# A STUDY ON PROPERTIES OF POLYPROPYLENE FIBER REINFORCED CONCRETE

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## Abstract

Concrete made with Portland cement has certain characteristics: it is relatively strong in· compression but weak in tension and tends to be brittle. These two weaknesses have limited its use. Another fundamental weakness of concrete is that cracks start to form as soon as concrete is placed and before it has properly hardened. These cracks are major cause of weakness in concrete particularly in large onsite applications leading to subsequent fracture and failure and general lack of durability. The weakness in tension can be overcome by the use of conventional rod reinforcement and to some extent by the inclusion of a sufficient volume of certain fibers.

Polypropylene is a synthetic hydrocarbon polymer, the fiber of which is made using extrusion processes by hot drawing the material through a die. Its use enables reliable and effective utilization of intrinsic tensile and flexural strength of the material along with significant reduction of plastic shrinkage cracking and minimizing of thermal cracking.

The paper deals with the effects of addition of various proportions of polypropylene fiber on the properties of concrete. An experimental program was carried out to explore its effects on compressive, tensile, flexural, shear strength and plastic shrinkage cracking. A notable increase in flexural, tensile and shear strength was found. However, no change in compression strength was noted. Furthermore, shrinkage cracking is reduced by 83 to 85% by addition of fibers in the range of 0.35 to 0.50%.

Keywords: Polypropylene fibers, plastic shrinkage cracking

## INTRODUCTION

Concrete is by nature a brittle material that performs well in compression, but is considerably less effective when in tension. Reinforcement is used to absorb these tensile forces so that the cracking which is inevitable in all high-strength concretes does not weaken the structure. For many years, steel in the form or bars or mesh (also known as "re-bar") has been used as reinforcement for concrete slabs that are designed to experience some form of loading, whether that loading would be carrying traffic, spanning a void or bearing another structure such as a wall. In many slabs, steel mesh has been used a crude (and often ineffective) method of crack control.

Latest developments in concrete technology now include reinforcement in the form of fibers, notably polymeric fibers, as well as steel or glass fibers 1-5. Fiber-reinforcement is predominantly used for crack control and not structural strengthening. Although the concept of reinforcing brittle materials with fibers is quite old, the recent interest in reinforcing cement-based materials with randomly distributed fibers is quite old; the recent interest in reinforcing cement-based materials with randomly distributed fibers is based on research starting in the 1960's. Since then, there have been substantial research and development activities throughout the world. It has been established that the addition of randomly distributed polypropylene fibers to brittle cement based materials can increase their fracture toughness, ductility and impact resistance. Since fibers can be premixed in a conventional manner, the concept of polypropylene fiber concrete has added an extra dimension to concrete construction.

Tavakoli[6] performed experiments on concrete specimens reinforced randomly with propylene fibers. The results showed that compressive strength did not change significantly, but tensile strength had an increase of about 80 percent. Tu L and Kruger D[7] presented field application tests and proposed a new chemical treatment process "Oxyfluorination" on the properties of polypropylene fiber reinforced concrete. Segre[8] evaluated the stability of polypropylene fibers in environments aggressive to cement based materials.

Spades[9] analyzed the behaviour of polypropylene fiber reinforced concrete with 0.05-0.4% content in fiber. His experimental results showed that a good choice of length and content in fibers improves ductility and impact strength of concrete.

Soroushian[10] investigated the effects of collated fibrillated polypropylene fibers on the permeability of concrete materials with different binder compositions experimentally. He concluded that the polypropylene fibres, used in laboratory conditions that do not promote shrinkage cracking, had not statistically significant effect on chloride permeability of concrete materials.

## EXPERIMENTAL PROGRAM

In this experimental work, effect of polymer fibers on different properties of concrete was seen by adding different amounts of polymer fibers to the concrete. The concrete mix proportions were kept as 1: 2: 4.

To check the effect of fibers on compressive strength of concrete, total of thirty six concrete cylinders of 6 inches diameter and 12 inches high were made in four sets of 9 cylinders each. In three sets, different amounts of fibers were added whereas the fourth set was made without fibers as control cylinders. The results are compared with the control specimens.

To see the effect of fibers on tensile strength of concrete, total of twelve concrete cylinders of 6 inches diameter and 12 inches high were made in four sets of 3 cylinders each. In three sets, different amounts of fibers were added whereas the fourth set was made without fibers as control cylinders. The results are compared with the control specimens.

To evaluate the effect of fibers on flexural strength of plain concrete, total of sixteen concrete beams of 4″ x 4″ x 20 were made in four sets of 4 beams each. In three sets, different amounts of fibers were added whereas the fourth set was made without fibers as control beams. The results are compared with the control specimens.

To study the effect of fibers on flexural strength of reinforced concrete, total of sixteen concrete beams of 4″ x 4″ x 20″ were made in four sets of 4 beams each. In three sets, different amounts of fibers were added whereas the fourth set was made without fibers as control beams. The results are compared with the control specimens.

To see the effect of fibers on shrinkage cracks, four slab panels were made. In three slabs, different amounts of fibers were added whereas the fourth slab was made without fibers as control specimen. The results are compared with the control specimens.

To verify the effect of fibers on shear strength of reinforced concrete beams, total of eight concrete beams of 9″ x 9″ x 60″ were made in four sets of 2 beams each. In three sets, different amounts of fibers were added whereas the fourth set was made without fibers as control beams. The results are compared with the control specimens. The specimen details and results are summarized in Table 1.

## RESULTS AND DISCUSSION

**1. Compressive Strength:** The addition of polypropylene fibers at low values i.e. 0.18% to 0.40% actually increases the 28 days compressive strength by about 5% but when the volumes get higher like 0.55% to 0.60% then the compressive strength decreases from original by 3 to 5%.
The results in Table 2 seem to indicate that there may be an effective volume threshold for adversely effecting the compressive strength of concrete that is exceeded at 0.40%.

All things considered, it appears that at low dosage rates (0.1% to 0.35% the addition of polypropylene fibers does not significantly detract from, and even improve the compressive strength. Higher dosage rates however decrease the strength of concrete matrix due to higher volumes of fibers interfering with the cohesiveness of the concrete matrix. The graphical representation of the test results is given in Figures 1 to 3.

**2. Tensile Strength:** The tensile strength of concrete is only about 10 % of its compressive strength. It is clear that addition of fibers to a concrete mixture is beneficial to the tensile properties of concrete. The fibers act as crack arresters in the concrete matrix prohibiting the propagation of cracks in plastic state and propagation of cracks in hardened state.

According to Table 3, Tensile/ Flexure strength of concrete increases linearly only with addition of fibers upto about 0.40% after which the tensile strength decreases with addition of more fibers. The key to success in achieving strength seem to lie on two points i.e. fibers must be uniformly distributed in mix and fiber proportion must be carefully selected. The tensile strength increases about 65%~70% % upto 0.40% after which it decreases. Tensile strength is increased due to bridging mechanism of polypropylene fibers and after certain ration it reduced the bond strength between concrete ingredients so results in quick failure as compared to less volumes of fibers. . The graphical representation of the test results is given in Figures 4 to 6.

**3. Flexure Strength (plain concrete):** The behavior of concrete in flexure seems to be identical with polypropylene fiber reinforced concrete as that in tensile strength, but the difference that dosage amount for which best result is achieved is 0.25%. There is about 80% increase in flexure strength by adding 0.20% fibers in concrete after which strength starts reducing with further increment in fiber ratios.

As shown in Table 4 and figure 7, the increase in 07 days strength in much more greater than 28 days because of arresting the initial cracking of concrete by polypropylene fibers which is its useful properly.

**4. Flexural Strength (Reinforced):** Flexure strength behavior in reinforced beams seems to be identical as of plain beams with change of maximum load bearing ration from 0.20% to 0.35 % which is obviously due to participation of steel in arresting tensile loads at later stage and near failure. The test results are given in Table 5 and Figure 8.

**5. Shear Strength:** Polypropylene fiber gives resistance to first crack but do not provide resistance if once the crack forms. The shear capacity of concrete increases when fibers are added. There is a remarkable increase in load carrying capacity upto first crack appears. After the first crack the failure load is somewhat less then the control sample for minor ratios i.e. 0.20% to 0.40%, which indicates that no proper bridging action is developed in less percentage. But when the percentage of fibers increases upto 0.60% there is an increase in failure load by a little percentage. The test results are given in Table 6 and figures 10 and 11.

It looks that as testing on beams in done by single point loading by which beams cannot resist much in shear with polypropylene fibers. In our opinion if the testing would have been done in shear by UDL, there can be or linear increase by shear capacity of polypropylene fiber reinforced concrete, as uniformly distributed fibers can properly arrest the distributed cracks due to UDL.

**6. Plastic Shrinkage Cracking:** There are two major cracking in concrete: -

1. Cracking due to hardening (drying)of concrete
2. Plastic shrinkage cracking.

Polypropylene fibers have been studied as a way to reduce plastic shrinkage cracking. Study in Table 7 and figure 9, shows that by using about 0.35% fibers by volume reduced plastic shrinkage cracking to such an extent that no cracks could be observed and lower volumes i.e. 0.15 to 0.20% visibly restrained the crack width compared to samples that were not fiber reinforced. The shrinkage cracking is reduced by 83 to 85% by addition of fibers upto 0.35% and 0.50 %.

Permeability of concrete greatly decreases by polypropylene fibers again by controlling the cracks which indirectly increase concrete life and service, ability as less permeable a concrete sample is, the less susceptible it will be to water, chlorides and other damaging agents. Actually fibers can act as crack bridging mechanism and the can therefore contribute to improved cracking resistance.

The controlled cracking by polypropylene can be converted into useful economical advantage as: -

i. Less use of shrinkage steel.
ii. Reduction in thickness of slab by upto 30%.
iii. Ideal for joint free design.

## CONCLUSIONS

1. The addition of polypropylene fibers at low values actually increases the 28 days compressive strength but when the volumes get higher then the compressive strength decreases from original by 3 to 5%.
2. The tensile strength increases about 65%~70% % upto 0.40% after which it decreases
3. There is about 80% increase in flexure strength by adding 0.20% fibers in concrete after which strength starts reducing with further increment in fiber ratios
4. The shear capacity of concrete increases when fibers are added. There is a remarkable increase in load carrying capacity upto first crack appears.
5. The shrinkage cracking is reduced by 83 to 85% by addition of fibers upto 0.35% and 0.50 %.

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## Table 1: Specimen Details

| Sr.No | Test | Specimen | Numbers | Volume (Cft) | Type | Ratio | Cement (Kg) | Sand (KG) | Crush (Kg) | Water (0.60 W/C) (Kg) | Fibers (gm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | crushing Strength | Cylinder | 9 | 1.764 | A (Control) | 1:02:04 | 16 | 30 | 70 | 9.6 | 0 |
| 2 | crushing Strength | Cylinder | 9 | 1.764 | B (1Lb/CYD) | 1:02:04 | 16 | 30 | 70 | 9.6 | 29.596 |
| 3 | crushing Strength | Cylinder | 9 | 1.764 | C (2Lb/CYD) | 1:02:04 | 16 | 30 | 70 | 9.6 | 59.192 |
| 4 | crushing Strength | Cylinder | 9 | 1.764 | D (3Lb/CYD) | 1:02:04 | 16 | 30 | 70 | 9.6 | 88.788 |
| 5 | Tensile Strength | Cylinder | 3 | 0.588 | A (Control) | 1:02:04 | 5 | 10 | 23 | 3 | 0 |
| 6 | Tensile Strength | Cylinder | 3 | 0.588 | B (1Lb/CYD) | 1:02:04 | 5 | 10 | 23 | 3 | 9.86533 |
| 7 | Tensile Strength | Cylinder | 3 | 0.588 | C (2Lb/CYD) | 1:02:04 | 5 | 10 | 23 | 3 | 19.7307 |
| 8 | Tensile Strength | Cylinder | 3 | 0.588 | D (3Lb/CYD) | 1:02:04 | 5 | 10 | 23 | 3 | 29.596 |
| 9 | Flexural (Plain) | Beam (20"*4"*4") | 4 | 0.74 | A (Control) | 1:02:04 | 7 | 13 | 30 | 4.2 | 0 |
| 10 | Flexural (Plain) | Beam (20"*4"*4") | 4 | 0.74 | B (1Lb/CYD) | 1:02:04 | 7 | 13 | 30 | 4.2 | 12.4156 |
| 11 | Flexural (Plain) | Beam (20"*4"*4") | 4 | 0.74 | C (2Lb/CYD) | 1:02:04 | 7 | 13 | 30 | 4.2 | 24.8311 |
| 12 | Flexural (Plain) | Beam (20"*4"*4") | 4 | 0.74 | D (3Lb/CYD) | 1:02:04 | 7 | 13 | 30 | 4.2 | 37.2467 |
| 13 | Flexural (Reinforced) | Beam (20"*4"*4") | 4 | 0.74 | A (Control) | 1:02:04 | 7 | 13 | 30 | 4.2 | 0 |
| 14 | Flexural (Reinforced) | Beam (20"*4"*4") | 4 | 0.74 | B (1Lb/CYD) | 1:02:04 | 7 | 13 | 30 | 4.2 | 12.4156 |
| 15 | Flexural (Reinforced) | Beam (20"*4"*4") | 4 | 0.74 | C (2Lb/CYD) | 1:02:04 | 7 | 13 | 30 | 4.2 | 24.8311 |
| 16 | Flexural (Reinforced) | Beam (20"*4"*4") | 4 | 0.74 | D (3Lb/CYD) | 1:02:04 | 7 | 13 | 30 | 4.2 | 37.2467 |
| 17 | Shrinkage Cracks | Slab panel | 1 | 3.515 | A (Control) | 1:02:04 | 31 | 60 | 140 | 18.6 | 0 |
| 18 | Shrinkage Cracks | Slab panel | 1 | 3.515 | B (1Lb/CYD) | 1:02:04 | 31 | 60 | 140 | 18.6 | 58.9739 |
| 19 | Shrinkage Cracks | Slab panel | 1 | 3.515 | C (2Lb/CYD) | 1:02:04 | 31 | 60 | 140 | 18.6 | 117.948 |
| 20 | Shrinkage Cracks | Slab panel | 1 | 3.515 | D (3Lb/CYD) | 1:02:04 | 31 | 60 | 140 | 18.6 | 176.922 |
| 21 | Shear Strength | Beam (5'x9"x9") | 2 | 5.625 | A (Control) | 1:02:04 | 50 | 95 | 225 | 30 | 0 |
| 22 | Shear Strength | Beam (5'x9"x9") | 2 | 5.625 | B (1Lb/CYD) | 1:02:04 | 50 | 95 | 225 | 30 | 94.375 |
| 23 | Shear Strength | Beam (5'x9"x9") | 2 | 5.625 | C (2Lb/CYD) | 1:02:04 | 50 | 95 | 225 | 30 | 188.75 |
| 24 | Shear Strength | Beam (5'x9"x9") | 2 | 5.625 | D (3Lb/CYD) | 1:02:04 | 50 | 95 | 225 | 30 | 283.125 |
| | | **Totals** | **92** | **51.888** | | | **464** | **884** | **2072** | **278.4** | **1305.85** |

**Table 2: Compressive Strength**

| | 07 Days (Psi) | | | Average | 28 Days (Psi) | | | Average |
|---|---|---|---|---|---|---|---|---|
| A (Control) | 2227 | 2287 | 1989 | 2168 | 2652 | 2942 | 2869 | 2821 |
| B (1Lbs/Yd3) | 2546 | 2086 | 2864 | 2499 | 2925 | 2783 | 3015 | 2908 |
| C (2Lbs/Yd3) | 3063 | 3182 | 2784 | 3013 | 2783 | 3022 | 3101 | 2969 |
| D (3Lbs/Yd3) | 2148 | 2148 | 1750 | 2015 | 2460 | 2650 | 3100 | 2737 |

**Table 3: Tensile strength**

| | 07 Days (Psi) | | | Average | 28 Days (Psi) | | | Average |
|---|---|---|---|---|---|---|---|---|
| A (Control) | 183 | 220 | 202 | 202 | 280 | 312 | 302 | 298 |
| B (1Lbs/Yd3) | 202 | 220 | 210 | 211 | 300 | 290 | 315 | 302 |
| C (2Lbs/Yd3) | 239 | 202 | 276 | 239 | 325 | 312 | 285 | 307 |
| D (3Lbs/Yd3) | 239 | 185 | 202 | 209 | 239 | 345 | 300 | 295 |

**Table 4: Flexure Strength plain concrete beams**

| | 07 Days (Psi) | | Average | 28 Days (Psi) | | Average |
|---|---|---|---|---|---|---|
| A (Control) | 562 | 562 | 562 | 900 | 843 | 871.5 |
| B (1Lbs/Yd3) | 843 | 675 | 759 | 1011 | 900 | 955.5 |
| C (2Lbs/Yd3) | 562 | 562 | 562 | 787 | 787 | 787 |
| D (3Lbs/Yd3) | 450 | 337 | 393.5 | 675 | 675 | 675 |

**Table 5: Flexure strength of RC beams**

| Specimen | 07 Days (Psi) | | Average | 28 Days (Psi) | | Average |
|---|---|---|---|---|---|---|
| A (Control) | 675 | 900 | 787.5 | 1911 | 2350 | 2131 |
| B (1Lbs/Yd3) | 900 | 900 | 900 | 2436 | 1950 | 2193 |
| C (2Lbs/Yd3) | 787 | 1180 | 983.5 | 4327 | 2437 | 3382 |
| D (3Lbs/Yd3) | 618 | 787 | 702.5 | 2417 | 2417 | 2417 |

**Table 6: Shear Strength of beams**

| Beam Set-1 Beam Set-2 | First Crack | Intermediate Crack | Intermediate Crack | Failure | First Crack | Intermediate Crack | Intermediate Crack | Failure |
|---|---|---|---|---|---|---|---|---|
| A (Control) | 12 | 23.7 | 28.1 | 28.9 | 11.2 | 17.3 | 24.6 | 28.6 |
| B (1Lbs/Yd3) | 13.1 | 13.5 | 14 | 15.2 | 12.9 | 17.3 | 18.5 | 20.7 |
| C (2Lbs/Yd3) | 14.2 | 15 | 15.8 | 16.1 | 15.1 | 16 | 18.5 | 21 |
| D (3Lbs/Yd3) | 16 | 21.6 | 25.9 | 31 | 17.3 | 23.7 | 28.1 | 32 |

**Table 7: Plastic shrinkage cracking**

| | | | |
|---|---|---|---|
| A (Control) | 0.447 | 100% | 0.00% |
| B (1Lbs/Yd3) | 0.135 | 30.20% | 69.80% |
| C (2Lbs/Yd3) | 0.075 | 16.78% | 83.22% |
| D (3Lbs/Yd3) | 0.066 | 14.77% | 85.23% |

**Figure 1: Effect of Fibers on compressive strength at 7 days**

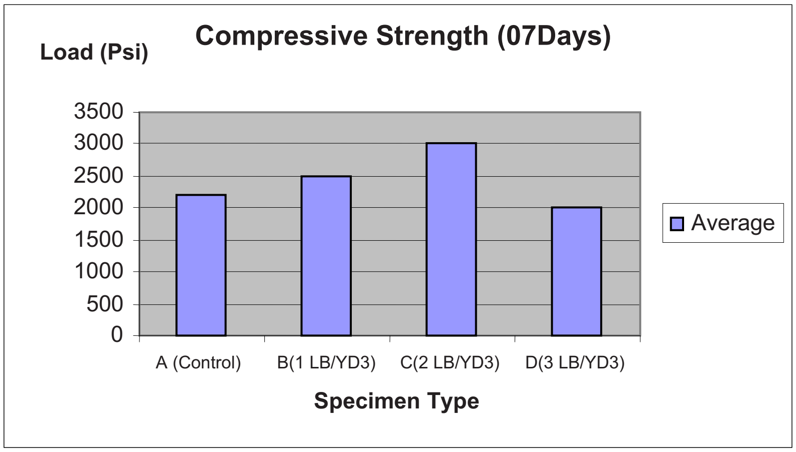



**Figure 2: Effect of Fibers on compressive strength at 28 days**

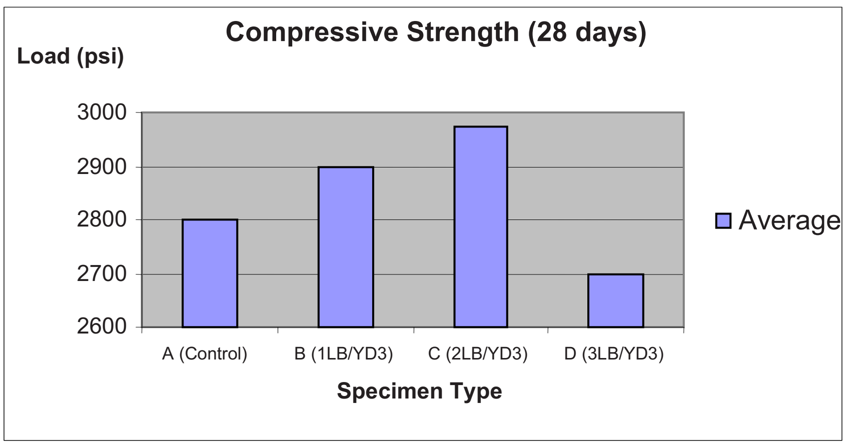



**Figure 3: Comparison of compressive strength at 7 and 28 days**

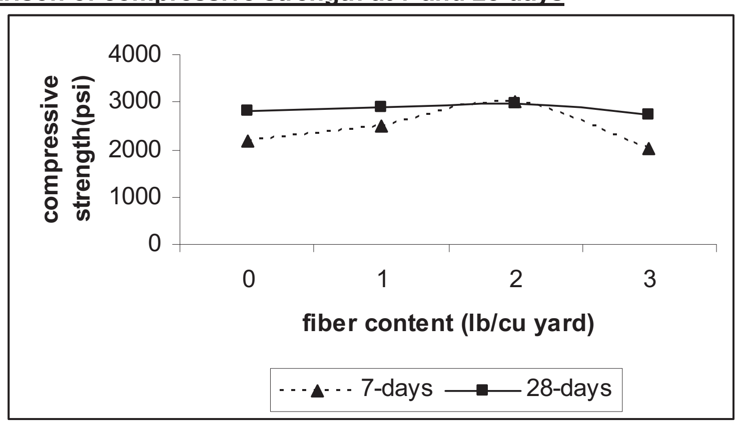


Figure 4: Effect of Fibers on Tensile strength at 7 days

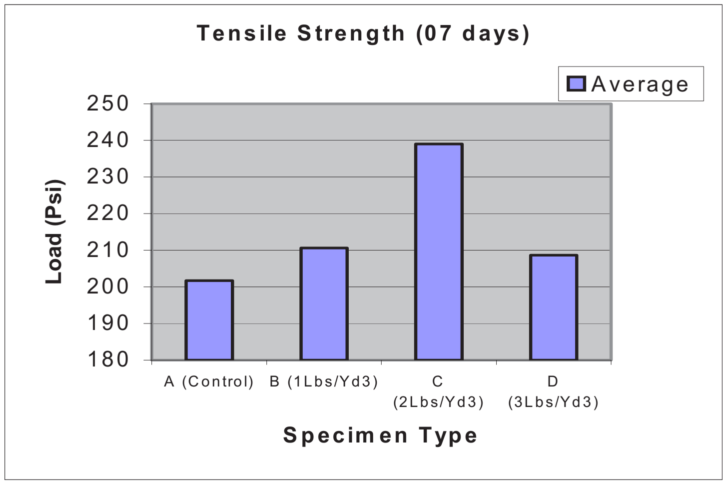



Figure 5: Effect of Fibers on Tensile strength at 28 days

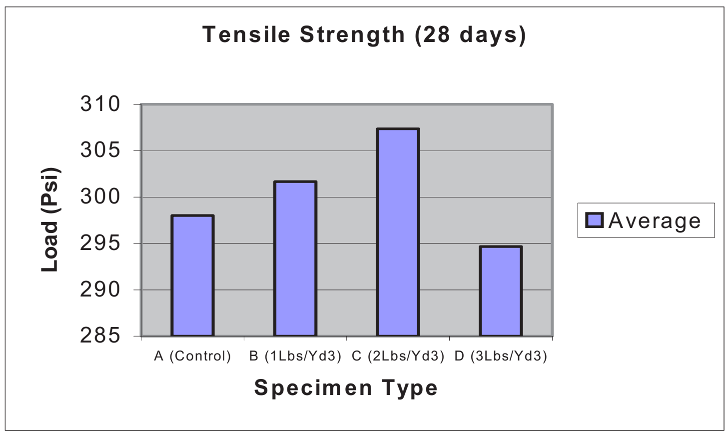



Figure 6: Comparison of Tensile strength at 7 and 28 days

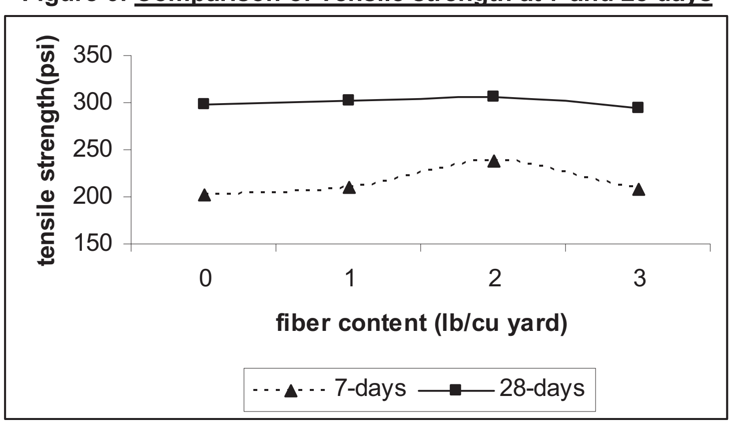


**Figure 7: Effect of Fibers on Flexural strength of plain concrete beams**

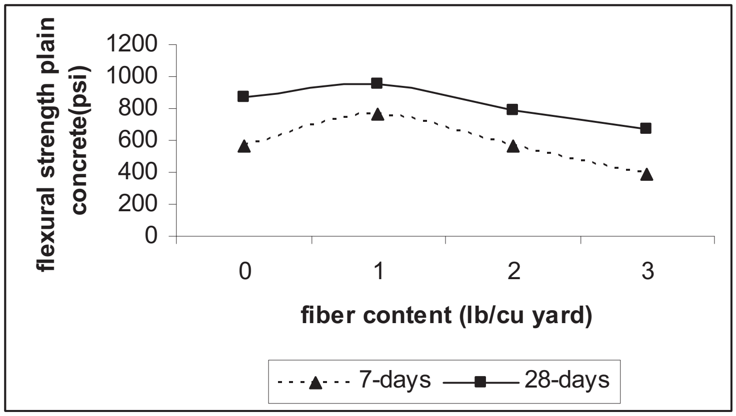



**Figure 8: Effect of Fibers on Flexural strength of RCC beams**

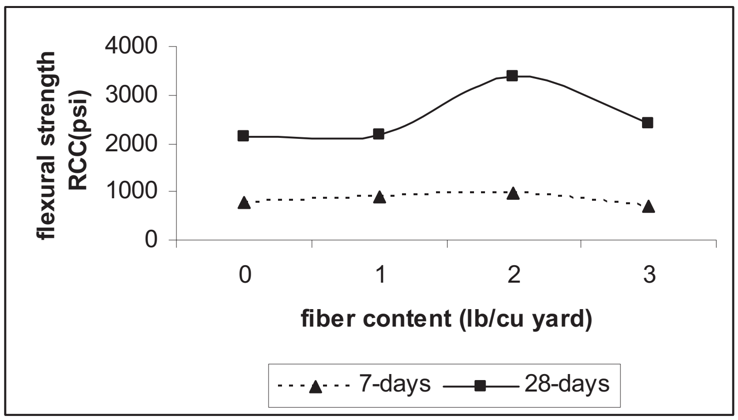
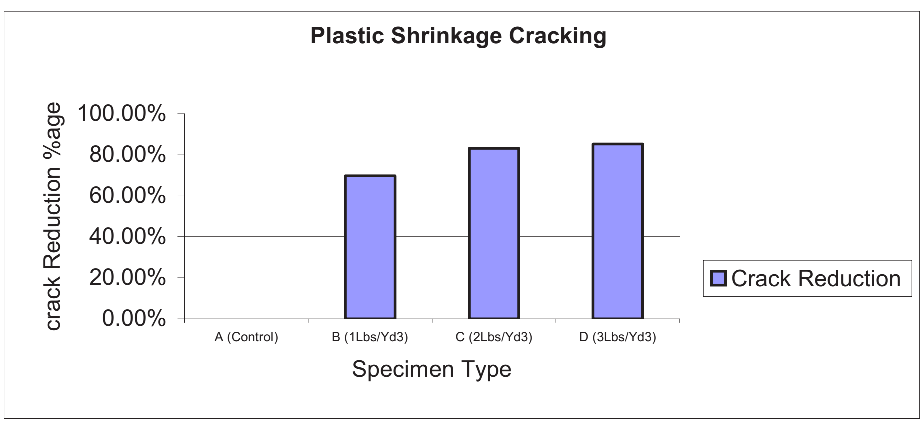



**Figure 9: Effect of Fibers on Plastic shrinkage of slabs**



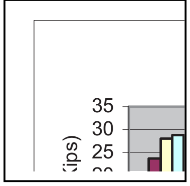



Figure 10: <u>Effect of Fibers on Shear strength of RCC beams</u>

**(Set-1)**

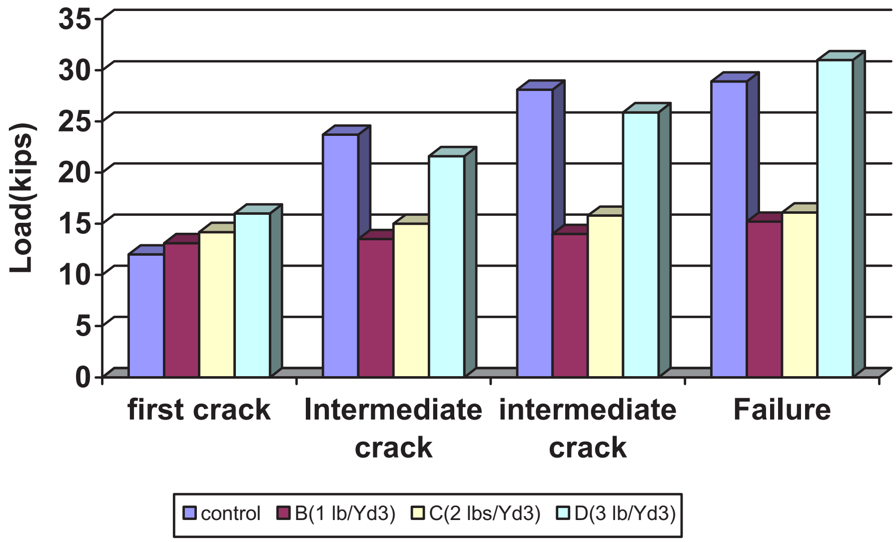



Figure 11: <u>Effect of Fibers on Shear strength of RCC beams</u> (Set-2)