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# Effect of Polypropylene Fibers in Geopolymer Concrete

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**Abstract:**
Construction is an everlasting activity and is one of the main contributors to the growth of an economy of a country. Due to growing environmental concerns of the cement industry, alternatives like Geopolymer Concrete (GPC) have become indispensable for environmental and durability performance. Fly ash can be used as a substitute for OPC to manufacture concrete due to its abundant availability. To improve the mechanical properties of GPC, polypropylene fibers were added to GPC in various percentages in this study. Geopolymer Concrete (GPC) is manufactured by alkali activation on dry mix which contains fly ash, coarse and fine aggregates. Sodium hydroxide and Sodium silicate were used as an alkali activator solution. Super plasticizer is added to improve the workability of GPC. GGBS, a by-product from steel industries, is used to replace flyash at the rate of 10% to avoid heat curing of Geopolymer concrete in this study. Based on the various literature reviews, the effect of polypropylene fibers in various proportions viz., 0.5% to 5% in geopolymer concrete was tested in this study. For this, the basic properties of geopolymer concrete like compressive strength, split tensile strength and flexural strength were carried out. Test results shown that PP fibers at 2.5% resulted in 73.47% increase in compressive strength, 13.40% increase split tensile and 44.24% increase flexural strength compared to other combinations. Hence it is concluded that the polypropylene fibers at 2.5% can be used as a promising additive to the geopolymer concrete to enhance the properties of geopolymer concrete.

**Keywords:** Geopolymer, GGBS, Polypropylene fiber, Alkaline Solution.

## I. INTRODUCTION

Geopolymer materials represent an innovative technology that is generating considerable interest in the construction industry, particularly considering the on-going emphasis on sustainability. Since Portland cement is responsible for upward of 85% of the energy and 90% of the carbon dioxide attributed to a typical ready-mixed concrete, the potential energy and carbon dioxide savings using geopolymer can be considerable. Consequently, there is growing interest in geopolymer applications in construction infrastructure. Concrete usage around the world is second only to water. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one tonne for every tonne of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminium. On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilize this by-product of burning coal, as a substitute for OPC to manufacture concrete. In 1978, Davidovits (1999) proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or by-product materials such as fly ash and rice husk ashare termed these binders. As S. Palomo et al. (1999) suggested that pozzolans such as blast furnace slag might be activated using alkaline liquids to form a binder and hence totally replace the use of OPC in concrete. In this scheme, the main contents to be activated are silicon and calcium in the blast furnace slag. The main binder produced is a C-S-I gel, as the result of hydration process. The demand for cement is rising, and the developing world has started using more and more of Portland cement. As per the estimates ofIndian Bureau of Mines, the limestone deposits that are available to produce cement have a limited life and are not going to last for more than 35-40 years. Being a developing country, our per capita consumption of cement is increasing every year, and therefore it is more pertinent for us to look for alternatives. However, in the last 15 years, we have not seen much progress on this front. The other facet of the story is the technological alternative for the product. While looking for substitute products, the category of developments can be divided into different sections: cements developed without the use of limestone; cements still using limestone, but with less of carbon footprint; making use of gaseous $CO_2$ for production of concrete and producing calcium carbonates which is a raw material for cement from sea water or algae. One such concrete is **Geopolymer Concrete**, coined by Prof.Davidovits. To date, there are no widespread applications of geopolymer concrete in Indian infrastructure, although the technology is rapidly advancing in Europe and Australia. One North American geopolymer application is a blended Portland geopolymer cement known as Pyrament® (patented in 1984), variations of which continue to be successfully used for rapid pavement repair. Other portland-geopolymer cement systems may soon emerge. In addition to Pyrament®, the U.S. military is using geopolymer pavement coatings designed to resist the heat generated by vertical take-off and landing aircraft. In the short term, there is potential for geopolymer applications for bridges, such as precast structural elements and decks as well as structural retrofits using geopolymer-fiber composites. Geopolymer technology is most advanced in precast applications due to the relative ease in handling sensitive materials (e.g., high-alkali activating solutions) and the need for a controlled high-temperature curing environment required for many current geopolymer systems. To date, none of these potential applications has advanced beyond the development stage, but the durability attributes of geopolymers make them attractive for use in high-cost, severe-environment applications such as bridges. Other potential near-term applications are precast pavers and slabs for paving.The superior properties of Geopolymer concrete are i) sets at room temperature ii) Non-toxic, bleed free, iii) Long working life before stiffening iv) Impermeable v) Higher resistance to heat and resist all inorganic solvents vi) Higher compressive strength.

## II LITERATURE REVIEW

Eswaramoorthi and Arunkumar(2014) conducted experiments to study the performance of concrete using fly ash as the major binding material without of cement. Low calcium fly ash is preferred as a source material than High calcium fly ash because of to reducing more carbondioxide emission. Alkaline liquid sodium hydroxide and sodium silicate solution are used in this project as binders which are used in polymerization process. Reaction occurred at high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate compared to the use of only alkaline hydroxides. A mix proportion for Geopolymer concrete was designed and carried out tests for different grade of concrete. The tensile strength and compressive strength of Geopolymer concrete have been studied and compared with OPC. Polypropylene is one of the cheapest & abundantly available polymers. It is concluded that Polypropylene fibres are resistant to most of the chemicals & it would be cementations matrix, which deteriorate first under aggressive chemical attack Karthik and Chandrasekaran (2014) investigated mechanical properties of high-strength concrete of grade of M60 at 28 days. The characteristic strength with different replacement levels of cement with silica fume are considered in this study. Standard cubes (150mm x 150mm x 150mm), standard cylinders (150mm dia x 300mm height) and standard prisms (100mm x 100mm x500mm) were cast in the investigation, with and without polypropylene fibre. The mechanical properties viz., compressive strength, flexural strength and split tensile strength, of high strength concrete with various replacement of polypropylene fibre 0.5%, 1%,1.5%and 2% and silica fume viz., 10%, 20%, and 30%, has been studied. Test results show that compressive strength of the Geopolymer concrete with PP fibers has increased by 10.70% than Conventional concrete. Similarly, split tensile strength of Geopolymer concrete with fibers has increased by 13.62%than conventional concrete. TamilSelvi and Thanda vamoorthy (2014) presented the test results of strength of concrete cubes and cylinders using M30 grade concrete and reinforced with steel and polypropylene fibres are presented. Also, hybrid fibres with crimped steel and polypropylene were used in concrete matrix to study its improvements in strength and durability properties. The steel, polypropylene and hybrid consisting of polypropylene and steel (crimped) fibres of various proportion i.e., 4% of steel fibre, 4% of polypropylene fibre and 4% of hybrid (polypropylene and steel (crimped) fibres each of 2 % by volume of cement were used in concrete mixes. Besides cubes, cylinders of 150 mm diameter high of M30 grade concrete were cast with 4 per cent of steel fibre, 4 % of polypropylene fibre, and 4% of hybrid fibre, respectively, by volume of cement. The rapid chloride permeability test and water absorption test were conducted on 7, 28, 56 and 90 days and the test results show that the addition of steel and polypropylene fibres to concrete exhibit better performance. The test results show that use of steel fibre reinforced concrete improves compressive strength and split tensile strength. The durability of such concrete is also improved. Subbiah Ilamvazhutiand Gopalakrishna (2013) dealt with the advantageous results of geopolymer concrete with polypropylene fibre. The geopolymer concrete mixes with polypropylene fibres were prepared and the cylinders were heat cured in laboratory oven. Slump tests and compressive tests were done. Better workability and increase in compressive strength were noticed. Durability tests were conducted for sulphate and sulphuric acid resistance and the cylinders were durable to chemical environment. The work has been extended to the structural members like slab, beam, column and its behaviour were studied. Srinivasan et al. (2013) determined the performance characteristics of geo polymer reinforced concrete. The mechanical properties of the specimen were studied for both ambient and heat curing. The strength properties test was carried out after 28 days for ambient curing and 24 hours for heat curing showed that the increase of mechanical properties (Compressive, Split tensile and Flexural strength) resulting from added of polypropylene fibre was relatively high. From the test results, it was observed that 100% GGBS binder composition with 0.25% polypropylene fibres has shown better performance. Priti A.Patel et.al. (2012) experimentally investigated the properties such as compressive strength, flexural strength, split tensile strength and shear strength of polypropylene fiber reinforced concrete. In an attempt to increase concrete ductility and energy absorption, researchers introduced polypropylene fiber reinforced concrete (PFRC). Their study is part of a research program on evaluating the performance of polypropylene fiber reinforced concrete. The fiber volume fraction $V_f$of 0%, 0.5%, 1%, 1.5% and 2%. No significant change is found for compressive strength when compared to the plain concrete but flexural, split tensile and shear strength improves greatly. Roohollah Bagherzadeh et.al. (2012) investigated the influence of polypropylene fibers in different proportioning and fiber length to improve the performance characteristics of lightweight cement composites has been studied. In this study, they have used fibers in two different lengths (6mm and 12mm) and fiber proportions (0.15% and 0.35%) by cement weight in the mixture design. Hardened concrete properties such as compressive strength, splitting tensile strength, flexural strength, water absorption, and shrinkage were evaluated at 7- and 28-day. All reinforced lightweight concrete specimens displayed improvement in their mechanical strength. Among all fiber specimens, only the Polypropylene fiber with12mm length and proportion 0.35 % performed better in all respects compared to the physical and mechanical properties of reinforced lightweight concrete. Slamet Widodo (2012) conducted to evaluate the effects of polypropylene fiber addition on fresh state characteristics of SCC mixes, and investigate the effects of polypropylene fiber on some hardened properties of SCC. In their research work they were added polypropylene fiber of 0%, 0.05%, 0.10%, and 0.15% volume fraction in concrete mixes. Authors have observed that the compressive strength of concrete specimens improved proportionally with the addition of polypropylene fiber up to 0.05 % by concrete volume, and then tend to decrease after 0.10 % of polypropylene addition in the concrete mix. They also observed that the splitting tensile strength of concrete specimens improved proportionally with the addition of polypropylene fiber up to 0.10 % by concrete volume, and then tend to decrease after 0.15 % of polypropylene addition in the concrete mix. According to the evaluation of fresh and hardened properties of Self-Consolidating Concrete (SCC), they concluded that polypropylene fibers allowed to be added into the concrete mixes up to 0.10 % by concrete volume. Fareed Ahmed Memon et al. (2011) reported the results of an experimental work conducted to investigate the effect of curing conditions on the compressive strength of self-compacting Geopolymer concrete prepared by using fly ash as base material and combination of sodium hydroxide and sodium silicate as alkaline activator. The experiments were conducted by varying the curing time and curing temperature in the range of 24-96 hours and 60-90°C respectively. The essential workability properties of freshly prepared Self-compacting geopolymer concrete such as filling ability, passing ability and segregation resistance were evaluated by using Slump flow, V-funnel, L-box and J-ring test methods. The fundamental requirements of high flow ability and resistance to segregation as specified by guidelines on self-compacting concrete by EFNARC were satisfied. Test results indicate that longer curing time and curing the concrete specimens at higher temperatures result in higher compressive strength. There was increase in compressive strength with the increase in curing time; however, increase in compressive strength after 48 hours was not significant. Concrete specimens cured at 70°C produced the highest compressive strength as compared to specimens cured at 60°C, 80°C and 90°C. K.Vijai et al. (2012) reported the effect of setting time and necessity of heat curing to gain strength in geopolymerconcrete. The two limitations of GPC mix were eliminated by replacing 10% of fly ash by OPC which results in GeopolymerConcrete Composite (GPCC mix). Replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced compressive strength, split tensile strength and flexural strength by 73%, 128% and l7%respectively with reference to GPC mix. Addition of steel fibers in geopolymer concrete composites enhanced its mechanical properties. Compressive strength split tensile strength and flexural strength of steel fiber reinforced geopolymer concrete composites increases with respect to the increase in the percentage volume fraction from 0.25 to 0.75. Addition of 0.25% volume fraction of steel fibers resulted in an enhanced compressive strength. Deshmukh &Kawade (2016) presented the data on the engineering properties of geopolymer concrete with varying molarity (11.5 to 14.5 M) & different percentage of polypropylene fibers& steel fiber (0.2%,0.4% ,0.6%,0.8%, 1%). Ratio of $Na_2SiO_3$ / NaOH is kept as 2 & $Na_2O$ / $SiO_2$ is kept as 2.25. It was concluded that flexural strength and split tensile strength increases as the Molarity increases. Optimum results were obtained at 13M, thereafter, the strength of the geopolymer concrete decreases in this study. Steel fibers at 0.8% and Polypropylene fibers at 0.2% by mass of concrete obtained enhanced properties of geopolymer concrete.

## III MATERIALS USED

### 3.1 Fly Ash

In the present work, low calcium Class F fly ash was used, and it was obtained from the Tuticorin Thermal Power Station. Specific gravity of fly ash was obtained as 1.65. In the past, fly ash was generally released into the atmosphere, but air pollution control standards now require that it be captured prior to release by fitting pollution control equipment. In the U.S, fly ash is generally stored at coal power plants or placed in landfills. About 43% is recycled, often used as a pozzolan to produce hydraulic cement and a replacement or partial replacement for Portland cement in concrete production. Pozzolans ensure the setting of concrete and plaster and provide concrete with more protection from wet conditions and chemical attack. The specific gravity of fly ash was 1.652.

**3.2 GGBS:** Ground Granulated Blast Furnace Slag is obtained by quenching molten iron slag (by product of iron and steel industries) from a blast furnace in water or stream, to produce a glassy, granular product that is then dried and ground into a fine powder. GGBS is a Waste product generated from iron making industry. These operate at a temperature of about 1500$^{o}$C and are fed with a carefully controlled mixture of iron-ore, coke and limestone. The iron ore is reduced to iron and the remaining materials form a slag that floats on top of the iron. This slag is periodically tapped off as a molten liquid and if it is to be used for the manufacture of GGBS, it has to be rapidly quenched in large volumes of water. In this study, Flyash is replaced by GGBS @ 10% to avoid heat curing of Geopolymer concrete specimens. GGBS avoids delayed setting, enhances curing time at ambient temperature. Since the properties of GGBS and Portland Cement is more or less same, more than 10% replacement of GGBS is avoided. GGBS is procured from local supplier M/s Astrra Chemicals, Chennai for this project.

**3.3 Fine Aggregate:** Locally available clean river sand was used as fine aggregate in the study. The specific gravity was calculated as 2.60 and the fineness modulus was obtained as 2.48. The fine aggregate used conforms to Zone-II as per IS: 383-1970.The specific gravity and fineness modulus for fine aggregate were found to be 2.60 and 2.48 respectively.

**3.4 Coarse Aggregate:** Locally available crushed granite of maximum size 12 mm down size was used as a coarse aggregate. The specific gravity of coarse aggregate was computed as 2.70. The coarse aggregate used conforms to Zone-II as per IS: 383-1970.The specific gravity of Coarse Aggregate was determined in the laboratory and it was found to be 2.70.

**3.5 Polypropylene Fibers:** Polypropylene fiberswere first suggested as an admixture to concrete in 1965 for the construction of blast resistant buildings for the US Corps of Engineers. The fiber has subsequently been improved further and at present it is used either as short discontinuous fibrillated material for production of fiber reinforced concrete or a continuous mat for production of thin sheet components. Since then, the use of these fibers has increased tremendously in construction of structures because addition of fibers in concrete improves the toughness, flexural strength, tensile strength and impact strength as well as failure mode of concrete. Polypropylene is cheap, abundantly available and has consistent quality. According to the manufacturer, the specific gravity of PP is between 0.90 g/cm$^3$.

**3.6 Alkaline Solution:** Sodium silicate and sodium hydroxide were used as activators to react with the aluminium and the silica in the fly ash and GGBS. Commercially available sodium silicate in pellet form was used for this experimental work. Sodium hydroxide solution of 10 molarityconcentration was prepared by dissolving sodium hydroxide flakes with 97% purity in the water. The ratio of sodium silicate to sodium hydroxide solution was fixed as 2.5. The alkaline solution was prepared by mixing both sodium silicate solution and sodium hydroxide solution together at least one day prior to use, so that effective reaction of alkaline solution to takes place. Weight in grams of sodium hydroxide is 400gms for 10 M (i.e.) 10 x 40 = 400 gms, where 40 is the molecular weight of NaOH.

**3.7 Super Plasticizer:** High range water reducing super plasticizer CONPLAST SP-430 SNF (Sulphonated Naphthalene Formaldehyde) manufactured by FOSROC India, was added to improve the workability of geopolymer concrete.

## IV. EXPERIMENTAL PROGRAM

**Preparation of Alkaline Solution:** To start with, weighed quantity of Sodium hydroxide (NaOH) in flakes form to suit 10 Molarity (10M) is dissolved in distilled water or RO water to avoid any impurities present in water. Approximately 300 gms of NaOH solution can be obtained when 100 gms of NaOH pellets is mixed with 250 ml of water in a jar. In this study, 3 cubes each for varying percentages of PP fibre was castand tested for each varying proportions of PP fibers including conventional concrete specimens of M20 nominal mix. For 3 cubes of GP concrete, 460 gms of NaOH solution was needed.So, 153 gms of NaOH pellets was taken in a beaker and 382.5 ml of water was added and mixed thoroughly with a glass rod, until the solution was cooled. After the mix was cooled, it was weighed excluding the beaker weight. Then, 2.5 times the weight of sodium silicate was mixed with it waspoured in a plastic tray. The solution thus prepared was kept in a tray for 24 hours.This waiting time allows the polimerization process among the alkaline solution mixed. The mix of sodium hydroxide and sodium silicate was added to the dry mix of flyash, GGBS, polypropylene fibers, fine aggregate and coarse aggregate in a metallic tray. Water was added to the dry mix slowly as per the calculated quantity. Prior, the dry mix was thoroughly mixed for 5 minutes. Measured quantity of super plasticizer also added to the mixture for the considerable workability.To get a uniform mix, small amount of extra water @ 12% ofFlyash + GGBS was also added to the mix at the end. Polypropylene fibers were used in various proportions from 0.5% to 5% of the mass of Flyash + GGBS. It is sprinkled uniformly throughout the concrete for uniform mix. For identification of the specimens it is designated as FxGyPz. For example, F90G10P0.5 represents specimens with 90% flyash, 10% GGBS and 0.5% PP fibers. The specimen details are tabulated in table 1. The fresh concrete was casted into moulds immediately after mixing. The fresh concrete was casted into 150 x 150 x 150 mm cubes, 100 mm (dia) x 300 mm (height) cylinders, and 500 x 100 x 100 mm prisms, to find the compressive strength, split tensile strength and flexural strength respectively. The specimens for compressive and flexural strength were prepared and tested in accordance with IS 516:1959. Test for split tensile strength was done as per the procedure discussed in IS 5816:1999. After casting, all the specimens were kept undisturbed at room temperature for ambient curing at 32$^{o}$C (average lab temperature) and after de-moulding the specimens on the next day, they were kept at ambient temperature, till the date of testing. The cast cubes, cylinders and prisms, after ambient curing (32$^{o}$C average), were tested at 7 days and 28 days in the compression testing machine for their compressive and split tensile strength and in universal testing machine for its flexural strength and the results were noted. The test set up of cube, cylinder and prism are shown in Fig. 1 to 3.

**Figure.1. testing of gpc cubes**

**Figure.2. testing of gpc cylinders**

**Figure.3. testing of gpc flexure beam**

**Table.1. Specimen details**

| Specimen ID | Number of Cube specimen | Number of cylinder specimen | Number of Prism specimen |
|---|---|---|---|
| | **7 & 28 days** | **7 & 28 days** | **7 & 28 days** |
| Control Specimen | 6 | 6 | 6 |
| F90G10P0 | 6 | 6 | 6 |
| F90G10P0.5 | 6 | 6 | 6 |
| F90G10P1.0 | 6 | 6 | 6 |
| F90G10P1.5 | 6 | 6 | 6 |
| F90G10P2.0 | 6 | 6 | 6 |
| F90G10P2.5 | 6 | 6 | 6 |
| F90G10P3.0 | 6 | 6 | 6 |
| F90G10P3.5 | 6 | 6 | 6 |
| F90G10P4.0 | 6 | 6 | 6 |
| F90G10P4.5 | 6 | 6 | 6 |
| F90G10P5.0 | 6 | 6 | 6 |
| Total Specimens | 72 | 72 | 72 |

## V. RESULTS AND DISCUSSIONS

### 5.1 Compressive Strength

The compressive strength test results of Geopolymer concrete cubes with various combinations of Polypropylene fibers at 7 days and at 28 days are given in table 2. From the results, it can be observed that the specimen F90G10P0.25 resulted in highest compressive strength at both 7 days (27.11 N/mm$^2$) and 28 days (39.03 N/mm$^2$). For various percentages of PP fiber at 7 days, it can be observed that the compressive strength slowly decreased from 15.74 N/mm$^2$ (for 0% PP) to 24.54

N/mm$^2$ (for 2% PP). For F90G10P2.5, there is a sudden increment in the compressive strength (27.11 N/mm$^2$) and it again started converging and finally ended at 12.79 N/mm$^2$ (for 5% PP).Similarly, for 28 days strength, it can be observed that the compressive strength slowly decreased from 22.50 N/mm$^2$ (for 0% PP) to 35.58 N/mm$^2$ (for 2% PP).

For F90G10P2.5, there is a sudden increment in the compressive strength (39.03 N/mm$^2$) and it again started converging and finally ended at 22.58 N/mm$^2$ (for 5% PP).Fig. 4 shows the comparison of compressive strength graphically at 7 days and 28 days respectively.From table 2, it can be identified that for the specimen F90G10P2.5, the percentage increase in compressive strength is highest. It was 14% and 72.24% when compared to conventional concrete and GP concrete respectively at 7 days. Similarly, it was 35.99% and 73.47% when compared to conventional concrete cube and GP concrete cube respectively at 28 days.

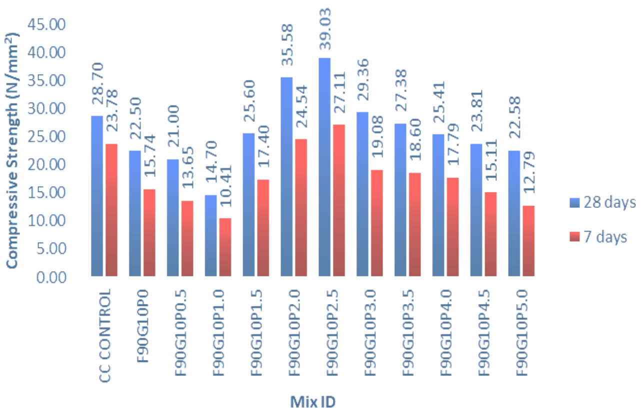


**Figure.4. comparision of compressive strengths**

**5.2 Split Tensile Strength**

The split tensile test was carried according to IS 5816:1999, Code of Practice for Method of Test Splitting Tensile Strength of Concrete. Test results at different ages of concrete are given in Table 3. From the results obtained, it can be identified that specimen F90G10P2.5 exhibited highest split tensile strength at both 7 days (1.87 N/mm$^2$) and 28 days (2.71 N/mm$^2$). For various percentages of PP fiber at 7 days, it can be observed that the split tensile strength slowly decreased from 1.69 N/mm$^2$ (for 0% PP) to 1.34 N/mm$^2$ (for 2% PP). For F90G10P2.5, there is a sudden increment in the split tensile strength (1.87 N/mm$^2$) and it again started converging and finally ended at 0.87 N/mm$^2$ (for 5% PP).

Similarly, for 28 days strength, it can be observed that the split tensile strength slowly decreased from 2.39 N/mm$^2$ (for 0% PP) to 2.05 N/mm$^2$ (for 1.5% PP). For F90G10P2.0, there is a sudden increment in the split tensile strength (2.60 N/mm$^2$) and for F90G10P2.5, it attained the highest value among the entire specimen (2.71 N/mm$^2$) and it again started converging and finally ended at 1.26 N/mm$^2$ (for 5% PP). Fig. 5 shows the comparison of split tensile strength graphically at 7 days and 28 days respectively.

From the table 5, it can be identified that for the specimen F90G10P2.5, the percentage increase in split tensile strength is highest. It was 15.43% and 10.65% when compared to conventional concrete cylinder and GP concrete cylinder respectively at 7 days. Similarly, it was 23.74% and 13.40% when compared to conventional concrete cylinder and GP concrete cylinder respectively at 28 days.

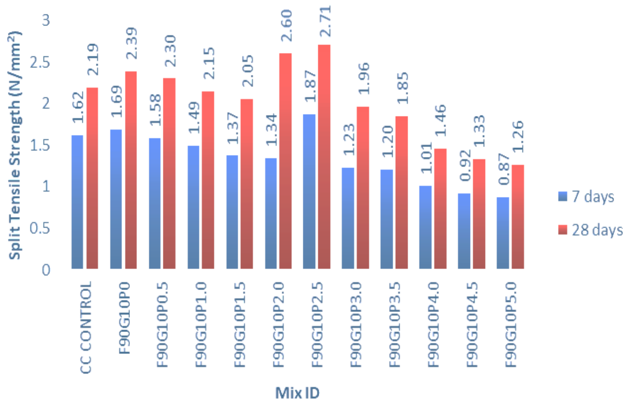


**Figure.5.Comparision of Split Tensile Strength**

**5.3 Flexural Strength Test**

Flexural tests were carried out on 500 x 100 x 100 mm prism specimens according to IS 516-1959, Code of Practice for Method of tests for strength of concrete. The flexural test results at different ages of concrete are given in table 4. From the results, it can be clearly observed that the specimen F90G10P2.5 exhibited highest flexural strength at both 7 days (5.61 N/mm$^2$) and 28 days (8.02 N/mm$^2$). For various percentages of PP fiber at 7 days of curing, it can be observed that the flexural strength slowly decreased from 3.89 N/mm$^2$ (for 0% PP) to 3.29 N/mm$^2$ (for 2% PP). For F90G10P2.5, there is a sudden increment in the flexural strength (5.61 N/mm$^2$) and it again started converging and finally ended at 3.46 N/mm$^2$ (for 5% PP). Similarly, for 28 days flexural strength, it can be observed that the flexural strength slowly decreased from 5.56 N/mm$^2$ (for 0% PP) to 5.09 N/mm$^2$ (for 2% PP). For F90G10P2.5, there is a sudden increment in the flexural strength (8.02 N/mm$^2$) and it again started converging and finally ended at 4.94 N/mm$^2$ (for 5% PP). From the table 6, it can be seen that for the specimen F90G10P2.5, the percentage increase in flexural strength is highest. It was 55.83% and 44.22% when compared to conventional concrete prism and GP concrete prism respectively at 7 days. Similarly, it was 52.47% and 44.24% when compared to conventional concrete prism and GP concrete prism respectively at 28 days. Figure 6 shows the comparision of test results of flexural strength test.

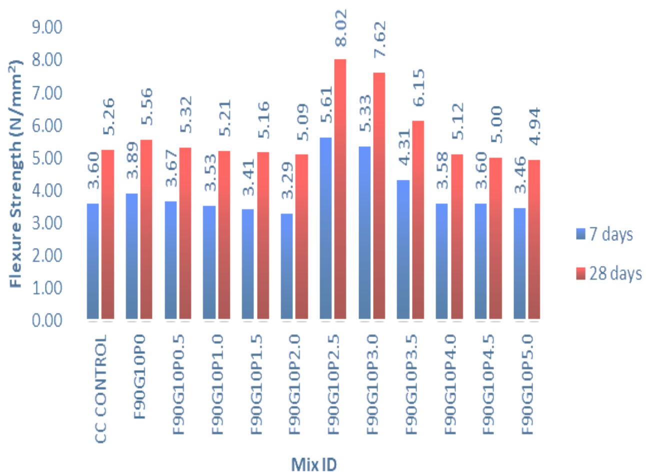


**Figure.6. comparision of flexural strength test**

**Table.2. Test results of compression test**

| Specimen ID | Compressive Strength (N/mm$^2$) | | | | | |
|---|---|---|---|---|---|---|
| | 7 days | % increase / decrease compared to | | 28 days | % increase / decrease compared to | |
| | | CC Cube | GP Cube | | CC Cube | GP Cube |
| CC Control Cube | 23.78 | - | +51.08 | 28.70 | - | +27.56 |
| F90G10P0 | 15.74 | -33.81 | - | 22.50 | -21.60 | - |
| F90G10P0.5 | 13.65 | -42.60 | -13.28 | 21.00 | -26.83 | -6.67 |
| F90G10P1.0 | 10.41 | -56.22 | -33.86 | 14.70 | -48.78 | -34.67 |
| F90G10P1.5 | 17.40 | -26.82 | +10.55 | 25.60 | -10.80 | +13.78 |
| F90G10P2.0 | 24.54 | +3.20 | +55.91 | 35.58 | +23.97 | +58.13 |
| F90G10P2.5 | 27.11 | +14.00 | +72.24 | 39.03 | +35.99 | +73.47 |
| F90G10P3.0 | 19.08 | -19.76 | +21.22 | 29.36 | +2.30 | +30.49 |
| F90G10P3.5 | 18.60 | -21.78 | +18.17 | 27.38 | -4.60 | +21.69 |
| F90G10P4.0 | 17.79 | -25.19 | +13.02 | 25.41 | -11.46 | +12.93 |
| F90G10P4.5 | 15.11 | -36.46 | -4.00 | 23.81 | -17.04 | +5.82 |
| F90G10P5.0 | 12.79 | -46.22 | -18.74 | 22.58 | -21.32 | +0.36 |

**Table.3. Test results of split tensile strength**

| Specimen ID | Split Tensile Strength (N/mm$^2$) | | | | | |
|---|---|---|---|---|---|---|
| | 7 days | % increase / decrease compared to | | 28 days | % increase / decrease compared to | |
| | | CC Cylinder | GP Cylinder | | CC Cylinder | GP Cylinder |
| CC Control Cylinder | 1.62 | - | -4.14 | 2.19 | - | -8.37 |
| F90G10P0 | 1.69 | +4.32 | - | 2.39 | +9.13 | - |
| F90G10P0.5 | 1.58 | -2.47 | -6.51 | 2.30 | +5.02 | -3.77 |
| F90G10P1.0 | 1.49 | -8.02 | -11.83 | 2.15 | -1.83 | -10.04 |
| F90G10P1.5 | 1.37 | -15.43 | -18.93 | 2.05 | -6.39 | -14.23 |
| F90G10P2.0 | 1.34 | -17.28 | -20.71 | 2.60 | +18.72 | +8.79 |
| F90G10P2.5 | 1.87 | +15.43 | +10.65 | 2.71 | +23.74 | +13.40 |
| F90G10P3.0 | 1.23 | -24.07 | -27.22 | 1.96 | -10.50 | -18.00 |
| F90G10P3.5 | 1.20 | -25.93 | -28.99 | 1.85 | -15.53 | -22.60 |
| F90G10P4.0 | 1.01 | -37.65 | -40.24 | 1.46 | -33.33 | -38.80 |
| F90G10P4.5 | 0.92 | -43.21 | -45.56 | 1.33 | -39.27 | -35.00 |
| F90G10P5.0 | 0.87 | -46.30 | -48.52 | 1.26 | -42.47 | -47.28 |

**Table.4. Flexural strength results**

| Specimen ID | Flexural Strength (N/mm$^2$) | | | | | |
|---|---|---|---|---|---|---|
| | 7 days | % increase / decrease compared to | | 28 days | % increase / decrease compared to | |
| | | CC Prism | GP Prism | | CC Prism | GP Prism |
| CC Control Prism | 3.60 | - | -7.46 | 5.26 | - | -5.40 |
| F90G10P0 | 3.89 | +8.06 | - | 5.56 | +5.70 | - |
| F90G10P0.5 | 3.67 | +1.94 | -5.66 | 5.32 | +1.14 | -4.32 |
| F90G10P1.0 | 3.53 | -1.94 | -9.25 | 5.21 | -0.95 | -6.29 |
| F90G10P1.5 | 3.41 | -5.28 | -12.34 | 5.16 | -1.90 | -7.19 |
| F90G10P2.0 | 3.29 | -8.61 | -15.42 | 5.09 | -3.23 | -8.45 |
| F90G10P2.5 | 5.61 | +55.83 | +44.22 | 8.02 | +52.47 | +44.24 |
| F90G10P3.0 | 5.33 | +48.06 | +37.02 | 7.62 | +44.87 | +37.05 |
| F90G10P3.5 | 4.31 | +19.72 | +10.80 | 6.15 | +16.92 | +10.61 |
| F90G10P4.0 | 3.58 | -0.56 | -7.97 | 5.12 | -2.66 | -7.91 |
| F90G10P4.5 | 3.50 | -2.78 | -10.03 | 5.00 | -4.94 | -10.07 |
| F90G10P5.0 | 3.46 | -3.89 | -11.05 | 4.94 | -6.08 | -11.15 |

## VI. CONCLUSIONS

**From the experimental investigations carried out in this study, the following conclusions were drawn:**

- The mechanical properties of geopolymer concrete mixed with polypropylene fiber such as compressive strength, flexural strength, split tensile strength decreases with the increase in PP fibre and it is optimum at 2.5% of cementitous materials. Beyond 2.5% PP, the strength of the Geopolymer concrete decreases.
- In all the tests, the strength of GPC cubes, cylinders, prisms show enhanced strength, with PP mixed upto 2.5% of cementitous materials than the conventional M20 concrete.
- In compressive strength test, the specimen F90G10P2.5 (GP concrete with 2.5% PP fibre), the percentage increase in compressive strength was found to be highest. It was 14% and 72.24% when compared to conventional concrete and GP concrete respectively at 7 days. Similarly, it was 35.99% and 73.47% when compared to conventional concrete cube and GP concrete cube respectively at 28 days.
- Similarly, in split tensile strength test, the specimen F90G10P2.5, the percentage increase in split tensile strength is highest. It was 15.43% and 10.65% when compared to conventional concrete cylinder and GP concrete cylinder respectively at 7 days. Similarly, it was 23.74% and 13.40% when compared to conventional concrete cylinder and GP concrete cylinder respectively at 28 days.
- In a similar manner to Compressive strength and Split Tensile strength, in Flexure strength, the specimen F90G10P2.5, the percentage increase in flexural strength is highest. It was 55.83% and 44.22% when compared to conventional concrete prism and GP concrete prism respectively at 7 days. Similarly, it was 52.47% and 44.24% when compared to conventional concrete prism and GP concrete prism respectively at 28 days.
- It is possible to produce a concrete of rich grade of GPC using 10% GGBS and 90% fly ash and 2.5% PP fibers.
- Due to the high early strength, geopolymer concrete can be effectively used in the precast industries.
- This study can be extended to find the properties of Geopolymer concrete with other types of fibers.

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