# STRENGTH EVALUATION OF RETROFITTED GEOPOLYMER CONCRETE USING NATURAL FIBRE

**V. Sreevidya[1], M. Ponkishan[2]**

*[1]Associate Professor, [2]Post Graduate, Department of Civil Engineering, Sri Krishna College of Technology, Coimbatore, India*

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**Abstract** - *The paper presents an experimental study on a noval confining technique using natural fibre rope. Sisal is the natural fibre used which possess a good tensile strength, equips itself to resist the failures. This technique of confinement of sisal fibre along with the wrapping of chicken mesh helps to achieve greater strength and acts as an external strengthening reinforcement. Sisal fibre and chicken is manually confined on the respective members that are experimented without any impregnment of resins. Confining of concrete with fibre ropes leads to substantial upgradement of concrete. Their resistance against failures shows it can be used in constructions as retrofitting and as strength reinforcement members. The experimental method was carried for three categories – geopolymer concrete (GPC), GPC retrofitted without cracks GPC retrofitted with cracks. The results after interpretation concluded that the GPC retrofitted without cracks possesses greater resistance to failure and better efficiency.*

## 1. INTRODUCTION

Concrete is a major resource made by human kind for a developing civilization and has become the necessity for today's world. The main component of concrete being used is cement. Cement carries an important role since it is the binding material and its hydrating formula holds the concrete to give the desired strength. Although it has advantages in most of the parameters, it carries a huge disadvantage of carbon emission.

In recent years carbon emission due to cement production released around 8% of the global total where more than half was from calcinations process. Meanwhile, the growth of the coal-fired power plant industries produce greater amount of flue gases such as fly ash and bottom ash as waste products. Subsequently the use of such supplementary products along with silica fume, rice husk ash, granulated furnace slag and metakaolin etc in Portland cement is a step towards sustainability which reduced carbon emission over the last few years. This transition is now evolved into **Geopolymer** it is a binder with no cement.

### 1.1 Geopolymer Concrete

Geopolymers are materials that are formed by chemical actions of inorganic molecules which are eco-friendly and an alternative to Portland Cement concrete. It is a demand in current world as it reduces the carbon emission since no cement is used here. It is manufactured from the waste products such as fly ash and GGBS(ground granulated blast furnace slag).

Geopolymer is also known as alkali-activated cement or inorganic polymer cement. They are amorphous to semi crystalline equivalents of certain zeolitic materials which possess excellent properties such as high fire resistance, erosion resistance and high strength materials.

NaOH used here is an activator solution whose concentration is in the range of 8-14m. In recent years, geopolymer is the most researched topic due to their excellent characteristics including high compressive strength, fire resistance, immobilization of hazardous, toxic and radioactive wastes. Therefore, it is a concrete for a cleaner and sustainable environment.

### 1.2 Fibre Rope Confinement for Retrofitting

There are number of retrofitting techniques that are being followed by the construction industries over years. Some new techniques are now employed which are derived from the already existing techniques. Few such techniques are

a) Externally bonded Fibre Reinforced Polymer (FRP) Composites or Fibre Ropes
b) Ferrocement
c) Fibre Composites Plates and Tendons

In this research work Fibre rope and ferrocement are carried out to show the easy mechanism of retrofitting which gives higher flexural, shear, axial strengthening and ductility enhancement.

Fibre ropes have reduced mechanical fixing, gives good durability of strengthening system, improved fire resistance whereas, ferrocement possess good durability, stiffness, long term behaviour, fatigue behaviour, alkaline resistance. These advantages are put together to make an efficient retrofitting technique that will be economical and give the required strength in all parameters.

Natural fibre (Sisal) the chicken mesh are employed for this study where the natural fibre rope is confined over the damaged specimen and a layer of ferrocement is applied over the confinement as plastering to give it an even finish on the surface also adding to its strength. During the last decade there has been a greater interest on the natural fibres as a substitute for conventional FRP materials such as carbon fibres and glass fibres which are choosen for its potential advantages of weight saving, lower raw material price, and 'thermal recycling' and its ecological advantages of using resources which are renewable also natural fibres are sustainable materials.

One such natural fibre used in this research is Sisal Fibre. It is a renewable, easily available and cheap. It has also exhibited good tensile strength and can significantly improve the performance of concrete. It is easily cultivated. Sisal is a hard fibre extracted from the leaves of the sisal plant (Agave sisalana). These fibres have a good tension resistance. They have good resistance against heat. The chicken mesh is usually used same as the reinforcement of the concrete. It strengthens against the additional external force that gives a risk for shrink and movement cracks. Thus, using mesh here is to plaster around the fiber ropes which are confined around the cracked members. Mesh is being selected because of its reinforcement property and wide usage as plasters. This system of confinement and plastering over the cracked members acts as retrofitting.

### 1.3 OBJECTIVE OF THE PROJECT

- To study the compressive, split tensile and flexural strength of the retrofitted concrete with fibre rope confinement and mesh wrapping on geopolymer concrete.
- To make a comparative strength study of the retrofitted geopolymer concrete with the control geopolymer concrete.
- Interpretation and representation of the results.

## 2. LITERATURE REVIEW

**Theodoros C. Rousakis, (2014)** investigated on confining technique using fiber ropes made of vinyl on or polypropylene with different elastic modulus as external strengthening reinforcement without the impregnation of resin. The cylinders are confined with different confinement volumetric ratio. The research studies the effectiveness of the rope composite reinforcements considering the whole axial stress versus axial and lateral strain behaviour, also the failure values from monotonic or cyclic compressive loading of concrete cylinders. Thus concluding that confinement of fiber ropes on the concrete leads to substantial upgradement of concrete strain at failure reaching values of 13% strain along with the enhancement in its strength.

**Sandeep kumar L.S., Dr.H.N.Jagannatha Reddy, Rumina Nizar(2013)** studied the effect of retrofitting RC beams using natural silk fibre reinforced polymer having high impact strength inspite of having moderate tensile and flexural properties compared to other fibers. Material study shows that natural fibre (silk) helps in reduction of weight upto 10-30%, good impact properties, excellent acoustical absorption properties. The test investigation was a comparative study of control beam with the retrofitted beam behaviour in tension and flexure zone.

**Suhelmidawati ETRI, Muneyoshi NUMADA, Kimiro MEGURO, (2015) enquired** the strength parameters of Unreinforced masonry (URM) walls by retrofitting it with Fibre Reinforced Mortar(FRM) and Abaca Rope Mesh(ARM) Subjected to diagonal Compression test. The diagonal compression test results, Abaca fiber performed a high tensile strength of 957MPa which concludes FRM and ARM can increase strength and deformation capacity of masonry wallets their retrofitting had high potential for retrofitting.

**QudeerHussain, Kraisornwongsopit and Pichayut Jarusbumrungroj, Sharukh Shoaib, (2017)** carried out an experimental investigation to find out the axial behaviour of natural rope confined concrete. Confined and un-confined concrete columns were tested under monotonic axial compression. The results indicate that the rope confinement was very effective to enhance ultimate strength and strain of confine concrete. The confinement level with higher thickness or which was confined with more layers had a greater effect on strength and ductility of the concrete.

**Shamim A. Sheikh, (2001) Performance** of concrete structures retrofitted with fibre reinforced concrete was studied. Tests on full-size models of wall-slabs, beams and columns were carried out to evaluate the effects of using external FRP reinforcement. Wall-slab specimens were repaired to improve their flexural resistance and the beam specimens were retrofitted for shear enhancement. It is concluded that retrofitting with FRP gives a feasible rehabilitation technique for repair and strengthening. FRP reinforcing is very effective in enhancing flexural strength of the damaged slabs, shear resistance of the damaged beams and seismic resistance of columns.

**Kurt Lembo, Weena Lokuge, Warna Karunasena, (2014)** This research investigates structural performance of geopolymer concrete with FRP wrapping (Carbon Fibre Reinforced Polymer and Glass Fibre Reinforced Polymer). Twenty geoploymer concrete samples (ten 100×200 mm and ten 150×300 mm) were casted. It was observed that both CFRP and GFRP confinement are effective in improving the strength and ductility of geoploymer concrete. FRP confinement is equally effective on large geoploymer cylindrical samples as the smaller counterparts. The outcomes of this study can be used to improve the design and development of geopolymer concrete and FRP technologies. Thus, aiding sustainable construction methods.

**Theodoros C. Rousaki, (2013)** studied the hybrid confinement of concrete by FRP sheets and fibre ropes under cyclic axial compressive loading. Thus, the mechanical behaviour of concrete lightly confined by glass fibre reinforced polymer (FRP) sheets and polypropylene fibre ropes (PPFRs) are studied. PPFRs have ultrahigh deformation at failure. They included confinement of one layer of glass FRP and fibre ropes in different volumetric ratios. The outcome evaluates the axial stress versus axial and lateral strain behaviour of the columns. This shows that the fibre ropes ensures increased axial strain (higher than 5%) and dissipated energy of concrete. The load shows temporary yet controlled loss, followed by an increase in further loading.

**Mohana Rajendran and Nagan Soundarapandian, (2013)** investigates the flexural behaviour of thin cement and fewer composite panels reinforced with welded rectangular wire mesh and chicken mesh with varying number of mesh layers along with varying concentrations of alkaline solution. A total of 30 panels has been tested under flexural loading. It was concluded that the cracks were less and the crack space of geopolymer fereocement panels was less conpared to the control concrete. Also it was noted that the compressive strength of the geopolymer specimens increases with increase in the molaritt of the alkaline solution.

**Chau-KhunMa, Nazirah Mohd Apandi, Sofrie Chin Siew Yung, Ng Jen Hau, Lo Wen Haur, (2016)** reviewed on the use of confinement as a repairing technique along with the study of design and installation processes involved. It was found that the confinement repair techniques are effective as they restore the original capacities of damaged concrete members.

**Rajagopal Vadivambal, Vellaichamy Chelladurai, Fuji Jian and Digvir S.Jaya, (2015)** experiments the elongation and the tensile strength of hemp and sisal ropes of varying diameters (6, 8 and 10 mm) at different temperatures ranging from 40$^0$C to 60$^0$C. Temperature and humidity sensor-cables used in grain bins are made of steel or synthetic materials. The potential use of natural fibres as cables was tested. It was noted that the tensile strength of the fibres examined was not significantly affected by freezing temperatures but was lowered at 60$^0$C and did not increase linearly with increase in diameter.

**Rajashekhar Siddappa Talikoti and Sachin Balkrishna Kandekar, (2019)** investigated the durability of aramid-fibre-wrapped and unwrapped concrete cube specimens subjected to acid attack and temperature rise by considering the compressive strength of the concrete cube. Concrete cubes were prepared with double wrapping of aramid fibres. Diluted hydrochloric acid solution was used in curing technique for a period of 7, 30 and 70 days. This showed that aramid-fibre wrapping reduced the weight loss by 40% and improved compressive strength by 140%. It also gave good resistance to fire.

**Abass Abayomi Okeola, Silvester Ochieng Abuodha and John Mwero (2018)** experimented on physical and chemical properties of sisal fibre reinforced concrete. Sisal fibres were added at 0.5% to 2% in an increment of 0.5 by the weight of cement. From the study it was concluded that the sisal fibre can enhance the split tensile strength and young's modulus of concrete but cannot enhance its compressive strength, workability and water absorption.

## 3. MATERIALS USED

### 3.1 Fly Ash

Fly ash is a by-product of combustion of pulverized coal in the thermal power plants. In modern coal-fired power plants. Fly ash is the collection of ashes that are captured before the flue gases reach chimneys. Fly ash is a pozzolan which is a substance that contains aluminous and siliceous material that gives cementitious properties in the presence of water.

**Table-1:** Properties of Fly Ash

| Properties | Test results |
|---|---|
| Specific gravity | 2.16 |
| Consistency | 29% |

### 3.2 Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag is obtained from molten iron slag. It has hydraulic properties and blends well in concrete which increases the strength and durability of the concrete structure. It reduces voids in concrete and hence reducing permeability. It also gives a workable mix.

### 3.3 Sisal Fibre

Sisal fibre is fully biodegradable, green composites that are fabricated with soy protein resin modified with gelatin. It is a highly renewable resource of energy. It is durable and low maintenance with minimal wear and tear. It is a stiff fibre manufactured from the vascular tissue of the sisal plant (AGAVESISALANA) traditionally used in making rope, twine and also dartboats. It is used in automotive friction parts, where it imparts green strength for better performance and for enhancing texture in coating applications.

**Table-2:** Chemical Composition of Sisal Fibre

| Chemical Composition | Percent age |
|---|---|
| Cellulose | 65% |
| Hemicelluloses | 12% |
| Lignin | 9.9% |
| Waxes | 2% |

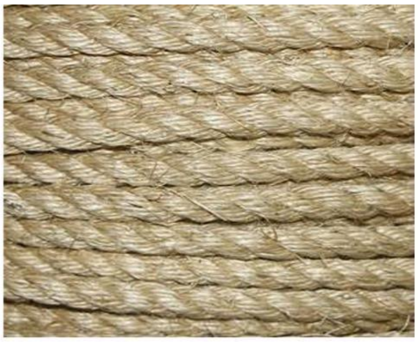


**Fig-1:** Sisal Fibre Rope

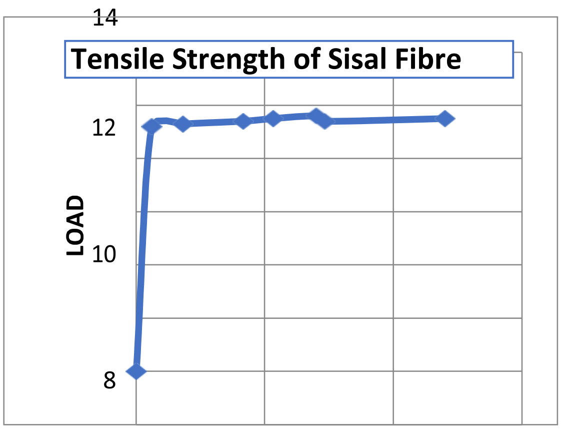



**Chart-1:** Graph showing tensile strength of Sisal fiber rope

### 3.4 Chicken Mesh

The chicken mesh here is used as a material for retrofitting along with sisal fibre rope. This also acts as a material for plastering to give a smooth finish over the confined layer of rope. Chicken wire mesh is formed by two adjacent wires to form a strong honey comb mesh. This structure gives high strength and durability. The hexagonal shape of chicken mesh prevent the formation of internal stresses. Due to its flexible nature it is convenient for wrapping it over the curved and angled surfaces. Other advantages are its twisted mesh improves corrosion resistance. These properties make it a suitable material for retrofitting, plastering, leveling floors and façade works. The properties of the chicken wire mesh are listed belo

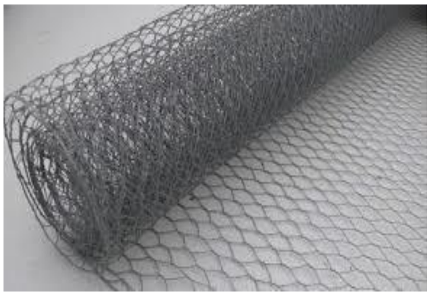


**Fig-3: Chicken Wire Mesh**

**Table-3:** Properties of wire mesh

| Properties | Value |
|---|---|
| Size of Mesh wire | 25mm |
| Grade of Steel | Fe250 |
| Yield Strength | 400 $N/mm^2$ |
| Ultimate Strength | 511.36 $N/mm^2$ |
| Percentage elongation at failure | 2.52% |

### 3.5 SODIUM HYDROXIDE

Sodium hydroxide is a base and alkali that decomposes proteins at ordinary ambient temperatures and may cause severe chemical burns. It is highly soluble in water and readily absorbs moisture and carbon dioxide from the air. Sodium hydroxide solution is a colourless liquid. It is denser than water. Direct contact may severely irritate skin, eyes, and mucous membranes. It is toxic by ingestion and corrosive to metals and tissue. At room temperature, sodium hydroxide is a white crystalline odorless solid that absorbs moisture from the air.

### 3.6 SODIUM SILICATE

Sodium silicate is a generic name for chemical compounds with the formula Na 2xSiO 2+x or (Na 2O) x·SiO 2, such as sodium metasilicate Na2SiO3, sodium orthosilicate Na 4SiO4, and sodium pyro silicate Na 6Si 2O 7. The anions are often polymeric. They are colourless transparent solids or white powders and soluble in water.

Sodium Silicate is produced by melting high purity sand with sodium carbonate (soda ash) in high temperature. The resulting product is a water-soluble silicate powder which is known as water glass or sodium silicate solution once it is dissolved in water. The sodium silicate has a weight ratio of 3.22 (SiO2:Na2O), which breaks down as ~28.7% silica (SiO2) to ~8.9% sodium oxide (Na2O), and that translates into a solution that is approximately 37.5% sodium silicate by weight in water.

### 3.7 MANUFACTURE SAND

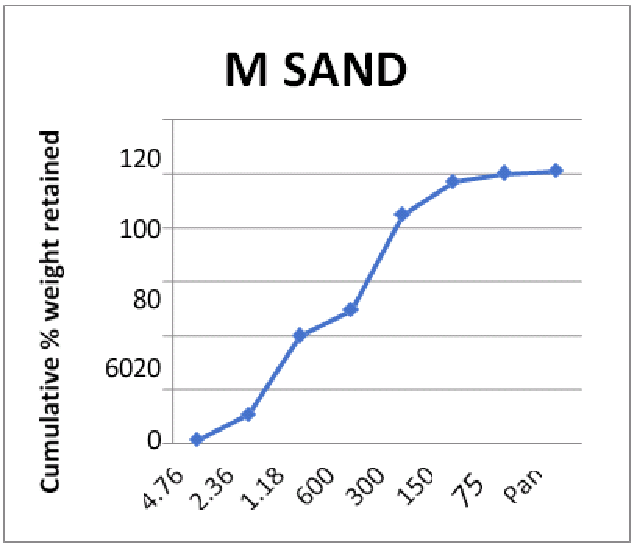
Manufacture sand is an alternative of river sand. It is obtained from crushing the hard granite rocks. It is free from dust and hence it meets the required grading for all constructions. The sand have particle size from 150 microns to 4.75mm in proper proportion. The demand for M sand has increased tremendously due to fast growing construction using M Sand. Transportation cost of M Sand has become economical.

**Table-4: Properties of M Sand**

| Propertie s | Test results |
|---|---|
| Specific gravity | 2.34 |
| Fineness Modulus | 4.8 |

**Fig-4:** Manufacture Sand

### 3.8 COARSE AGGREGATE




**Sieve size**

Coarse aggregates can be round, angular, or irregular shape. The coarse aggregate grading limits are given in IS 383-1970, table 2, Clause 4.1 and 4.2 for single size aggregate and grated aggregate. The grading of coarse aggregate is important to achieve cohesive and concrete. The voids created by larger coarse aggregate particles are filled by smaller coarse aggregate particles and so on. This way the volume of mortar required to fill the final voids is minimum. By proper grading the possibility of segregation is reduced, especially for higher workability. Proper grading of coarse aggregates also improves the compatibility of concrete.

**Table-5: Properties of coarse aggregate**

| Property | Value |
|---|---|
| Specific Gravity | 2.74 |
| Finesses Modulus | 6.94 |

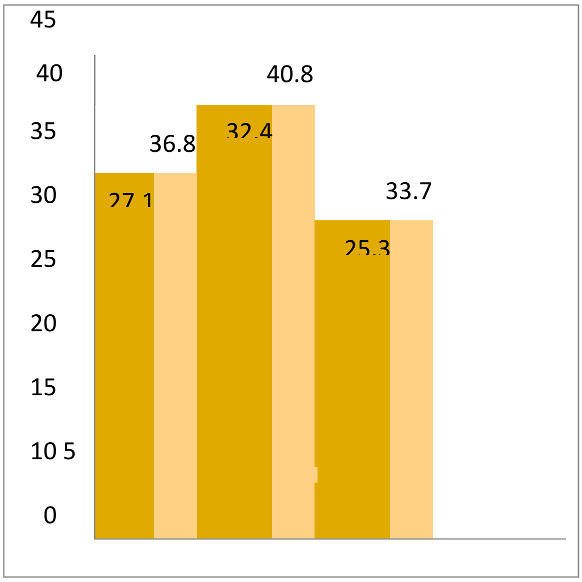
### 3.9 RECYCLED AGGREGATE:

Recycled aggregate is a concrete made with recycled concrete aggregates instead of natural aggregates. They are received from clean concrete waste where constitutes other than building waste must be very low. The addition of recycled aggregates over natural aggregates can be 100% or partial according to the research purpose and the nature of source of recycled aggregates.

**Fig-5: Recycled Aggregates**

## 4. MIX DESIGN

There is no standard mix design for geopolymer concrete. Yet a mix design was designed with the tireless efforts of




various researchers. Various journals were referred to follow certain guidelines for geopolymer concrete incorporating natural fibres as retrofitting techniques.

**Table-6: Mix Proportions**

| | |
|---|---|
| Quantity of Fly Ash (kg) | 425 |
| Solution / Binder Ratio | 0.45 |
| Quantity of NaOH Pellets (kg) | 21 |
| Quantity of NaOH Solution (l) | 138 |
| Quantity of $Na_2SiO_3$ Solution (l) | 55 |
| Quantity of Fine Aggregate (kg) | 630 |
| Quantity of Coarse Aggregate (kg) | 1249 |
| Mix Binder Ratio : F.A : C.A | 1:1.45:2.95 |

## 5. RESULTS AND DISCUSSION

### A. COMPRESSIVE STRENGTH

Compressive Strength of M30 grade concrete at 7th and 28th days strength is given below.

**Table-7: Compressive Strength**

| Casting Members | Compressive Strength ($N/mm^2$) | |
|---|---|---|
| | 7th day | 3 28th day |
| Conventional | 27.1 | 36.8 |
| Retrofitting without Crack | 32.4 | 40.8 |
| Retrofitting with Crack | 25.3 | 33.7 |

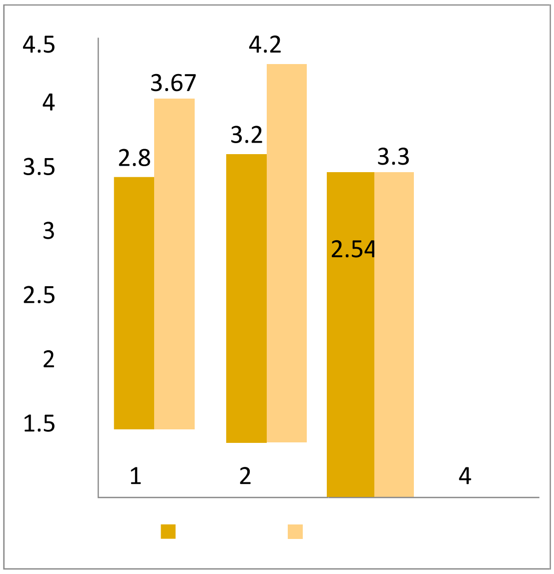



**Fig-6: Compressive strength**

- Compressive strength increases when concrete is retrofitted without crack compared to conventional geopolymer concrete.
- In case of concrete retrofitted with crack compressive strength decreases when compared to conventional geopolymer concrete and concrete retrofitted without crack.

### A. SPLIT TENSILE STRENGTH

Split tensile Strength of M30 grade concrete at 7th and 28th days strength are given below.

**Table VIII Split Tensile Strength**

| Casting Members | Split Tensile Strength ($N/mm^2$) | |
|---|---|---|
| | 7th day | 28th day |
| Conventional | 2.8 | 3.67 |
| Retrofitting without Crack | 3.2 | 4.2 |
| Retrofitting with Crack | 2.54 | 3.3 |

**Fig. 6. Tensile strength**

- Split tensile strength increases when concrete is retrofitted without crack compared to conventional geopolymer concrete.
- In case of concrete retrofitted with crack split tensile strength decreases when compared to conventional geopolymer concrete and concrete retrofitted without crack.

### B. FLEXURAL STRENGTH

Flexural Strength of M30 grade concrete at 28th days strength is given below.

**Table IX Flexural strength**

| Casting Members | Flexural Strength ($N/mm^2$) |
|---|---|
| Conventional | 13.26 |
| Retrofitting without Crack | 14.76 |
| Retrofitting with Crack | 11.82 |

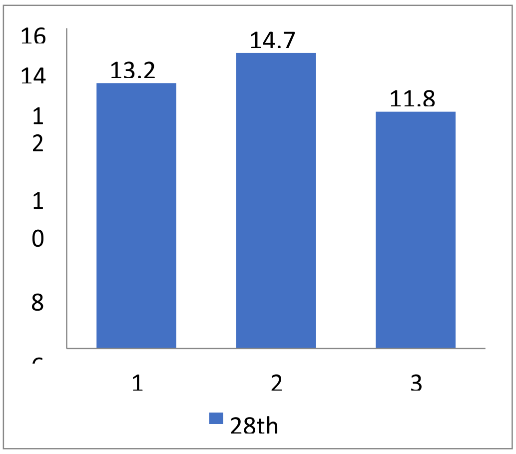



**Fig. 7. Flexural Strength**

- Flexural strength increases when concrete is retrofitted without crack compared to conventional geopolymer concrete.

- In case of concrete retrofitted with crack flexural strength decreases when compared to conventional geopolymer concrete and concrete retrofitted without crack.

## 6. CONCLUSIONS

The following conclusions can be inferred from the above results and discussions obtained in this study. Compressive strength increases the strength of concrete in case of concrete retrofitting without crack from 27.1MPa to 32.4Mpa at 7th day and 36.8MPa to 40.8MPa at 28th day.

- In case of split tensile the strength increases for concrete retrofitting without crack from 2.8MPa to 3.2MPa at 7th day and from 3.67MPa to 4.2MPa at 28th day.
- In case of flexural the strength increases for concrete retrofitting without crack from 13.26MPa to 14.76MPa.
- Thus, the concrete retrofitting with crack obtains minimum strength compared to retrofitting without crack.
- It was concluded that retrofitting without crack attains maximum strength in compressive strength, split tensile strength and flexural strength.
- The retrofitted concrete with crack shows nearer strength to the conventional geopolymer concrete indicating that this type of retrofitting is much beneficial and can be implemented on cracked members to regain their characteristics strength.
- As the member retrofitted without crack has showed much greater strength, this technique can be practiced in structures where additional strength is necessary.

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