INFLUENCE OF FIBER ASPECT RATIO ON SHEAR CAPACITY OF DEEP BEAMS USING ARTIFICIAL NEURAL NETWORK TECHNIQUE

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ABSTRACT

This paper deals with the effect of fiber aspect ratio of steel fibers on shear strength of steel fiber reinforced concrete deep beams loaded with shear span to depth ratio less than two using the artificial neural network technique. The network model predicts reasonably good results when compared with the equation proposed by previous researchers. The parametric study involves deep beams of M55 grade concrete with fiber volume fraction 0.5% to 2% of fiber aspect ratio ranging from 50 to 100 and longitudinal steel percentage varying from 0% to 2.5%. The analysis reveals that the fiber aspect ratio also affects the shear strength and needs to be combined with fiber volume fraction.

Keywords: fiber aspect ratio; steel fibre reinforced concrete; volume fraction; deep beam; shear span; neural network.

1. INTRODUCTION

The beams are considered to be deep beams when the span to overall depth ratio (L/D) is relatively small. The Indian code of practice, IS456-2000 [1] assumes the beams as deep if L/D ratio is less than 2, while American code, ACI-318 [2] considers L/D < 4 with shear span to depth ratio (a/d) less than 2.5. The geometrical proportioning of deep beams develops different load carrying mechanism than shallow beams due to which the strength is governed by shear rather than the flexure.

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The inclusion of steel fibers in the concrete improves its post cracking strength [3] which adds to shear strength of steel fiber reinforced concrete (SFRC) beams. Somehow lack of complete understanding of shear failure modes and various parameters affecting shear strength make the shear behaviour of SFRC deep beams very complex. It is therefore, required to study the shear strength of deep beams for suitable combinations of parameters of the ingredients. The artificial neural network technique is found to be most versatile and powerful technique to analyse such intricate problems [4-8].

Number of experimental investigations are being carried out by researchers to explore the usefulness of steel fibers by studying its parameters such as fiber volume fraction (V_f %) [9-12], fiber aspect ratio (l_f/d_f) [13], fiber orientation [14, 15] and shape [16], etc. The literature review show that most of the studies are carried out using fiber volume fraction as a key parameter [17-26] and very few researchers have studied the effect of fiber aspect ratio which helps enhancement of pull out resistance of fibers[27]. Hence, it needs to understand effect of fiber aspect ratio on shear strength of SFRC deep beams.

2. METHODS

2.1 Artificial neural network

A large number of highly interconnected elements, called 'neurons', form the artificial neural network (ANN).Artificial neural network (ANN) has been successfully applied in various disciplines including the field of civil engineering in recent past. The results of ANN developed, for deep beams are more accurate results than by ACI code and strut and tie method. The ANN model has higher potential in predicting the ultimate shear strength of both normal and high strength normal concrete deep beams when compared with calculated values using ACI code [2].Each neuron has an activation value that is a function of the sum of inputs received from other nodes through the weighted connections. The processing units of ANN are grouped into layers of Input, Hidden and Output processing units. The development of neural network requires reliable data which include input parameters affecting the system and corresponding output. These data can be experimental test results, reliable empirical data or theoretical results. The experimental test results obtained by previous researchers have been used as input data in this study.

2.2 Experimental data

The experimental data of total 373 tests, carried on steel fiber reinforced concrete deep beams to predict the ultimate shear strength, are collected from various literature published. The data is thoroughly sorted and only those beams having failed in shear and shear span to depth ratio less than 2.5, have been considered for the training. It is found that a number of 193 test data out of 373 resembles to criteria of deep beam as shear span to depth ratio less than 2.5.

Out of 193 tests, 160 tests were carried on normal stress concrete with f_c<55MPa and 33 tests on high strength concrete with f_c > 55 (as per IS 456 2000) SFRC deep beams. These

experimental results were obtained from tests carried by Anant P et al [3], Ashour SA et al [11], Gustavo Parra M[19], Kwak YK et al [20] , Mansur et al [21], Narayan R and Darwish IYS [24,25] , Madan SK et al [23], Apparao G et al [10], Remigijus S and Gediminas M [26], Minelli F et al [22].

The database selected consists of the SFRC deep beams are rectangular cross section with compressive strength ranging from 19MPa to 99MPa, Width:50mm to 305mm, Overall depth: 100mm to 1000mm, Longitudinal steel: 0 % to 4.58 %, Shear span to depth ratio: 0.4 to 2.5, Steel Fiber volume fraction: 0% to 2%, Fiber aspect ratio : 0 to 133.

The collected laboratory data were grouped randomly into three subsets: a training set, validation set, and the testing set. The literature does not define any criteria for division of the data base into subsets. Taking into consideration the number of parameters and heterogeneous behaviour of SFRC, large portion on the data base is required for training the ANN.

The randomly distribution of data into subsets is; training set: 90%, validation set: 05% and testing set: 05%. The statistics of the database are as given in Table 1.

Table 1: Statistics of tests carried on Normal and High strength SFRC deep beams

Parameter	b (mm)	D (mm)	d (mm)	A_{st} (%)	a/d	L* (mm)	fc (MPa)	V_f (%)	l_f/d_f	V_u (MPa)
Total Tests	193	193	193	193	193	91	193	193	193	193
Average	117.64	314.69	282.83	1.8	1.55	934.35	45.33	1.17	59.8	4.456
Max.	305	1000	910	4.58	2.5	4550	99	0	0	0.96
Min.	50	100	80	0	0.4	400	19	2	133	13.95
SD	53.43	155.67	144.72	1.02	0.693	24.03	15.28	5.93	31.87	2.83

* Data of length is available for 91 tests only.

2.3 Development of ANN model

The ANN model is built by using the toolbox available in MATLAB Version 7.8.0 R 2009a. Using the total data base collected of 193 tests, the problem is defined for this toolbox by arranging the set of input vectors as column matrix, say [p]. The output or target vectors are arranged in second matrix say [t]. The input matrix [p] has eight parameters width (b)mm, overall depth(D) mm, effective depth (d) mm, shear span –depth ratio (a/d), compressive strength of concrete (f_c) MPa, volume fraction (v_f) % and fiber aspect ratio (l_f/d_f)arranged in column and total 193 columns. The size of [p] is 8 X 193. The target matrix contains the results of each experimental test arranged in matrix [t] of size 1 x 193.

The total database is divided conveniently in percentage into training; 90%, validation: 5% and testing: 5%. The Neural Network Toolbox automatically divides the data randomly in the prescribed percentages. The number of neurons in input layer is equal to number of parameters which is eight (08) for this study. The number of neurons are arbitrarily assumed to start the training and gradually adjusted till satisfactory training is achieved. The results of output matrix [a] are verified with actual targets and the results showing diversity are

removed from database. The revised database is again trained for better satisfactory performance. The final size of the network for this study has been finalized as 8 X 26 X 1. where,

  8= number of neurons in Input Layer
  26= number of neurons in Hidden Layer
  1= number of neurons in Output Layer

The comparison of ANN results with targeted results is shown in Fig. 1. The goodness of fit and 'R' square values shows its reliability.
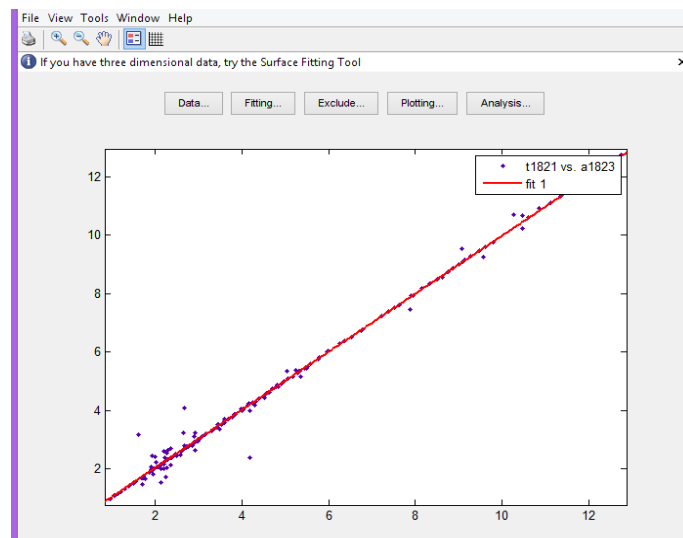

Figure 1. Comparison between ANN result and targeted strength

Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 =   0.9961 (0.9828, 1.009)
p2 =   0.02918 (-0.03865, 0.09701)
Goodness of fit:
SSE: 11.18
R-square: 0.9919
Adjusted R-square: 0.9918
RMSE: 0.2492

3. RESULTS AND DISCUSSIONS

This effect of inclusion of steel fibers is studied for deep beams of grade M55 for fiber volume fraction 0.5%, 1%, 1.5% and 2% of fiber aspect ratio ranging from 50 to 100. The cross sectional dimensions are 100mm width and depth 500mm with longitudinal steel percentage

0%, 1.5% and 2.5%. The shear span to depth ratio (a/d) considered is 0.5, 1 and 2.

The parametric study is carried out with the developed artificial neural network to evaluate the influence of parameter like fiber aspect ratio (l_f/d_f). The effect was studied by varying one of the input parameters with respect to varying fiber aspect ratio and all other parameter are set to constant values. The values of a/d ratio are assumed less than 2.5 to fit the beam in deep beam category.

3.1 Effect of fiber aspect ratio

The fiber aspect ratio is related with the geometry of the fibers. The influence of fiber aspect ratio on shear strength for different volume fraction and *a/d* ratio (less than two) and longitudinal steel ratio (A_{st} %) is represented in Fig. 2 to Fig. 5. The cross sectional dimensions are width = 100mmand 500mm overall depth. Many researchers like Narayanan and Darwish [24,25], Remigijus S [26] have combined the effect of fiber aspect ratio and volume fraction in their formulations.
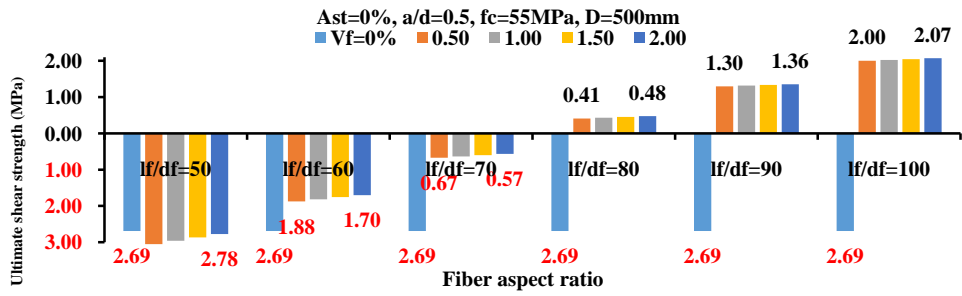
3.1.1Effect of fiber aspect ratio at a/d=0.5

Fig. 2 represents the variations of shear strength at a/d=0.5 for longitudinal steel ratio 0% to 2.5% for M55 grade SFRC deep beams.As seen from Fig. 2(a), the plain deep beam(without longitudinal steel and steel fibers) with a/d=0.5, will fail in shear for the assumed parameters. The inclusion of steel fibers with V_f = 0% to 2% having fiber aspect ratio ranging from 50 to 70, also predicts shear failure with building capacity to carry shear.Further increase in fiber aspect ratio ≥ 80, shows shear carrying capacity which enhances with increase in fiber aspect ratio along with increase in fiber volume fraction. Somehow, it almost remains constant at higher fiber aspect ratio even with increase in fiber volume fraction.

Fig. 2(b) shows the combined effect of steel fibers and longitudinal steel on shear capacity of SFRC deep beams with A_{st}= 1.5% and *a/d*=0.5. It predicts that provision of longitudinal steel does not suffice the shear strength of deep beam with assumed parameters. However, the inclusion of fibers built up the shear strength. The shear strength is seen increasing as an effect of increase in fiber aspect ratio. It is to be noted that the shear strength decreases with increase in fiber volume and almost remains constant at l_f/d_f≥ 80 for such combination of main steel and steel fibers.

Fig. 2(c) describes the variation of shear strength for combination A_{st}=2.5%, *a/d*=0.5 with different fiber volume fraction and aspect ratios. This permutation gives increase in shear strength without steel fibers. The inclusion of steel fibers further increases the shear capacity which increases with raise in shear capacity as the fiber ratio increases.
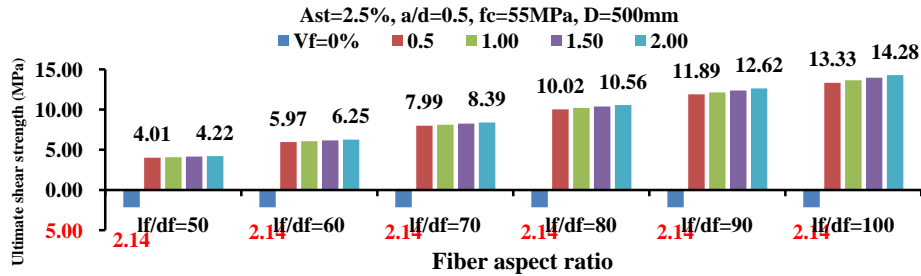It indicates that for small values of a/d = 0.5, increase in fiber volume of steel fibers needs to be combined with fiber aspect ratio to achieve the required shear strength. It is also noted that the increase in main steel increases the shear strength.

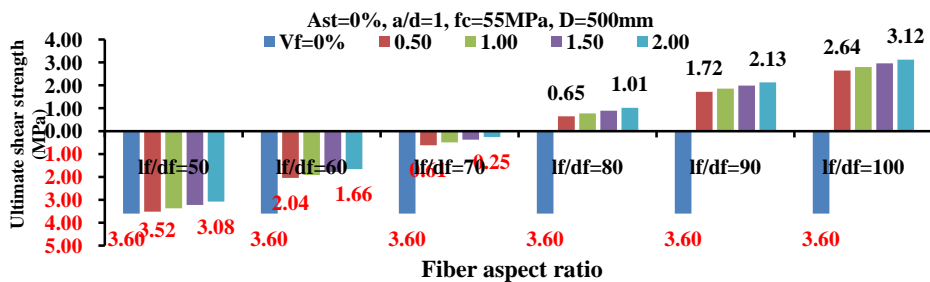(a): Variation of shear strength for Ast=0%
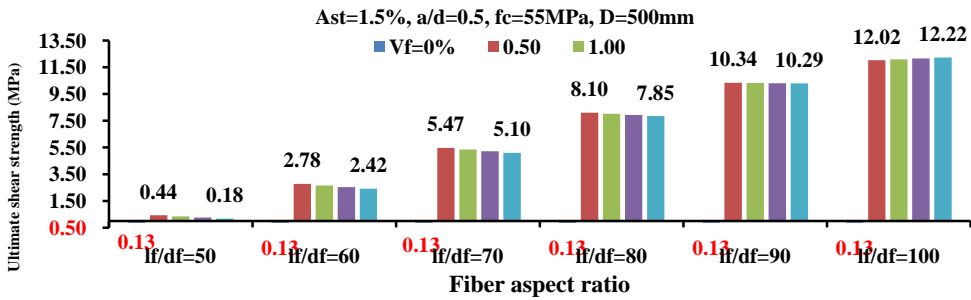
(b): Variation of shear strength for Ast=1.5%

(c): Variation of shear strength for Ast=2.5%

Figure 2. Effect of fiber aspect ratio on ultimate shear strength at a/d =0.5

3.1.2 Effect of fiber aspect ratio at a/d=1

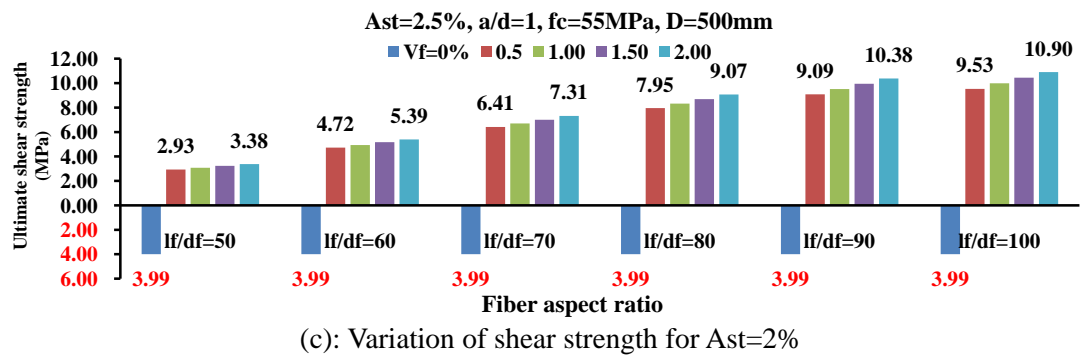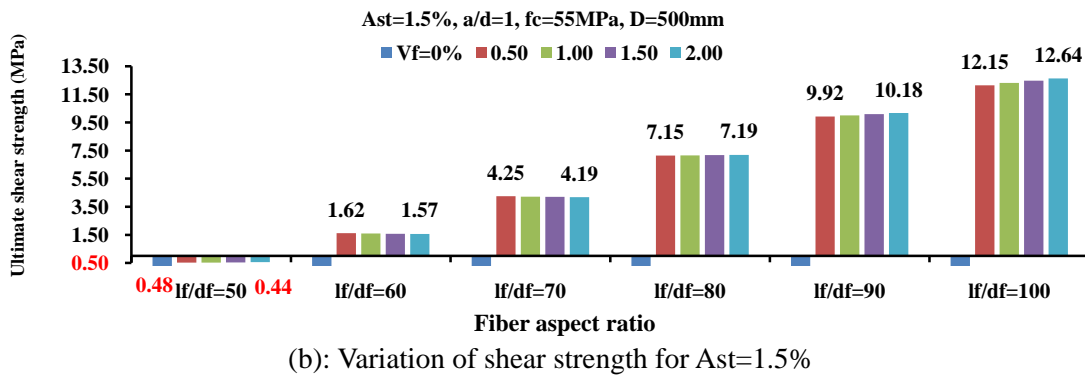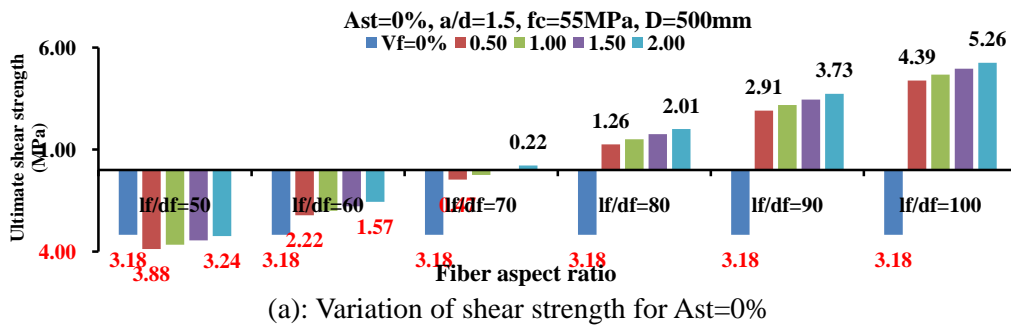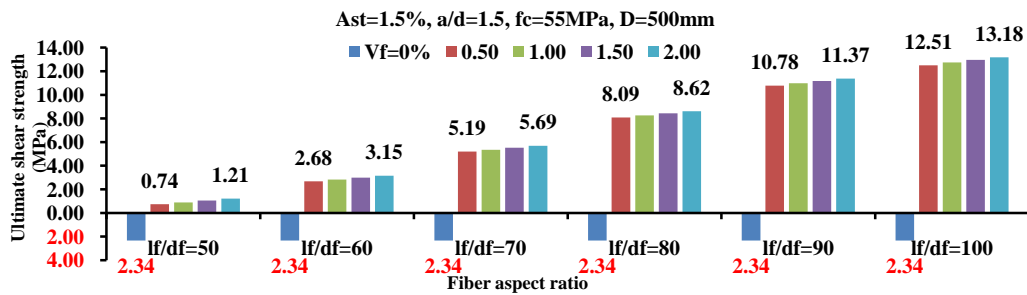(a): Variation of shear strength for Ast=0%

(b): Variation of shear strength for Ast=1.5%

(c): Variation of shear strength for Ast=2%

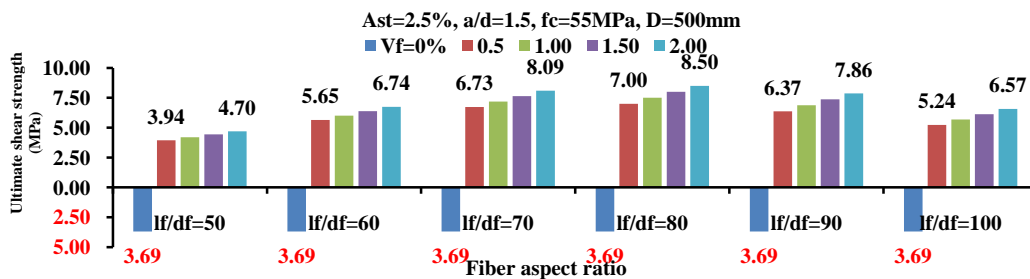Figure 3. Effect of fiber aspect ratio on ultimate shear strength at a/d=1

Fig. 3 represents the variation of shear strength at *a/d*=1 for A_{st} =0%, 1.5%, 2.5% for assumed parametric values. The trend of variation in Fig. 3(a) is observed similar to Fig. 2 (a) for *a/d*=0.5. The strength is seen increased at *a/d*=1 than at *a/d*=0.5. The fiber aspect ratio greater than 80 needs to be assumed for achieving the shear strength without the longitudinal steel at *a/d*=1. The provision of steel of 1.5% boosts the shear strength at l_f/d_f= 60 as seen from Fig. 3(b). Further increase in longitudinal steel to 2.5%, increases the shear strength at smaller fiber aspect ratio of 50 as observed in Fig. 3(c).

3.1.3 Effect of fiber aspect ratio at a/d=1.5

(a): Variation of shear strength for Ast=0%

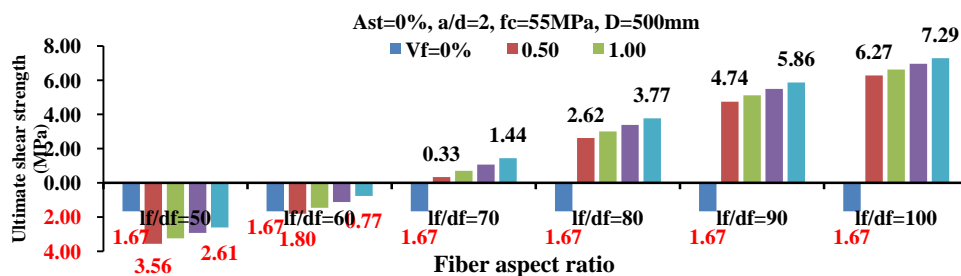(b): Variation of shear strength for Ast= 1.5%

(c): Variation of shear strength for Ast=2 %

Figure 4. Effect of fiber aspect ratio on ultimate shear strength at a/d=1.5

The shear strength of SFRC deep beams at a/d=1.5 without longitudinal steel has similar trend as the variation at a/d=0.5 and 1. It also suggests minimum fiber aspect ratio needs to be 80 for enhancement of shear strength with assumed parametric values as shown in Fig. 4(a).

The addition of longitudinal steel of 1.5% gives rise to shear strength of SFRC deep beams at all fiber volume fractions and increases with increase in fiber aspect ratio (Fig. 4(b)). It is also to be noted that the shear strength marginally increases at a/d=1.5 and Ast=1.5% with increase in fiber aspect ratio. Fig. 4(c) reveals that further increase in longitudinal steel to 2.5% enhances the shear strength up to fiber aspect ratio of 70. The shear strength is found decreasing with increase in fiber aspect ratio even though the fiber volume increases. It shows that the fiber aspect ratio also affects the shear strength of SFRC deep beams.
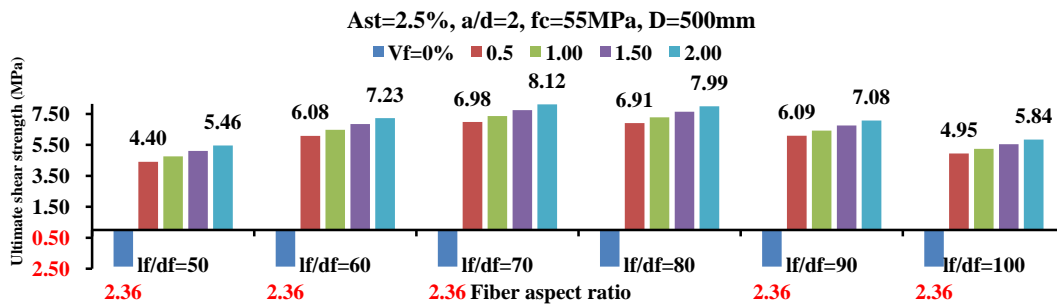
3.1.4 Effect of fiber aspect ratio at a/d=2

(a): Variation of shear strength for Ast=0%
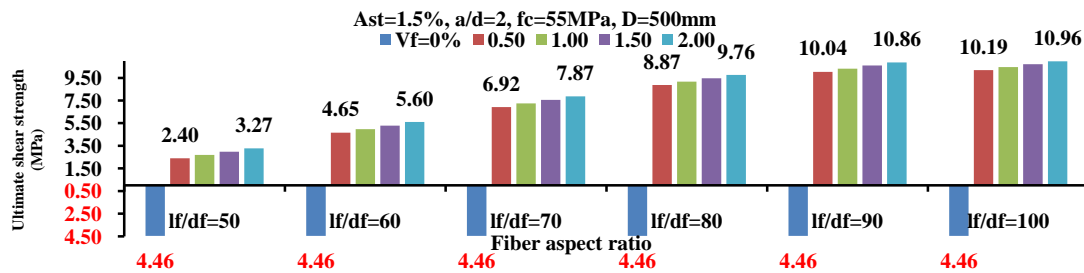
(b): Variation of shear strength for Ast=1.5%

(c): Variation of shear strength for Ast=2%

Figure 5. Effect of fiber aspect ratio on ultimate shear strength at a/d=2

The deep beam without longitudinal steel and loaded at *a/d*=2 behaves in similar way as at other shear span to depth ratios considered in this study with change in fiber volume and aspect ratio as shown in Fig. 5(a). It also shows that the shear strength is greater than at *a/d*=1.5. The addition of longitudinal steel of 1.5% increases the shear strength at all volumes and fiber aspect ratios considered in this study as seen from Fig. 5(b). The comparison between Fig. 4(b) and Fig. 5(b) indicates that the shear strength increases with increase in shear span to depth ratio as fiber volume and fiber aspect ratio up to 80 after which it is decreased at $l_f/d_f> 80$.However, the increase in longitudinal steel to 2.5% shows notable decrement in shear strength as observed in Fig. 5(c).

4. CONCLUSIONS

The ultimate shear capacity of steel fiber reinforced concrete deep beams is influenced by various factors related with its ingredients making the behaviour complex. The developed neural network with eight neurons, single hidden layer with twenty six neurons and output layer with single neuron proves to be successful in predicting the ultimate shear strength of SFRC deep beam in shear.

The comparison between the variation of ultimate shear strength at different *a/d* and A_{st} ratios with considered parameters reveals that the fiber aspect ratio also staples along with the fiber volume fraction as considered as fiber factor by Narayanan and Darwish [25]. For

the assumed parametric values (fc=55MPa, D=500mm, b=100mm) the analysis shows that-

I. At lower % of longitudinal steel (Ast <1%), the fiber aspect ratio must be greater than 80 at a/d ratios up to 2.

II. The combination of main steel and steel fibers increases the shear strength of SFRC deep beams marginally at longitudinal steel = 1.5% with increase in fiber volume and fiber aspect ratio.

III. The shear strength of deep beams without longitudinal steel increases with increase in a/d ratio while decreases for fiber aspect ratios greater than 70for beams with longitudinal steel 2.5%. It suggests shorter fibers for effective use of steel fibers with increase in longitudinal steel.

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