



Effect of Twisted Steel Fibers on Tensile Strength of Cement Concrete-A Finite Element Approach.

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ABSTRACT

As on date the most widely used construction material is still reinforced cement concrete as known very well. Concrete is strong in compression and weak in tension. Steel is placed in concrete wherever tension is anticipated. The process becomes cumbersome and expensive tool. Fiber reinforced concrete has emerged as a consequence which offers partial tensile strength in addition to the compressive resistance. Twisted Steel Fibers is the latest form of fiber reinforcement concrete where the Twisted Steel Fibers steel positions in different orientations in the concrete matrix offer tensile resistance in different directions, however a rational assessment of tensile strength in a said direction is still in doubt. Experiments were conducted in large scale to estimate the tensile strength in different directions. In this paper, a finite element based approach to assess the tensile strength contribution from Twisted Steel Fibers reinforcement in concrete is presented. The dosage, the shape, length and grade of concrete are varied while developing the FE model. The influence of different parameters on the tensile strength contribution from Twisted Steel Fibers reinforcement is presented.

Key words: Twisted Steel Fibers Fiber, Fiber Reinforced Cement Concrete, Tensile Strength.

Introduction

The most widely used construction material all over the world even as on date is still reinforced cement concrete only. It is a well known fact that concrete is strong in compression and weak in tension. As a reason steel is placed at appropriate locations in all concrete structural elements to resist the tensile stresses wherever they occur due to structural action. However, a construction material which can resist both compression and tension, if at all available and can be produced is most desirable on any day. Such a material shall also be economically viable, easily producible, comfortable for handling and placement, and yet durable like RCC. Twisted Steel Fibers concrete is the material matrix that exactly fits the above requirements.

Twisted Steel Fibers Concrete

Twisted Steel Fibers is another form of Ferro cement concrete with unique characteristics. It consists of twisted steel wires of approximately 1mm thick and 25mm long added to cement concrete during mixing, replacing the rebar to some extent or in full to achieve higher crack resistance and structural strength throughout the concrete mass in all directions. The shape and number of twists of steel wires vary and influences the bond between the steel and cement based concrete matrix. Twisted Steel Fibers steel wire, with its twisted profile is a more superior reinforcement and is a substantial improvement over fibers of any time. When concrete is stressed or bent, the conventional fibers which are flat will slide out smoothly with minimal possible friction, so the force required to pullout is not much. Adding deformation like a hooked end or corrugations to fibers add frictional resistance and increases pullout force substantially.

Twisted Steel Fibers's polygonal cross sectional shape and twists increases the frictional resistance in a form similar to removing a corkscrew from a cork without twisting it. Even at low dosages, usage of Twisted Steel Fibers results in dramatic performance improvements for all types of concrete. By virtue of its size, Twisted Steel Fibers steel reinforcement can be mixed more homogeneously in a concrete mass than the conventional fiber reinforcement which tends to cause segregation. Presently, Twisted Steel Fibers concrete is very widely used in varieties of structural applications and is used in different countries.

Un-reinforced concrete is very brittle. Twisted Steel Fibers fibers are added to wet concrete mix in certain dosage and the composite mass is mixed thoroughly to obtain a homogenous concrete mix. Addition of Twisted Steel Fibers allows either the elimination or minimizes the use of rebar. The reduced mesh/rebar usage saves time, manpower and money, making it a smart and economical way to replace the conventional reinforced cement concrete.

The additional flexural strength gained by concrete due to the presence of Twisted Steel Fibers is large enough to change the failure mechanism of the concrete mass. Twisted Steel Fibers must actually get untwisted, snapped or sheared of concrete before it fails. This requires considerably large force than mere frictional pullout and results in a fundamental increase in performance to levels, never realized before. With Twisted Steel Fibers, the more the number of twists, the stronger it gets since the required energy to untwist becomes even greater.

ADVANTAGES OF TWISTED STEEL FIBERS CONCRETE

Reinforced cement concrete structures need careful supervision during its construction process. It requires professional bar benders. Fabrication of bars according to the drawings is also a time consuming job and need skilled manpower. The strength contribution of concrete in tension zones is ignored. Using Twisted Steel Fibers concrete these problems can be reduced because the Twisted Steel Fibers concrete either needs no rebars or need very less reinforcement. Using Twisted Steel Fibers concrete construction time can be reduced considerably in comparison with RCC. Twisted Steel Fibers concrete is economical since full concrete is effective in taking applied force. In the present day scenario of infrastructural advancements and the need for urbanization, Twisted Steel Fibers concrete can prove to be a very economical replacement for RCC.

COMPARISON WITH OTHER FIBER REINFORCEMENTS.

The Ferro cement is a composite material consisting of steel wool and cement mortar. The width of steel wool varies between 0.5mm to 1mm with different lengths. The structural orientation of a steel wool fiber can be arbitrary. In the event of fiber reinforced concrete, again composite material steel, fibers of different lengths and sized are placed, arbitrarily in the concrete mass. In the both situations since the fibers have no definite shape or length, analytical modeling of fibers is not possible. All assessments regarding the strength of either Ferro cement or fiber reinforced concrete is based on experimental investigations only.

This apart, the contribution of the steel fibers to tensile strength, the shear strength and torsional strength cannot be worked out separately in conventional fiber reinforced elements but with Twisted Steel Fibers reinforcement, its shape and geometry and dosage being well defined, the analytical modeling using advanced computational tools like Finite Element Method is quite possible.

BRIEF METHODOLOGY

By now, the process of making Twisted Steel Fibers concrete is established, the normal sizes and shapes of Twisted Steel Fibers reinforcement and their dosages in Twisted Steel Fibers concrete are also furnished from the manufacturer. The debatable aspect is the assured tensile strength offered by Twisted Steel Fibers concrete in any chosen direction, it is accepted that, on mixing the Twisted Steel Fibers fibers are spread uniformly in the concrete mass, oriented in an arbitrary direction.

With this hypothesis, a composite FEA model with Twisted Steel Fibers steel inserted in concrete mass as illustrated.

Finite element modeling is carried-out using MSC NASTRAN software. A steel fiber with a cross-sectional shape of 1 mm square, 25mm long is placed in the middle of a cement concrete cylinder of 50 mm diameter. The steel fiber and concrete cylinder are meshed into a large number of 4-noded tetrahedron elements. The meshing is done such that node compatibility exists between the steel and concrete elements. The stress transfer between steel and concrete is achieved along the interface between the two materials. An axial force is applied on the steel fiber and the stress transferred to the concrete is determined with the help of MSC NASTRAN. The ultimate capacity of the section is determined corresponding to the failure of both steel and concrete.

Once the failure load corresponding to the steel and concrete is obtained as described above, the tensile stress carrying capacity of the section is obtained by dividing the failure load with the cross-sectional area of the cylinder. Similar studies are carried out changing number of twists, the cross-sectional shape of the fiber and the diameter of the cylinder to determine the capacity of the section. From this data the maximum permissible tensile stress carried by cylinder is calculated. The same process is repeated for different lengths of Twisted Steel Fibers and grades of concrete.

Based on the results obtained, the optimum dosage of Twisted Steel Fibers fibers with its parameters defined required in a cubic meter of concrete is calculated. The method does not need the preparation of any prototype models and soft computing techniques alone yield the desired results. The study is feasible and economical.

At present only limited set of analytical data based on Finite Element Analysis is available. Based on this data, general conclusions cannot be drawn. It is proposed to conduct some experimental investigations to validate the results obtained from FE Analysis.

FUNCTIONAL MECHANISM OF TWISTED STEEL FIBERS

Twisted Steel Fibers, with its unique twist, is unlike any other reinforcement known earlier and is a substantial improvement over the fibers of any type. When concrete is stressed or bent, a flat fiber will slide out with minimal friction - so the force required for it to pullout is generally small. Adding deformation, like a hooked end or corrugation, adds friction and increases force required to pull it out, but only marginally. Twisted Steel Fibers's polygonal cross sectional shape and twist increases the frictional resistance just like removing a corkscrew from a cork without twisting it. Each Twisted Steel Fibers locks like a tiny screw, instead of slipping like a nail. But the additional force required is so large that it changes the failure mechanism from simply pulling out to a torsional or untwisting mode. Twisted Steel Fibers must actually untwist or snap before it fails. This requires considerably large energy than mere frictional pullout and results in a fundamental increase in performance to levels realized never before. Also with Twisted Steel Fibers, the farther you twist the stronger it gets since the required energy to untwist becomes even greater.

PERFORMANCE OF TWISTED STEEL FIBERS VS REBAR

Like rebar, Twisted Steel Fibers too is made from steel. And just as increasing rebar size increases strength, so does adding more Twisted Steel Fibers. Unlike rebar, which only adds strength after the concrete has cracked; Twisted Steel Fibers works together with the concrete to provide both higher first crack strength and structural strength throughout the concrete and in all directions.

Always spread out multiple pieces of rebar rather than just use one thick piece; Twisted Steel Fibers carry that one step further and distributes tensile resistance across the entire section in all directions, making it even more efficient.

PRESENT WORK

In the present paper the analytical studies have been carried-out using **MSC Nastran**. The analytical studies have been carried-out on star cross sections of Twisted Steel Fibers as shown in figure 1 with star shape cross sectional area of one sq.mm., with one and two twists., five different lengths of Twisted Steel Fibers steel 25mm, 35mm, 50mm, 65mm and 80mm and three different diameters of concrete cylinder 50mm, 25mm and 10mm. Therefore, the work is carried-out on fifteen different models as listed in Table 1 for M25 grade of concrete.

MATERIAL PROPERTIES

Materials used in the present work are concrete and steel. Properties of steel and concrete are given below

Material	Young's Modulus in N/mm ²	Poisson's ratio	Density in N/mm ³
M25 Grade Concrete	25000	0.15	25E-6
Steel	200000	0.3	78.5E-6

GEOMETRIC MODELING

The Twisted Steel Fibers steel fiber embedded into cement concrete forms basis for generation of its finite element model. The present work methodology is completely demonstrated with the help of one model. In this, the Twisted Steel Fibers fiber one mm square, 25mm long with one twist is inserted into the middle of cement concrete cylinder of 50 mm diameter. The procedure is repeated by changing the length, twist of the fiber with different diameters of cylinder.

FINITE ELEMENT MODELING

Using the preprocessor module called PATRAN, the geometric model of Twisted Steel Fibers concrete is developed. The composite model has been meshed to form the discrete elements, separately for steel and concrete. The concrete and steel elements are modeled as 4-noded tetrahedron elements using mesh paver and test mesh options in MSC Nastran. The tetrahedron elements so formed are 3D elements with 4 numbers of nodes each. Each node possess three degree of freedom (3 translations), thereby amounting to 12 degrees of freedom for the element. The total numbers of elements are differing for different models. In the present example the total numbers of tetrahedron elements are 20598 with 4678 nodes. The elements are generated such that all the nodes along the interface between steel and concrete are common to both the materials. Care has been taken to ensure that the duplicate nodes and elements are eliminated and the aspect ratio of the elements is as admissible to the requirements of the package.

LOADS AND BOUNDARY CONDITIONS

Having generated the wire frame finite element model the boundary conditions for the elements are defined. The nodes corresponding to the bottom surface are restrained to move as shown in the Fig.4.5. The top surface is subjected to a vertical upward force of 1 Newton (causing tension in steel & concrete) is applied at each node on the Model.

ANALYSIS

After completion of all the above steps the analysis has been done using **MSC Nastran**. In the present project the analysis carried-out for all the models is **Linear Static Analysis**. The maximum principal stresses in all elements are worked out for unit loading. If the maximum principal stresses in the elements are less than the permissible limits, the loading needs to be scaled-up. The scaling factor should ensure that failure occurs in concrete also note down the corresponding stress taken by Twisted Steel Fibers. Now calculate the remaining stress to be taken by Twisted Steel Fibers only without concrete Model, and then calculate load carrying capacity of the composite section (load taken by concrete and Twisted Steel Fibers). The total load divided by the gross section of the composite element gives the tensile strength of cylinder. This loading is considered as the maximum load for that model. The procedure is repeated for all the models and found the maximum loading for each model and then concluded the optimum diameter of concrete, twist and length of Twisted Steel Fibers fiber for M25 grade concrete.

Sample Calculations for model 1

Model Properties:-

1. Twisted Steel Fibers fiber shape = Star
 2. Twisted Steel Fibers fiber length = 25mm
 3. Twisted Steel Fibers fiber twist = 1
 4. Concrete cylinder length = 25mm
 5. Concrete cylinder diameter (d) = 50mm
- ∴ Gross cross-sectional area of composite section = $\pi d^2/4$
 $= \pi (50)^2/4$
 (A) = 1963.495 mm²

Maximum Tensile force taken by the concrete elements when concrete stress is 3.5 Mpa (F_c) = 594 N.

Maximum Tensile force taken by the steel elements when concrete stress is 3.5 Mpa (F_s) = 23.5 N.

Maximum Tensile force taken by the Twisted Steel Fibers element without concrete (F_{rs}) = 233 Newton's

$$\begin{aligned} \text{Tensile strength of Gross section} &= \frac{\text{Maximum Tensile force taken by the composite section}}{\text{Gross cross-sectional area of composite section}} \\ &= \frac{F_c + F_s + F_{rs}}{A} \\ &= \frac{850.5}{1962.5} \\ &= 0.433 \text{ Mpa.} \end{aligned}$$

The Tensile strengths of remaining models are calculated similarly as explained above.

The Maximum principal stress for concrete elements is 5.089 Mpa. For model no.30 with 80mm length of Twisted Steel Fibers, two twist and 10mm diameter of cylinder.

COMPARISON OF MODELS USING GRAPHS

The results obtained in the Table 2 are shown in graphical representation. The results are discussed with five graphs.

DISCUSSIONS

The discussions presented here are based on the results shown in Table 2 and stress variation diagrams presented in Annexure-A.

- From the figures presented in the Annexure-A it is clear that for all the models the maximum principal stresses are occurring near the center of the model and along the interface of the steel and concrete elements.
- The objectives of the present study are to obtain maximum tensile strength of the Twisted Steel Fibers. All models shown in Table 1, pp 26 are used for this purpose.

- **Maximum tensile stress comparison:-**

Among all models with different length, Twist and diameter of concrete cylinder, Model-15 i.e. L=80mm, Twist=one with 10mm diameter of concrete giving maximum tensile stress among Model-1 to Model-15. In general Model-30 with same properties except two twist also giving high performance as compared from Model-16 to Model-30. From Fig 5.6, pp 42 it can be seen that for all models the star shaped fiber given better contribution towards the tensile strength to Twisted Steel Fibers.

- **Percentage of Twisted Steel Fibers dosage:-**

Among the three diameters of concrete i.e. 50mm, 25mm and 10mm from Table 5.2, pp 36 it is observed that the 10mm diameter cylinder is giving better contribution towards the tensile strength of Twisted Steel Fibers concrete with 1.274% of Twisted Steel Fibers.

• **Twisted Steel Fibers fiber Twist comparison:-**

Between the two twists of fibers that are one and two it is difficult to conclude the best twist of fiber because it is once again depends on the other combinations like length and concrete diameter. From Table 2, pp 33 and Fig 5.6, pp 42 it is observed that the tensile strength of Twisted Steel Fibers concrete with 2 twist fiber has been giving bit good results as compared to one twist.

CONCLUSIONS

Based on limited set of analytical studies carried out following are the list of concluded drawn.

1. 80mm long Twisted Steel Fibers gives better contribution to the tensile strength of concrete having star shape section with one twist.
2. The tensile strength contribution of Twisted Steel Fibers inserted in 10mm diameter cylinder gives better participation as compared to 25mm & 50mm diameter.
3. The tensile strength of Twisted Steel Fibers concrete with two twists is 65% more than that achieved using single twist.
4. The increased area of contact between the Twisted Steel Fibers fiber with concrete, the dosage of the Twisted Steel Fibers per unit volume of concrete and the thoroughness of mixing Twisted Steel Fibers in the concrete matrix would have a bearing on the tensile strength of Twisted Steel Fibers matrix.

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Model Number	Length of Twisted Steel Fibers (mm)	Number of Twists of Twisted Steel Fibers	Diameter of concrete cylinder (mm)	Total number of elements	Total Number of nodes
1	25	One	50	20598	4678
2	25	One	25	49846	9704
3	25	One	10	26343	5413

4	35	One	50	17261	3636
5	35	One	25	67316	12706
6	35	One	10	27621	5806
7	50	One	50	129462	23804
8	50	One	25	30403	5953
9	50	One	10	12519	2849
10	65	One	50	98268	18053
11	65	One	25	51402	9751
12	65	One	10	14861	3430
13	80	One	50	49003	9354
14	80	One	25	29539	5962
15	80	One	10	17232	3996
16	25	Two	50	44962	10263
17	25	Two	25	23272	4788
18	25	Two	10	12960	2828
19	35	Two	50	72065	14549
20	35	Two	25	12649	2823
21	35	Two	10	20764	4284
22	50	Two	50	55159	10694
23	50	Two	25	36646	7186
24	50	Two	10	17663	3830
25	65	Two	50	48058	9341
26	65	Two	25	36964	7202
27	65	Two	10	18799	4159
28	80	Two	50	81472	15526
29	80	Two	25	43224	8427
30	80	Two	10	20815	4652

Table 2: MAXIMUM PRINCIPAL STRESSES IN CYLINDER

Model Number	Area of Concrete (mm ²) (A ₁)	Load taken by concrete when(N) concrete stress is 3.5 Mpa (P ₁)	permissible stress in Concrete (Mpa)	Load(N) taken by Twisted Steel Fibers when concrete stress is 3.5 Mpa (P ₂)	Remaining Load(N) taken by Twisted Steel Fibers without concrete (P ₃)	Area of concrete (mm ²) (A ₁)	permissible stress in Twisted Steel Fibers (Mpa)	Total permissible stress in Cylinder (Mpa)
Model-1	1962.5	594	0.303	23.5	233	1962.5	0.131	0.433
Model-2	490.625	115	0.234	4	245	490.625	0.508	0.742
Model-3	78.5	38.375	0.489	2.7	245	78.5	3.155	3.644
Model-4	1962.5	444.18	0.226	26.92	204	1962.5	0.118	0.344
Model-5	490.625	178.4	0.364	7.84	223	490.625	0.471	0.834
Model-6	78.5	16.8	0.214	1.26	230	78.5	2.946	3.160
Model-7	1962.5	499.2	0.254	12.45	227	1962.5	0.122	0.376
Model-8	490.625	166.4	0.339	9.25	229	490.625	0.486	0.825
Model-9	78.5	46.83	0.597	8.92	230	78.5	3.044	3.640
Model-10	1962.5	434.6	0.221	18.3	234	1962.5	0.129	0.350
Model-11	490.625	142	0.289	12.62	235	490.625	0.505	0.794
Model-12	78.5	44.7	0.569	10.22	235	78.5	3.124	3.693
Model-13	1962.5	62.5	0.032	4.5	243	1962.5	0.126	0.158
Model-14	490.625	128.5	0.262	17.8	234	490.625	0.513	0.775
Model-15	78.5	54.6	0.696	10.6	239	78.5	3.180	3.875
Model-16	1962.5	440	0.224	11.81	199	1962.5	0.107	0.332
Model-17	490.625	178.9	0.365	12.34	198	490.625	0.429	0.793

Model-18	78.5	53.63	0.683	7.8	203	78.5	2.685	3.369
Model-19	1962.5	559.4	0.285	16.8	208	1962.5	0.115	0.400
Model-20	490.25	166	0.339	13.03	212	490.25	0.459	0.798
Model-21	78.5	65.2	0.831	9.7	215	78.5	2.862	3.693
Model-22	1962.5	644.8	0.329	32.25	202	1962.5	0.119	0.448
Model-23	490.25	187.7	0.383	15.65	218.5	490.25	0.478	0.860
Model-24	78.5	53.75	0.685	8.44	225.5	78.5	2.980	3.665
Model-25	1962.5	245.14	0.125	16.48	323	1962.5	0.173	0.298
Model-26	490.25	98.2	0.200	11.72	325	490.25	0.687	0.887
Model-27	78.5	59	0.752	10.05	327.5	78.5	4.300	5.052
Model-28	1962.5	284.1	0.145	12.85	325	1962.5	0.172	0.317
Model-29	490.25	144	0.294	17.72	317.5	490.25	0.684	0.978
Model-30	78.5	61.9	0.789	12.08	325.5	78.5	4.300	5.089

TABLE 3: PERCENTAGE OF TWISTED STEEL FIBERS DOSAGE / CUM

Model	Length of Twisted Steel Fibers	Twist of Twisted Steel Fibers	Diameter of cylinder	Max Permissible stress in cylinder (Mpa)	Percentage of Twisted Steel Fibers dosage/ Cum
Model-1	25	One	50	0.371	0.051
Model-2	25	One	25	0.515	0.204
Model-3	25	One	10	2.186	1.274
Model-4	35	One	50	0.292	0.051
Model-5	35	One	25	0.624	0.204
Model-6	35	One	10	2.061	1.274
Model-7	50	One	50	0.322	0.051
Model-8	50	One	25	0.607	0.204
Model-9	50	One	10	2.277	1.274
Model-10	65	One	50	0.293	0.051
Model-11	65	One	25	0.571	0.204
Model-12	65	One	10	3.470	1.274
Model-13	80	One	50	0.102	0.051
Model-14	80	One	25	0.551	0.204
Model-15	80	One	10	2.474	1.274
Model-16	25	Two	50	0.290	0.051
Model-17	25	Two	25	0.629	0.204
Model-18	25	Two	10	2.340	1.274
Model-19	35	Two	50	0.348	0.051
Model-20	35	Two	25	0.785	0.204
Model-21	35	Two	10	2.417	1.274
Model-22	50	Two	50	0.395	0.051
Model-23	50	Two	25	0.647	0.204
Model-24	50	Two	10	2.336	1.274

Model-25	65	Two	50	0.220	0.051
Model-26	65	Two	25	0.577	0.204
Model-27	65	Two	10	3.112	1.274
Model-28	80	Two	50	0.239	0.051
Model-29	80	Two	25	0.667	0.204
Model-30	80	Two	10	3.149	1.274

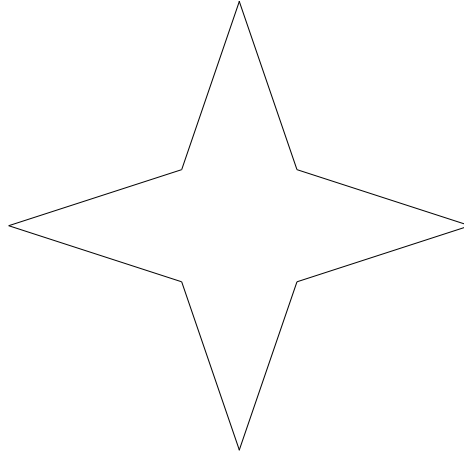


Figure 1Shape of Twisted Steel Fibers.

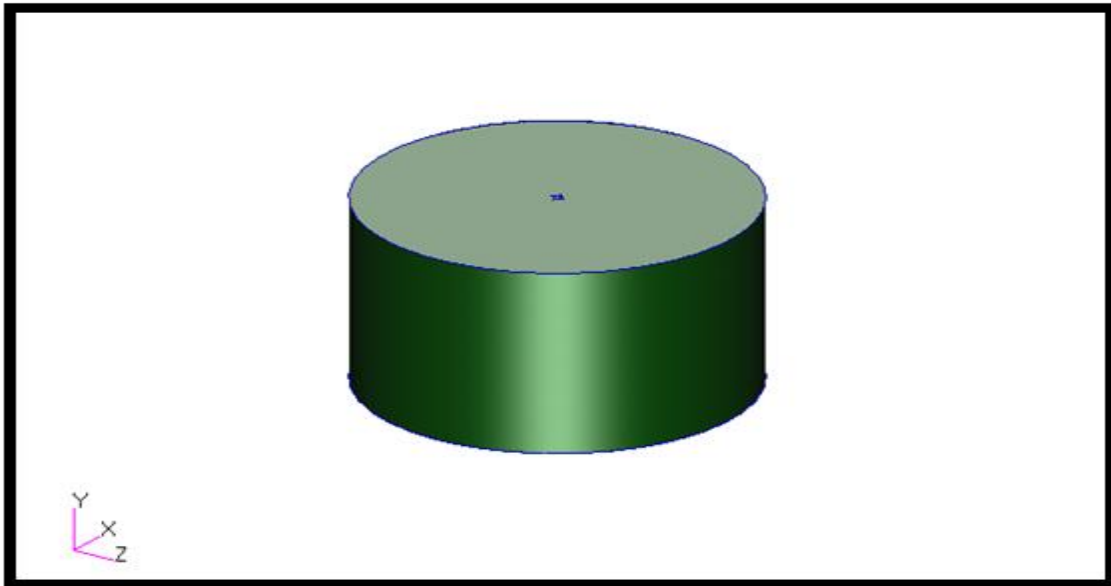


Figure 2 Composite model with Twisted Steel Fibers at center.

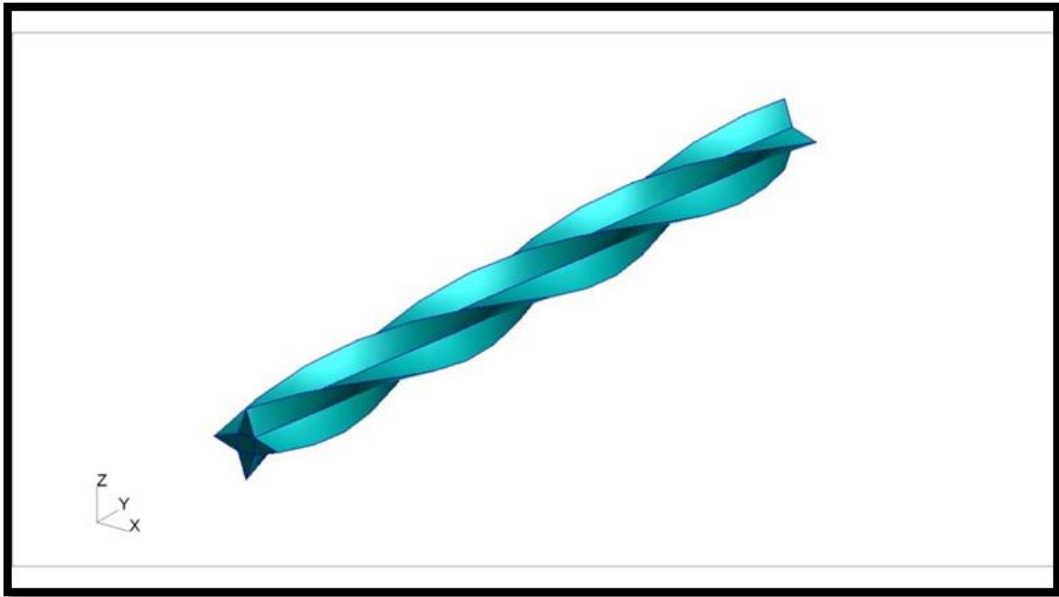


Figure 3 Star shaped 25mm long Twisted Steel Fibers fiber with one twist

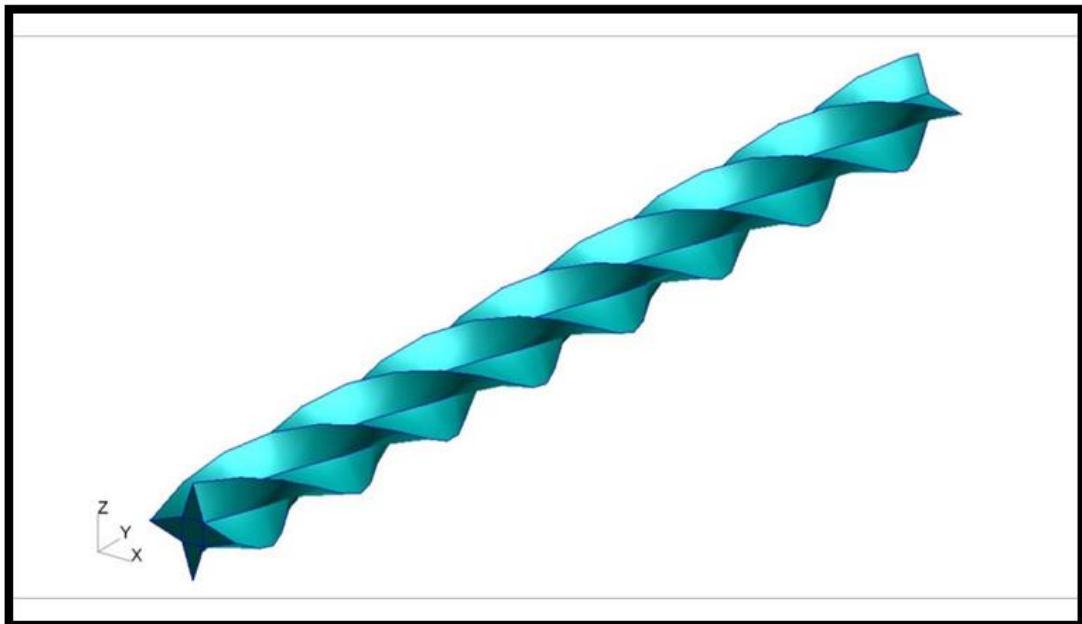
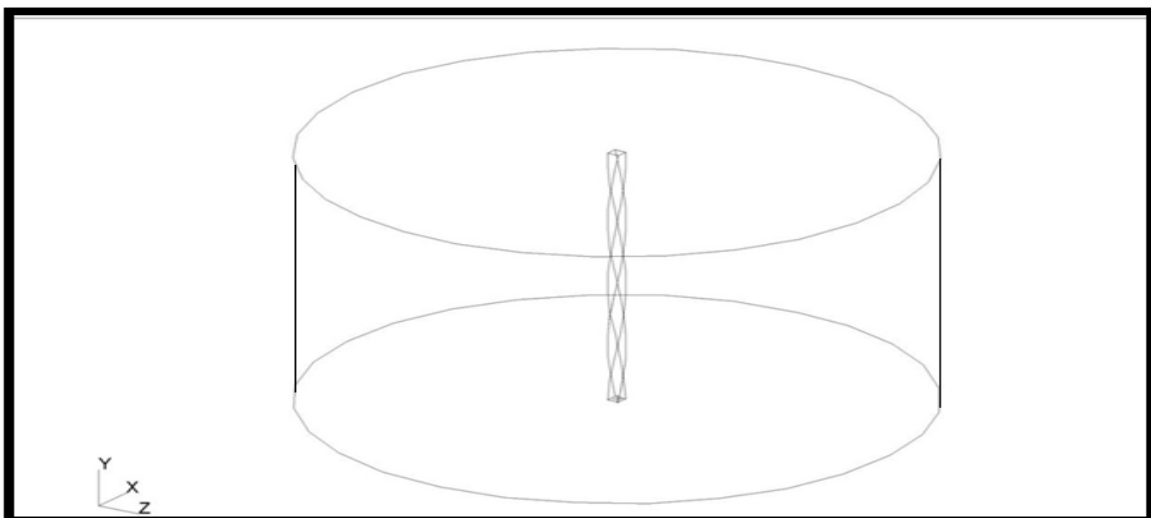


Figure 4 Star shaped 25mm long Twisted Steel Fibers fiber with two twists



5 Finite element model of the composite section

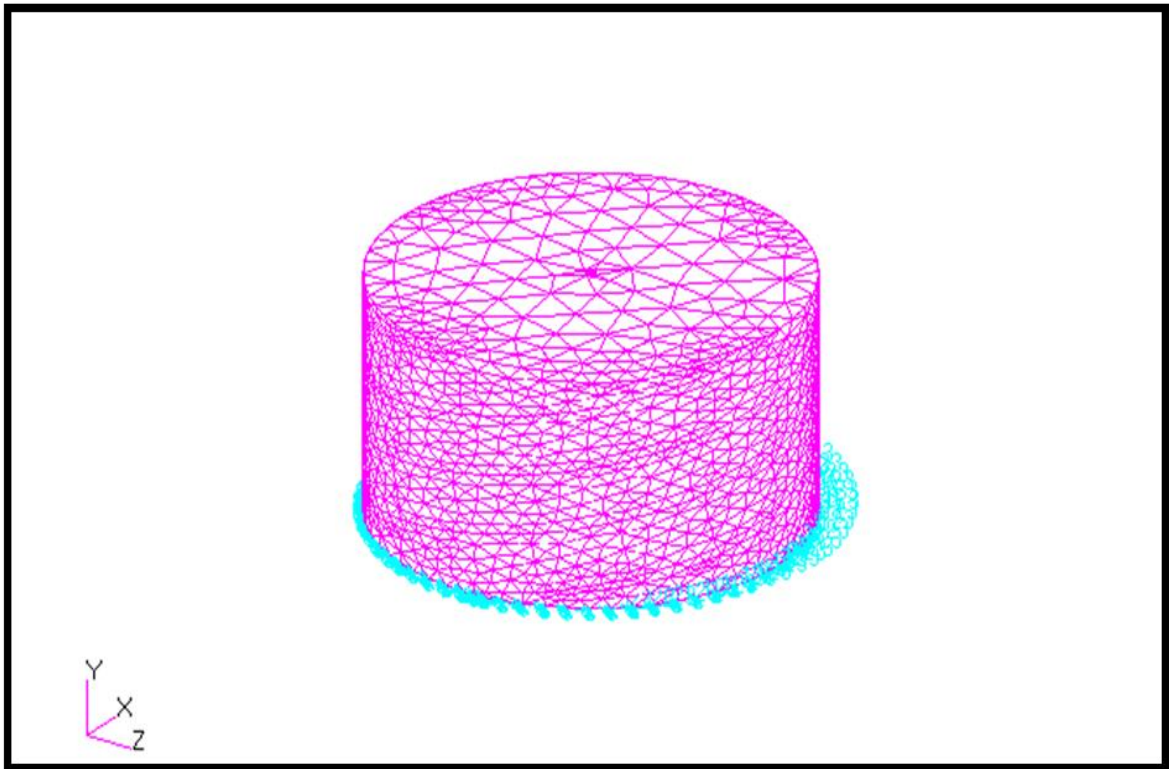


Fig. 6 Geometric model of the composite section

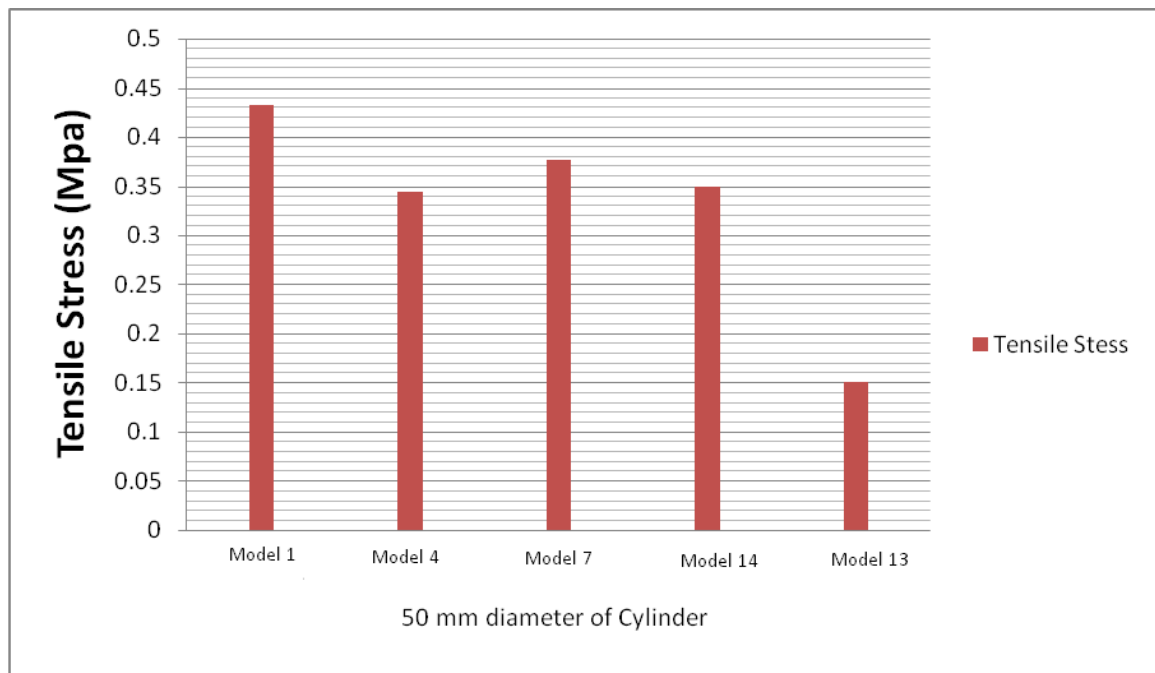


Figure 7 shows the comparison of tensile stress of concrete cylinder with diameter 50mm, length 25mm, 35mm, 50mm, 65mm & 80mm with one twist.

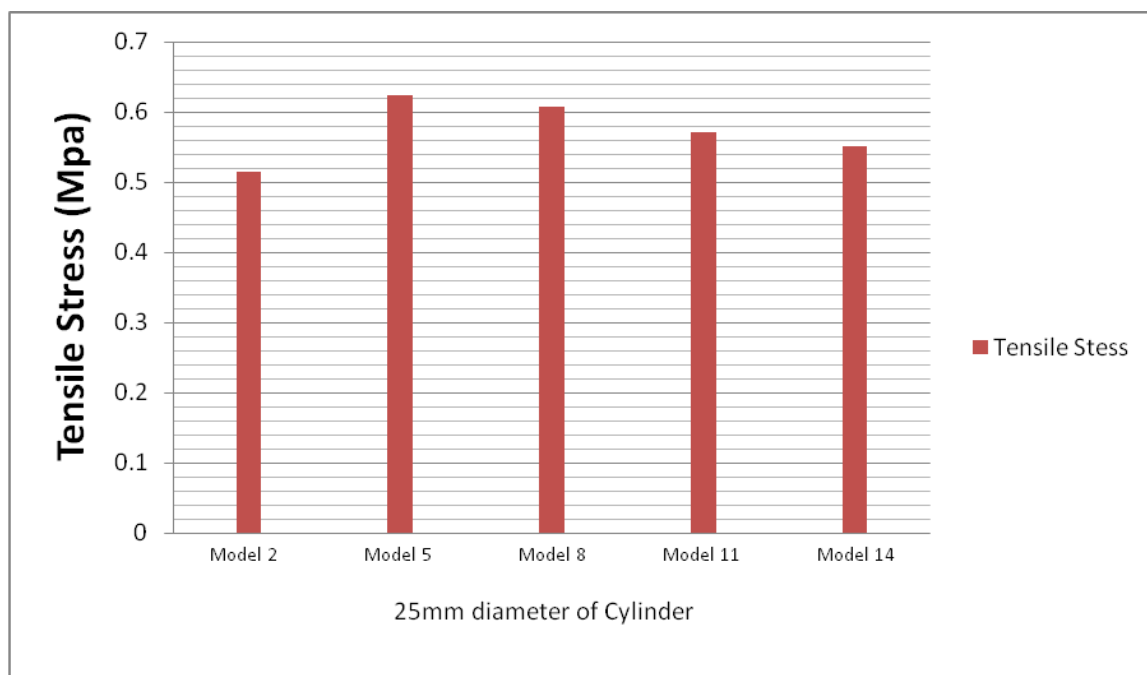


Figure 8 shows the comparison of tensile stress of concrete cylinder with diameter 25mm, length 25mm, 35mm, 50mm, 65mm & 80mm with one twist.

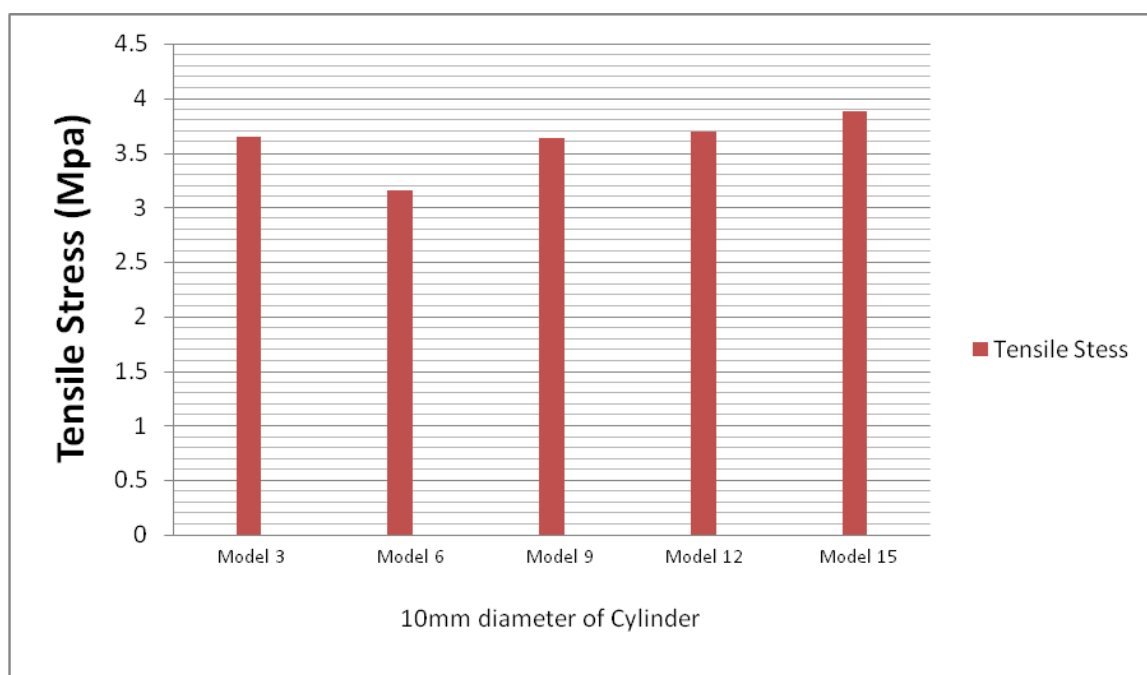


Figure 9 shows the comparison of tensile stress of concrete cylinder with diameter 10mm, length 25mm, 35mm, 50mm, 65mm & 80mm with one twist.

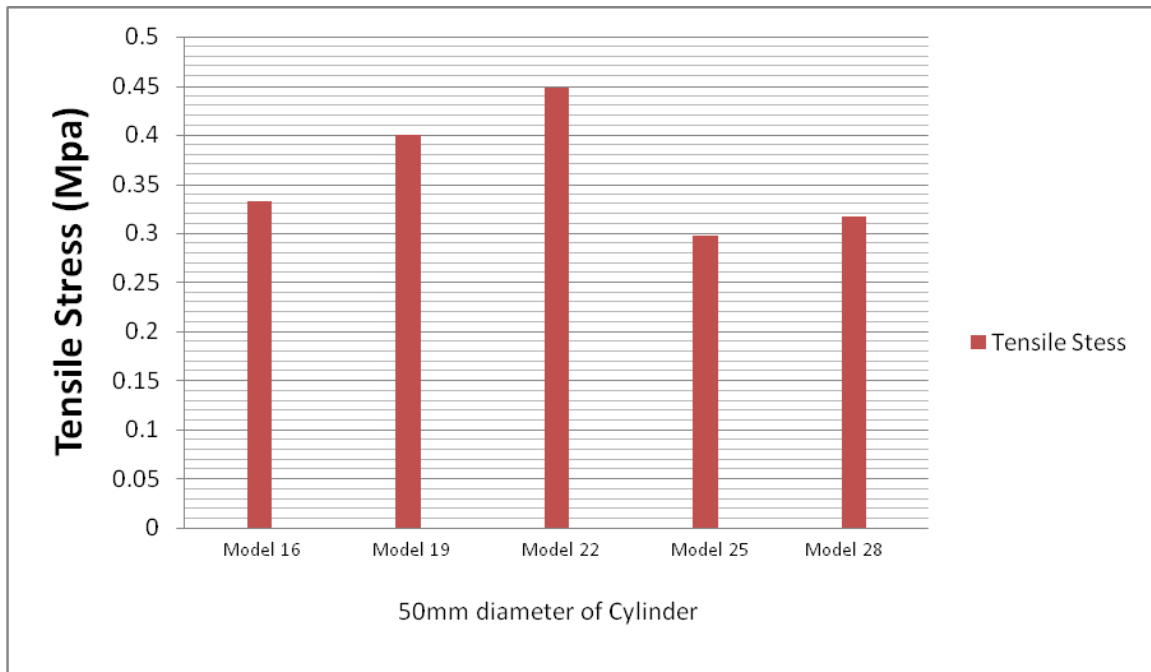


Figure 10 shows the comparison of tensile stress of concrete cylinder with diameter 50mm, length 25mm, 35mm, 50mm, 65mm & 80mm with two twists.

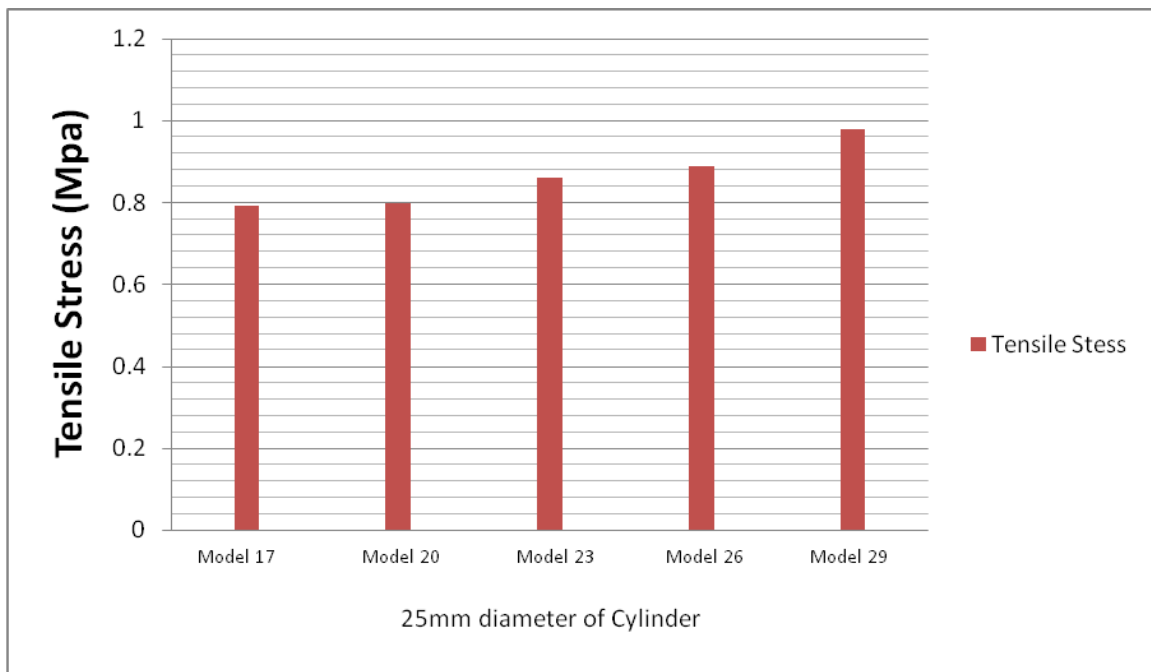


Figure 11 shows the comparison of tensile stress of concrete cylinder with diameter 25mm, length 25mm, 35mm, 50mm, 65mm & 80mm with two twists.

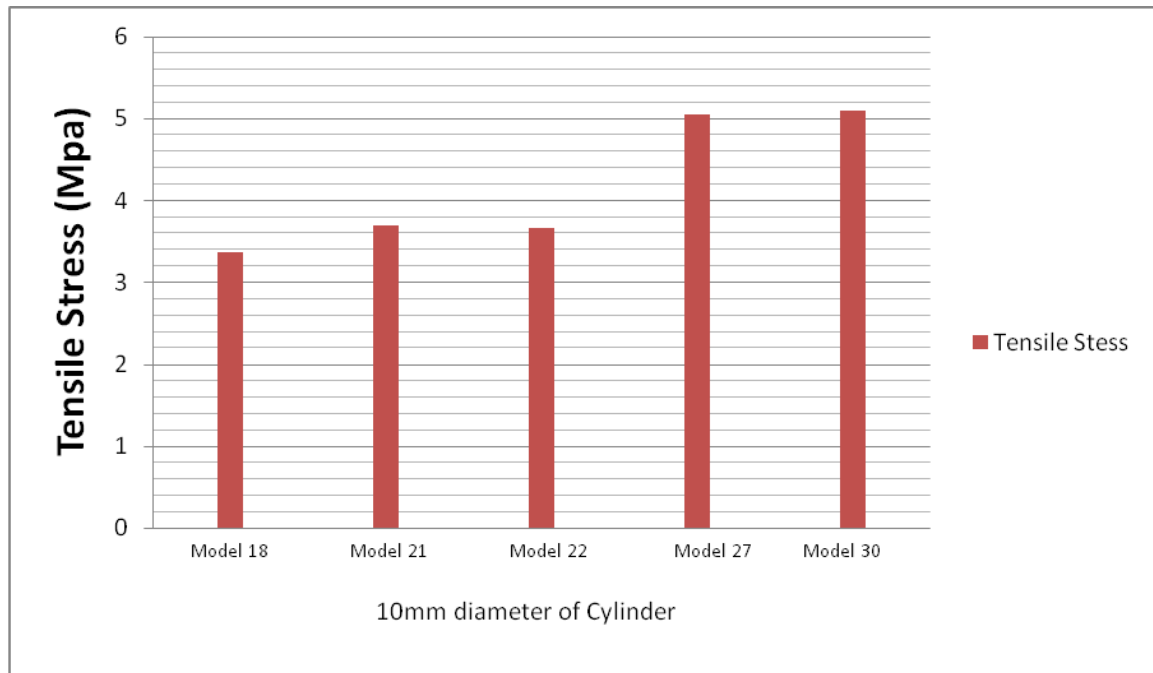


Figure 12 shows the comparison of tensile stress of concrete cylinder with diameter 10mm, length 25mm, 35mm, 50mm, 65mm & 80mm with two twists.