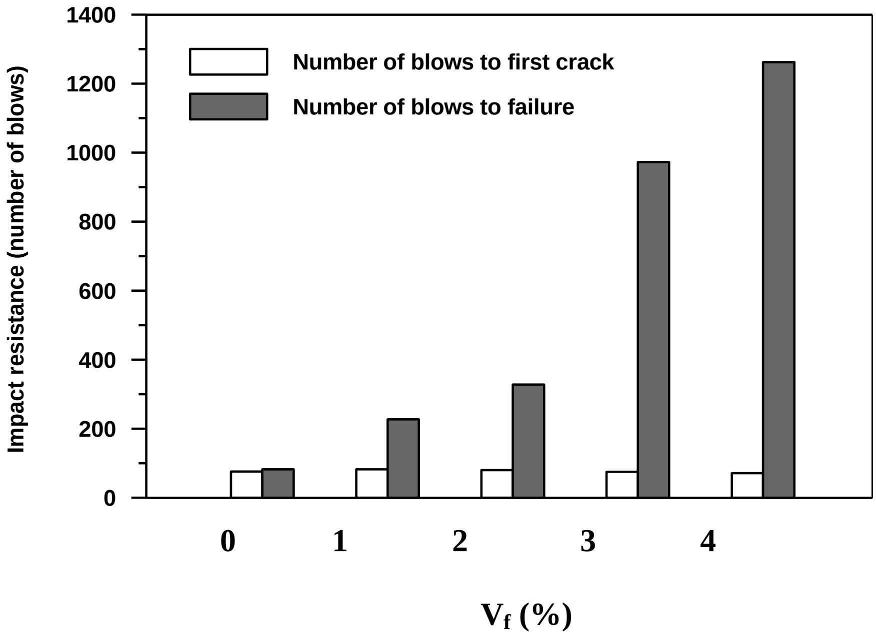


Fig.20: Variation of the 90 day impact resistance against volume fraction of waste flax fibers for series FWFS

Effect of Compressive Strength on Impact Resistance

The Effect on Plain Concrete Specimens

Keeping the same workability for the mixes, as the compressive strength increases the impact resistance of plain concrete also increases both to initiate the first crack and to produce failure. However, the plain specimens of series BSF at 90 days age adversely behaved when the number of blows at failure were even less than that produced by the weaker series ASF plain samples.

The Effect on SFRC Specimens

For the same steel fiber content, the impact resistance at failure generally increases with increasing compressive strength of the matrix up to a certain limit beyond which any increase in compressive strength reduces the impact resistance. This limit for the compressive strength is found to be around 45 MPa. For example, the values of the impact resistance to produce failure for concrete containing 1% crimped steel fibers are 846, 1125 and 809 blows for the matrix strength of 28.4, 44.8 and 53.1 MPa respectively. This behavior may be related to the dependence of the fiber pull out resistance on the strength of the matrix; at higher matrix strengths, more instances of fiber fractures have been reported to occur [(1)] and so the percentage of fibers which are effective in impact resistance control will be reduced. As a result, the SFRC will behave less ductile than the state before fracturing of fibers.

Recently, **Banthia *et al*.** [(1)] found a similar trend that the effectiveness of steel fibers in improving impact resistance decreases with the increase in compressive strength of the matrix. This conclusion was drawn when they used an instrumented impact machine as a testing tool and 0.5% volume fraction of different types of steel fibers. According to the available information, no other work has been previously published in this area.

The Effect on WFFRC Specimens

For the same waste flax fiber concentration, the impact resistance at first crack and at failure generally increases with the increase in matrix compressive strength.

It was found that it is difficult to formulate a strict relationship between impact resistance and compressive strength for each SFRC and WFFRC samples.

Effect of Age of the Specimens on Impact Resistance

Table 6 shows that the impact resistance at initial cracking and at failure of the plain concrete increases with age except for series BSF plain samples. It can also be seen from this table that the first crack resistance of SFRC in general increases with age with the exception of series BSF specimens. On the other hand, series ASF of SFRC experienced further resistance to impact at failure with increasing age, while series BSF and CSFS were adversely affected. Again, this behavior may have resulted from the higher strength of the latter two series which is significantly developed with age and hence some steel fibers are thought to be fractured during impact.

The results of series ASF of SFRC are generally in agreement with that recorded by **Ramakrishnan *et al.*** (6), which are the only reported work on this issue. In the case of the other series of SFRC, a similar comparison is not available as these workers considered the matrix strength of only 42 MPa at 90 days which is lower than the upper strength level for complete pulling out of fibers obtained in this study.

With a few exceptions, increasing the age of series FWFS samples leads to increase the impact resistance both to initiate first visual crack and to produce failure.

Conclusions

Based on the experimental results of the present research, the following conclusions can be drawn:

1. The inclusion of crimped steel fibers improves the compressive strength of concrete. Nevertheless, the maximum improvement is achieved at 0.7% volume of fibers. This improvement is about 8.5 to 20.4% at 28 days and 6.5 to 23.8% at 90 days.
2. The presence of waste flax fibers in concrete has an insignificant effect on the compressive strength. The compressive strength of WFFRC is varied from +5 to –8% with respect to plain concrete.
3. The percentage of increase in splitting tensile strength and modulus of rupture is directly proportional to the crimped steel fiber content. The 28 and 90 days increase in splitting tensile strength is in the range of 40.4 to 74.6% and 33.2 to 82.2% respectively for 1% steel fibers. The corresponding increase in modulus of rupture is about 25.5 to 46.0% and 27.8 to 48.7%.
4. It was found that the inclusion of waste flax fibers in plain concrete results in a slight increase in splitting tensile strength and modulus of rupture. The maximum increase is generally observed with the initial inclusion of fiber content, at 1% by volume. However, in general, there appears to be a limiting fiber content, V_f = 3%, beyond which both strengths are marginally reduce.
5. The impact resistance at first crack can be improved when increasing the percentage of crimped steel fibers.
6. The results show that the higher the volume fraction of crimped steel fibers the more resistant to impact at failure is the composite.
7. It was found that waste flax fibers have a moderate effect on the impact resistance up to first visible crack.
8. The results reveal that the capacity of concrete to resist impact loading at failure can be significantly improved by increasing the content of waste flax fibers.
9. With the SFRC, there appears to be a limit to matrix compressive strength beyond which the impact resistance at failure starts to decrease. A strength of around 45 MPa is such a limit.
10. It was found that WFFRC generally exhibits more resistance to impact at the higher matrix strengths and the later ages.

References

[1] Banthia, N., Mindess, S., and Trottier, J.F., "**Impact Resistance of Steel Fiber Reinforced Concrete**", ACI Materials Journal, Vol.93, No.5, Sep.-Oct. 1996, pp.472-479.

[2] Banthia, N., Yan, C., and Sakai, K., "**Impact Resistance of Fiber Reinforced Concrete at Subnormal Temperatures**", Cement and Concrete Composites, Vol.20, 1998, pp.393-404.

[3] ACI Committee 544, "**Measurement of Properties of Fiber Reinforced Concrete**", ACI Materials Journal, Vol.85, No.6, Nov.-Dec. 1988, pp.583-593.

[4] ACI Committee 544, "**Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete**", ACI Materials Journal, Vol.90, No.1, Jan.-Feb. 1993, pp.94-101.

[5] Aziz, M.A., Paramasivam, P., and Lee, S.L., "**Prospects for Natural Fiber Reinforced Concretes in Construction**", The International Journal of Cement Composites and Lightweight Concrete, Vol.3, No.2 , May 1981, PP.123-132.

[6] Ramakrishnan, V., Brandshaug, T., Coyle, W.V., and Schrader, E.K., "**A Comparative Evaluation of Concrete Reinforced with Straight Steel Fibers and Fibers with Deformed Ends Glued Together into Bundles**", ACI Journal, Vol.77, No.3, May-June 1980, pp.135-143.

[7] Abdul-Hameed, T.A., "**Ductility of Fiber Reinforced Concrete**", M.Sc. Thesis, University of Baghdad, 1981.

[8] Shaaban, A.M., and Gesund, H., "**Splitting Tensile Strength of Steel Fiber Reinforced Concrete Cylinders Consolidated by Rodding or Vibrating**", ACI Materials Journal, Vol.90, No.4, Jul.-Aug. 1993, pp.366-369.

[9] Synder, M.J., and Lankard, D.R., "**Factors Affecting the Flexural Strength of Steel Fibrous Concrete**", ACI Journal, Vol.69, No.2, Feb.1972, pp.96-100.

[10] [2] Al-Khafaji,A.H., "**Impact and Abrasion Resistance of Flax and Steel Fiber Reinforced Concrete** ", M.Sc. Thesis, University of Babylon,2002.

[11] American Society for Testing and Materials , C143-89a , " Standard Test Method for Slump of Hydraulic Cement Concrete " , **Annual Book of ASTM Standards, Vol.04.02, 1989, PP.85-86.**

[12] American Society for Testing and Materials , C93-79 , " Standard Test Method for Flexural Strength of Concrete **(Using Simple Beam with Center – Point Loading) . Annual Book of ASTM Standards, Vol.04.02, 1989, PP.165-166.**