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Study of Modulus of Elasticity of Steel Fiber Reinforced Concrete

Misba Gul, Alsana Bashir, Javed A Naqash

Abstract— ***Plain, unreinforced concrete is a brittle material, with a low tensile strength, limited ductility and little resistance to cracking. In order to improve the inherent tensile strength of concrete there is a need of multidirectional and closely spaced reinforcement, which can be provided in the form of randomly distributed fibers. Steel fiber is one of the most commonly used fibers. Short, discrete steel fibers provide discontinuous three-dimensional reinforcement that picks up load and transfer stresses at micro-crack level. This reinforcement provides tensile capacity and crack control to the concrete section prior to the establishment of visible macro cracks, thereby promoting ductility or toughness.***

The modulus of elasticity of concrete is a very important parameter reflecting the ability of concrete to deform elastically. In addition, in order to make full use of the compressive strength potential, the structures using high strength concrete tend to be slimmer and require a higher elastic modulus so as to maintain its stiffness. Therefore, knowledge of the modulus of elasticity of high strength concrete is very important in avoiding excessive deformation, providing satisfactory serviceability, and avoiding the most cost-effective designs.

The present experimental study considers the effect of steel fibers on the modulus of elasticity of concrete. Hook end steel fibers with aspect ratio of 50 and 71 at volume fraction of 0.5%, 1.0% and 1.5% were used. Study on effect of volume fraction and aspect ratio of fibers on the modulus of elasticity of concrete was also deemed as an important part of present experimental investigation. The results obtained show that the addition of steel fiber improves the modulus of elasticity of concrete. It was also analyzed that by increasing the fiber volume fraction from 0.5% to 1.5% and aspect ratio of fibers from 50 to 71 there was a healthy effect on modulus of elasticity of Steel Fiber Reinforced Concrete.

Index Terms—Aspect ratio, Compressometer, Modulus of Elasticity, Steel fiber reinforced concrete, volume fraction.

I. INTRODUCTION

The modulus of elasticity is essentially a measurement of the stiffness of a material. Modulus of elasticity of concrete is a key factor for estimating the deformation of buildings and members, as well as a fundamental factor for determining modular ratio, m, which is used for the design of section of members subjected to flexure. The precise determination of the modulus of elasticity of concrete is very important for structures that require strict control of the deformability. The modulus of elasticity is often used in sizing reinforced and non-reinforced structural members, establishing the quantity of reinforcement, computing stress for observed strain, and is especially important in the design of pre-stressed concrete members.

So, the elastic modulus of concrete is a very important parameter reflecting the ability of concrete to deform elastically. In addition, in order to make full use of the compressive strength potential, the structures using high strength concrete tend to be slimmer and require a higher elastic modulus so as to maintain its stiffness. Therefore, knowledge of the modulus of elasticity of high strength concrete is very important in avoiding excessive deformation, providing satisfactory serviceability, and avoiding the most cost-effective designs.

Plain, unreinforced concrete is a brittle material, with a low tensile strength, limited ductility and little resistance to cracking. Although the tensile strength of concrete can be improved by using conventional reinforced steel bars, they however, do not increase the inherent tensile strength of concrete itself. Cracks in reinforced concrete members extend freely until encountering a reinforcement bar. The need for multidirectional and closely spaced reinforcement for concrete arises.

This demands the use of some simple means by which various static and dynamic properties of concrete can be improved. One such means is the random addition of steel fibers in concrete, the concrete being referred to as Steel Fiber Reinforced Concrete (SFRC).

By incorporating steel fibers the mechanical properties of the concrete is changed resulting in significant load carrying capacity after the concrete has cracked (Chen)[1]. Laboratory studies on Steel Fiber Reinforced Concrete (SFRC) specimens suggest that dispersion of steel fibers in concrete improves the mechanical characteristics of the composite, notably resistance to dynamic load (Banthia et al.)[2], shear strength (Khaloo and Kim,)[3], fatigue resistance (Johnston and Zemp,)[4] and post cracking strength (Elsaigh and Kearsley,).[5]

Fibers influence the mechanical properties of concrete and mortar in all failure modes (Gopalaratnam and Shah) [6], especially those that induce fatigue and tensile stress, e.g., direct tension, bending, impact, and shear. The strengthening mechanism of the fibers involves transfer of stress from the matrix to the fiber by interfacial shear or by interlock between the fiber and matrix if the fiber surface is deformed. Stress is thus shared by the fiber and matrix in tension until the matrix cracks, and then the total stress is progressively transferred to the fibers.

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A.M Shende et al. [7] carried out the comparative study on steel fiber reinforced cum control concrete. Steel fibers of 50, 60 and 67 aspect ratio at volume fraction of 0%, 1%, 2% and 3% were used. It was observed that compressive strength, tensile strength and flexural strength from steel fibers were on higher side from 3% fibers as compared to that produced from 0%, 1% and 2% fibers. All the strength properties were observed to be on higher side for aspect ratio of 50 as compared to those for aspect ratio 60 and 67. Through utilization of steel fibers the compressive strength increased from 11 to 28%, flexural strength increased from 18 to 58% and tensile strength from 9 to 29%.

Mohammed Alias Yusof et al. [8] studied the mechanical properties of hybrid steel fiber reinforced concrete with different Aspect Ratio.. The results indicate that the hybrid steel fiber reinforced concrete (at volume fraction of 1.5%, consisting of 70% long fiber and 30% short fiber) gave the highest value of flexural strength and split tensile strength. On the other hand, the concrete mix containing 30% long fibers and 70% short fibers at 1.5% volume fraction gave the highest compressive strength. The results reveal that longer fiber performs better in flexural and tensile strength. On the other hand, concrete with short steel fiber performs better in compression as compared to concrete with longer steel fiber. It was also observed that by increasing the percentage of fiber volume in the mix, the workability of the concrete mix was reduced.

Er. Prashant Y.Pawade et al. [9] studied the Effect of Steel Fibers on Modulus of Elasticity of Concrete. Crimped steel fibers at volume fractions of 0, 0.5, 1.0, and 1.5 %, were used. The fibers were having diameter of 0.5mm and 1.0mm with a constant aspect ratio of 60. Addition of crimped steel fibers to concrete changed the basic characteristics of its stress-strain response. The slope of the descending branch decreased with increase in the volume fraction of steel fiber. The increase of strain at peak stress also showed a good agreement with the increase of fiber volume fraction. It was also concluded that the modulus of elasticity increased with an increase in fiber volume fraction or fiber reinforcing index. The modulus of elasticity for 1.0mm diameter steel fiber was more than that for 0.5 mm diameter steel fiber. In general, a significant improvement in various strengths was observed with the inclusion of steel fibers in plain concrete with high volume fractions.

Osman Gencel et al. [10] studied the Workability and Mechanical Performance of Steel Fiber-Reinforced Self-Compacting Concrete with Fly Ash. In this experimental investigation steel fiber having aspect ratio of 60 and geometry of cylindrical with hooked ends were used. The steel fibers were used at volume fractions of 0.2%, 0.4%, 0.6% and 0.8%. Water/Cement ratio (W/C), cement, fly ash and super plasticizer contents were kept constant at 0.40, 400, 120 and 6 kg/m^3, respectively. It was concluded that mechanical properties of concrete can be improved by the addition of steel fibers. However, the improvement in compressive strength does not always increase with a larger content of fibers The modulus of elasticity was improved only slightly with increasing fiber content. A significant improvement in the energy absorption and ductility in compression was achieved by adding fibers to concrete.

Saravana Raja Mohan. K, Parthiban. K [11] investigated the Strength and behavior of Fly Ash based Steel Fiber Reinforced Concrete Composite. In that investigation a control mixture of proportions 1:1:49:1.79 with Water/Cement (W/C) of 0.45 was designed. Cement was replaced with five percentages (10%, 15%, 20%, 25% & 30%) of Class C fly ash. Four percentages of steel fibers (0.15%, 0.30%, 0.45% & 0.60%) having 20 mm length were used. Based on experimental test, it was found that fly ash can serve as a good substitute for cement in reasonable proportions by volume and whatever deficiencies that may result can be easily overcome by use of steel fibers. Properties of the resulting composites show better performance than plain concrete both in terms of mechanical and structural strengths. In addition, the stress-strain curves show reasonable amount of energy absorption capabilities with good ductility. 15% fly ash with 0.15% of fiber gave an increase of 5% to 31 % increase in cube strength at the end of seven days and 12% to 55% at the end of 28 days. Similar enhancements in tensile strength and modulus of rupture were observed making these composites an efficient material over concrete with the use of local materials and technology. In general steel fiber composites show better performance upto 20% fly ash and 0.3% fiber content

J. Mater [12] worked on the mechanical properties of steel fiber-reinforced concrete. The study indicates that the fiber matrix interaction contributes significantly to enhancement of mechanical properties caused by the introduction of fibers.

Different authors have reported different opinions, some certainly demonstrated the enhancement in Modulus of elasticity, while, few researchers could not comply with it. So a common view, could be developing a standard specification or code of practice to identify the behavior of Steel Fiber Reinforced Concrete (SFRC). In this experimental study efforts have been made to evaluate rationally the effect of steel fiber on modulus of elasticity of concrete. Study on effect of volume fraction and aspect ratio of fibers on modulus of elasticity of concrete in particular has also been deemed as an important part of present experimental investigation.

II. EXPERIMENTAL PROGRAM

In this experimental investigation seven different mixtures of concrete, one control and six fiber-reinforced (three mixtures with fiber HK0750 and three with fiber HK0735), were prepared in each casting. Cement content, aggregate grading and water cement ratio were kept constant in all the mixtures. For the mixtures with steel fiber, the fiber ratios were 39.25, 78.50, and 117.75 kg/m^3. These ratios correspond to fiber volume fractions of 0.5%, 1.0% and 1.5% respectively. For all the mixes water/cement ratio (W/C) was kept constant at 0.37. Slump tests and compaction factor tests were conducted to examine the properties of fresh concrete. It was noticed that Steel fiber based concrete in the fresh state showed a drastically decreased workability with an increase in fiber content and aspect ratio of fibers and was raised to desired level by tuning the amount of superplasticizer suitably.

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Cylindrical specimens were cast in sufficient number to arrive at the properties of Steel Fiber Reinforced Concrete. Cylindrical samples were cast in 150 mm diameter and 300mm deep cylindrical moulds. The moulds were filled in three layers, with each layer vibrated for about 3 to 4 seconds with the help of a table vibrator. The samples were cured and then tested for modulus of elasticity. The results were then analyzed and conclusions were made.

A. Material

The materials used in the study were Ordinary Portland Cement 43 Grade, good quality river sand from local source, confirming IS grading zone II [13], crushed stone in sizes of 10 mm and 20 mm, tap water, water reducing superplasticizer namely cico viscoplast and Hook end steel fibers HK0750 and HK 0735 as shown in Fig. 1. Table I represents various properties of Hook End Steel Fibers.

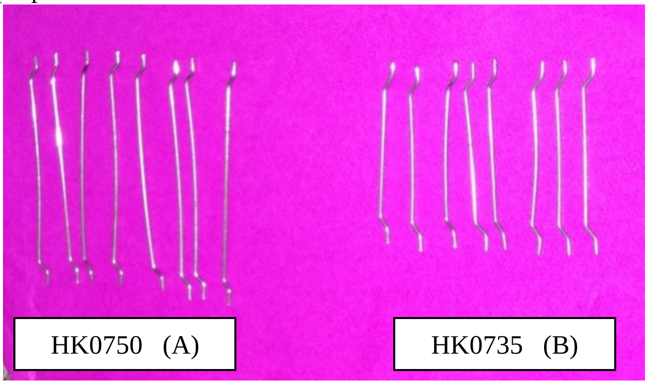

Fig1:- Hook End steel fibers used in the study.

Table I:- Properties of Hook End Steel Fibers

Fiber Type	**Designation**	**D mm**	**L mm**	**Aspect Ratio**	**Density kg/m^3**
HK 0750	A	0.7	50	71	7800
HK 0735	B	0.7	35	50	

D= Diameter of steel fiber in mm
L= Length of steel fiber in mm

The above specifications were specified by principal manufacturer of fiber.

B. Mixture Proportioning

The various mixture proportions used in this study are given in Table II. The concrete mixes were prepared by hand mixing on a non-absorbing platform. The mixing sequence followed for SFRC was different from that of control concrete. Initially the coarse aggregate, fine aggregate and 10 % of the steel fibers were dry mixed. Then cement and next 30 % of the steel fiber was added, followed by 70% of calculated amount of water. The mixture was thoroughly mixed. Later remaining quantities of steel fiber were sprinkled over the concrete mix and mixed. The remaining 30 % of water was mixed with the superplasticizer and was added to the concrete and mixed approximately for 3 minutes.

Table II:- Mix proportions of concrete

Mix ID	**C**	**FA**	**CA**		W/C	**SP (%)**	**A** (Kg/m^3)	**B** (Kg/m^3)
			20 mm	**10 mm**				
PC	437	756	726	484	0.37	0.30	0	0
A 0.5	437	756	726	484	0.37	1.00	39.25	0
A 1.0	437	756	726	484	0.37	1.25	78.50	0
A 1.5	437	756	726	484	0.37	1.40	117.75	0
B 0.5	437	756	726	484	0.37	1.0	0	39.25
B 1.0	437	756	726	484	0.37	1.20	0	78.50
B 1.5	437	756	726	484	0.37	1.35	0	117.75

C: Cement content (Kg/m^3)
FA: Fine Aggregates (Kg/m^3)
CA: Coarse Aggregates (Kg/m^3)
SP: Super-plasticizer by weight of cement (%)

C. End conditions of cylindrical specimens

Prior to testing, some cylindrical specimens were capped with rich cement paste. The capping was performed by winding a thick plastic strip around the cylinder with the help of rubber bands. The position of the plastic strip was adjusted with the help of level placed at the top. A rich cement paste was placed at the top of the cylinder with the help of spatula and was finished smoothly. Capping was followed by moist curing. The capping procedure was followed, to ensure parallel loading faces of test cylinders.

Some cylindrical specimens were having slight roughness in the top face. So in order to ensure parallel loading face of the test cylinders grinding was done.

In some cylindrical specimens thick paper and cardboard packing was placed to ensure parallel loading face of the test specimen.

D. Tests Conducted:

Test for Modulus of Elasticity: A compressometer equipped with a Linear Variable Differential Transducer (LVDT) was used to measure the deformation of concrete cylinder during a compression test in Automatic Compression Testing Machine(ACTM). The load and deformation data were recorded by means of a computer data acquisition system.

Since, the modulus of elasticity most commonly used in practice is secant modulus. The secant modulus decreases with an increase in stress, the stress at which the modulus has been determined must always be stated. For comparative purposes the maximum stress applied is chosen as a fixed proportion of the ultimate strength. This proportion is prescribed as 33% in BS 1881: Part 121:1983 [14], and as 40 % in ASTM C 469-94 [15]. The minimum is specified by BS 1881: Part 121:1983[14] as 0.5 MPa; ASTM C 469-94 [15] specifies a minimum strain of 50×10^{-6}.

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The modulus of elasticity of plain concrete and steel fiber based concrete mixes with different fiber volume fraction and aspect ratio were obtained from the data obtained from Automatic Compression Testing Machine. The values corresponded to 33% of the maximum stress.

Fig. 2:- Specimen with Compressometer in ACTM

III. Results and Discussions

The results of modulus of elasticity for plain concrete and Steel Fiber Reinforced Concrete are shown in Table III.

Results obtained have shown that modulus of elasticity of concrete increases with the addition of steel fibers to concrete as evident from Fig. 5 and Fig 6. It is also evident that modulus of elasticity of Steel Fiber Reinforced Concrete increases with increase in fiber volume fraction and aspect ratio of fibers as shown in Fig 7. The percentage increase in modulus of elasticity of steel fiber based concrete mixes relative to reference concrete were 8.90%, 10.23% and 19.75% for fiber having aspect ratio of 50 and 10.26%, 16.62% and 30.94% for fiber having aspect ratio of 71 at fiber volume fraction of 0.5%, 1% and 1.5% respectively.

Table V:- Modulus of Elasticity of Plain Concrete and Steel Fiber Reinforced Concrete.

MIX ID	σ_U	E_U (%)	σ	E (%)	$E_{33\%}$
PC	33	0.2	11	0.0374	29411
PC	32.03	0.2	10.676	0.0359	29738
PC	37.90	0.2	12.633	0.0453	27887
PC	35.10	0.2	11.700	0.0393	29771
A 0.5	35	0.3	11.667	0.0384	30383
A 0.5	48.80	0.4	16.266	0.0529	30748
A 0.5	36.10	0.3	12.033	0.0398	30233
A 0.5	37.90	0.3	12.633	0.0399	31661
A 1.0	35.50	0.3	11.833	0.0345	34298
A 1.0	43.30	0.5	14.433	0.0434	33256
A 1.0	40.90	0.3	13.633	0.0415	32850
A 1.0	38.60	0.3	12.866	0.0379	33947
A 1.5	45.20	0.5	15.066	0.0410	36746
A 1.5	43.20	0.5	14.400	0.0394	36548
A 1.5	46.40	0.5	15.466	0.0459	33694
A 1.5	40.80	1.3	13.600	0.0403	33746
B 0.5	33.40	0.3	11.133	0.0369	30170
B 0.5	42	0.4	14	0.0461	30369
B 0.5	33.70	0.3	11.233	0.0370	30359
B 0.5	31.80	0.3	10.600	0.0345	30724
B 1.0	46.70	0.3	15.566	0.0496	31383
B 1.0	38.20	0.3	12.733	0.0388	32817
B 1.0	36.30	0.3	12.100	0.0389	31105
B 1.0	34.90	0.4	11.63	0.0371	31348
B 1.5	50.30	0.3	16.766	0.0485	34569
B 1.5	36.10	0.3	12.033	0.0360	33425
B 1.5	39.50	0.3	13.166	0.0391	33672
B 1.5	32.40	0.7	10.800	0.0321	33645

σ_U= Ultimate stress of cylindrical specimens (N/mm^2)
E_U = Ultimate strain of cylindrical specimens (%)
σ = Stress at 33% of the ultimate strength (N/mm^2)
E = Strain of cylindrical specimens corresponding to stress of σ
$E_{33\%}$= Elastic Modulus at a stress corresponding to 33% of ultimate strength.

It was observed that the addition of steel fibers increased the ultimate stress and the corresponding ultimate strain with respect to the plain concrete. The percentage increase in ultimate stress and ultimate strain of steel fiber based concrete over that of plain concrete as the volume fraction of fibers is increased from 0.5% to 1.5% and the aspect ratio is changed from 50 to 71 is shown in Fig.8 and Fig.9 respectively. It was noticed that the gain in the ultimate strain was considerably more pronounced than that in the ultimate stress. The percentage increase in ultimate stress increased with increase in fiber volume fraction and aspect ratio of fiber.The percentage increase in ultimate strain was observed to increase with increase in fiber volume fraction for the same aspect ratio and with increase in aspect ratio for the same volume fraction of fibers, although it was more marked in the case of specimens with fiber aspect ratio of 71 than in the case of specimens with fiber aspect of 50.

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This may be due to the fact that the short fibers begin to pull out once the micro cracks start coalescing into macro cracks around the peak, thus providing lesser effect thereafter compared to longer fibers, which are now contributing to arrest these macro cracks.

Fig. 3:- SFRC cylinder at failure

Fig.4:- Plain concrete cylinder at failure

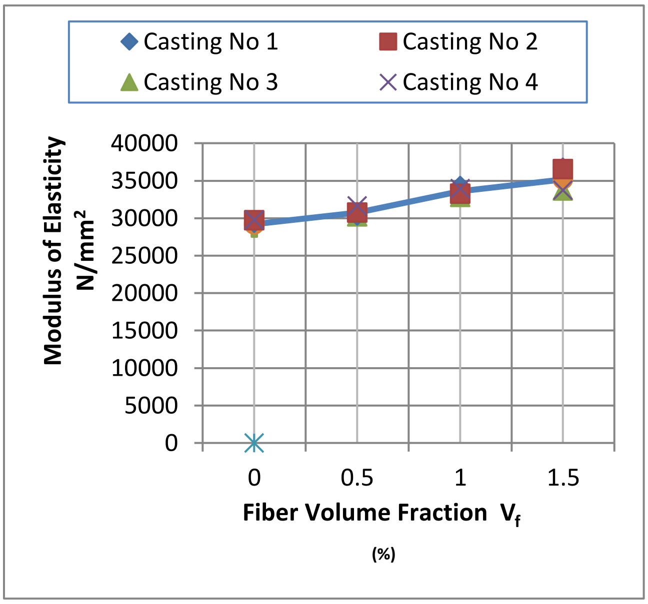

Fig 5:- Effect of fiber volume fraction of HK0750 (A) on the Modulus of Elasticity of SFRC

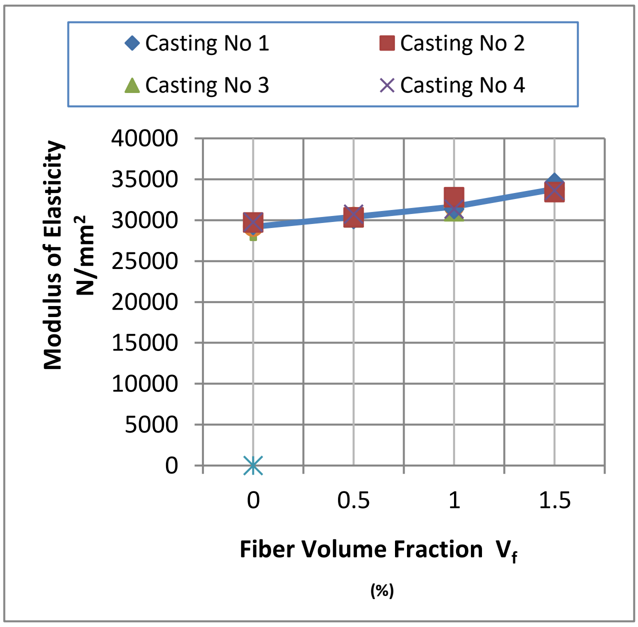

Fig 6:- Effect of fiber volume fraction of HK0735 (B) on the Modulus of Elasticity of SFRC

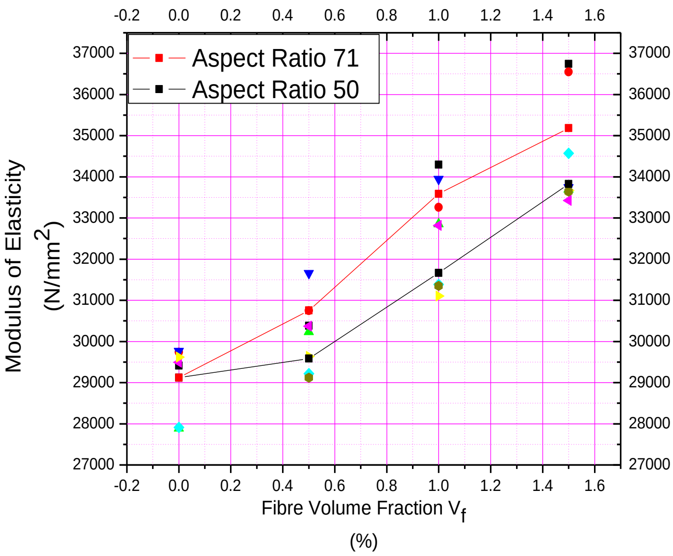

Fig 7:- Effect of fiber volume fraction on the modulus of elasticity of SFRC at two different aspect ratios.

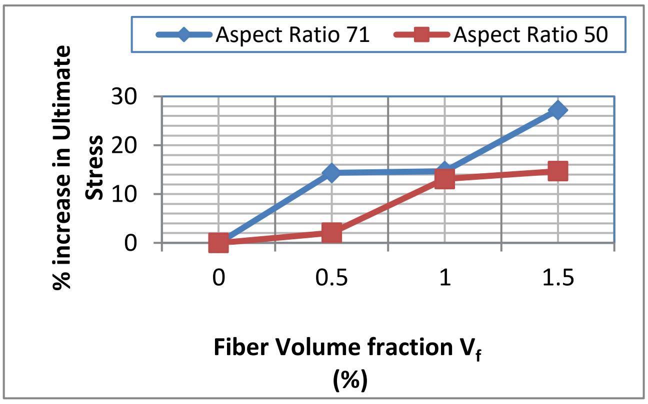

Fig 8 :- % increase in ultimate stress v/s volume fraction of fibers at two different aspect ratios.

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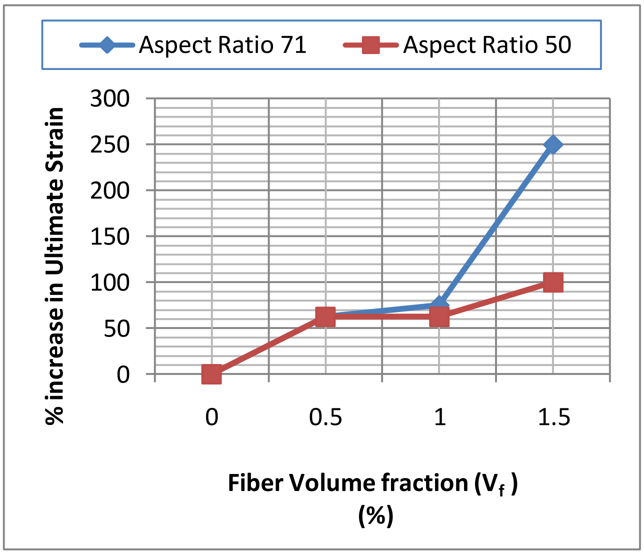

Fig 9:- % increase in peak strain v/s volume fraction of fibers at two different aspect ratios.

IV. CONCLUSION

From this experimental study it was concluded that, the modulus of elasticity of concrete is significantly improved by the addition of steel fibers. The optimum fiber volume fraction for better performance in terms of strength for both the aspect ratios is 1.5%.Fiber with aspect ratio of 71 gives better result as compared to fiber with aspect ratio of 50.At a constant aspect ratio of fiber, the modulus of elasticity of Steel Fiber Reinforced Concrete is observed to increase with an increase in the fiber volume fraction.

The gain in the ultimate stress, and ultimate strain over plain concrete increases with an increase in the fiber content and aspect ratio of fibers.

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