"Development of Polymerized Concrete with Addition of Jute Fiber"

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Abstract - *Fiber Reinforced Polymer Concrete (FRPC) is a relatively modern approach towards the conventional concreting techniques. It possesses excellent strength and durability properties at later age. Looking into the various advantages of Polymer Concrete (PC) and an attempt has been made to present review on polymer modified concrete dosed with Styrene Butadiene Rubber (SBR) Latex polymer & Low cost Jute fibers. The fibers used in this study are ordinary natural jute fiber. The motive of this project is to find out the optimum quantities of the jute fiber and SBR-latex polymer in the concrete mix. For achieving the optimized compressive and flexural strength results for M30 grade concrete tests has been performed.*

From the research work it is observed that in conventional cement concrete, introduction of fiber with polymer in a suitable combination may potentially not only improve the mechanical properties and strength but may also result in its performance synergy. Slump value based workability follows reverse linear trend and has maximum value 77 mm at 2% fiber and 5% polymer. The best result in compressive as well as flexural strength was obtained for 4% jute fiber and 10% SBR latex polymer based concrete matrix.

Keywords: *FRPC, SBR Latex, Low-cost Jute Fibers, Fiber Reinforce Concrete*

1. INTRODUCTION

The design of a durable and low cost fiber reinforced cement concrete for building construction is a technological challenge in developing countries. The type of fibers currently been used include steel, glass, polymers, carbon and natural fibers. Economic considerations have restricted the use of carbon fibers in cementitous composites on a commercial level for their non ecological performance. Natural fibers contain the prospective to be utilized as reinforcement to overcome the inherent deficiencies in cementitous materials. Extensive researches has been carried out for exploiting the reinforcing fibers like jute, bamboo, sisal, akwara, coconut husk, sugarcane, baggasse in cement composites mostly in case of building materials. Making use of naturally available fibers in a relatively brittle cement matrix has achieved substantial strength, durability and toughness of the composite matrix. The durability of natural organic fibers in a highly alkaline cement matrix must be taken into concern by effective modifications. A precise chemical composition has to be preferred that be capable of modifying the fiber surface as well as strengthening the cement composite.

Chemicals like polymer modified jute fibers was ultimately selected as the most ideal reinforcing element in cement concrete in which polymer will chemically bridge jute in one side and cement on the other side. Polymer modified jute fibers are anticipated to act as a flexible reinforcing agent in concrete enabling it to convey both static and dynamic stresses to its surrounding bulk as well as absorb a portion of the stress by virtue of its flexible nature. An optimized mass fraction of polymer modified jute fiber in cement concrete may lead to admirable mechanical properties. It has been anticipated that variation of jute fiber with polymer will reduce degradation possibilities.

1.1 Classification of Fibers

Concrete cracking is normal, Plastic shrinkage occurs when the evaporation loss of water from the surface of concrete is larger than the rising bleed or internal water. This results in a tensile stress being developed in hardened concrete, again causing the concrete to crack & disintegrate. Cracks lead to negative perception of quality, durability and serviceability, however in most cases they become only aesthetic problems. Cracks also results in disputes between the owner, Architect, design Engineer and contractor which results in job delays and cost increases due to work stoppages and evaluation which is more severe than the actual consequences of cracking.

The use of fibers help in modifying properties of concrete both in plastic and hardened stage and thus results into a more durable concrete. Introduction of synthetic fibers into the concrete mass helps in reducing thermal and shrinkage cracks. Addition of steel fibers enhances the ductility performance, post-crack tensile strength, fatigue strength and impact strength of concrete structures.

Fibers can be either naturally available or artificially manufactured based on their nature of availability, they are classified as follows:

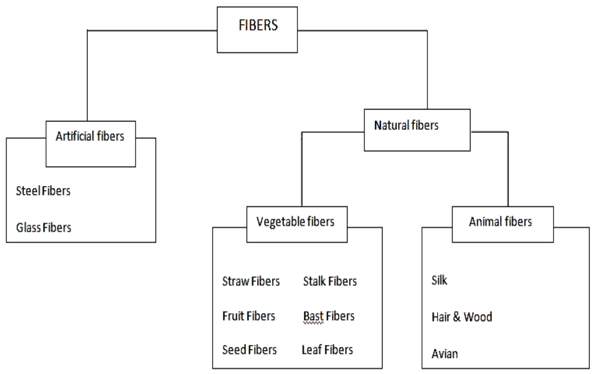

Fig. – 1: Classification of Fibers

Table – 1: Effect of Aspect Ratio on Concrete Strength

S. No	Property	Range of Values
1	Fiber Length (mm)	180 – 800
2	Fiber Diameter (mm)	0.10 - 0.20
3	Specific Gravity	1.02 - 1.04
4	Bulk Density (kg/m3)	120 – 140
5	Ultimate Tensile Strength (N/mm2)	250 – 350
6	Modulus of Elasticity (kN/mm2)	26 – 32
7	Elongation at Fracture ($)	2 – 3
8	Water absorption (%)	15–25

1.2 Effect of Fiber Addition to Concrete.

The quantity of fibers added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed as Volume fraction (V_f). V_f typically ranges from 0.1 to 3%. Aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d) as known from previous research work. Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the modulus of elasticity of the fiber is higher than that of the matrix, they help to carry the load by increasing the tensile strength of the material. Increase in the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers which are too long tend to "ball" in the mix and create workability problems.

1.3 Factors affecting the properties of FRC.

i. **Relative Fiber Matrix Stiffness**: The modulus of elasticity of concrete matrix should be preferred to be less than that of fiber for efficient stress transfer. Fiber having lower modulus such as nylons and polypropylene are, consequently, doubtful to give strength development, but the help in the absorption of large energy and therefore, impart greater degree of toughness and resistance to impact.

ii. **Orientation of Fibers:** A main difference between conventional reinforcement and fiber reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while fibers might be aim minimum oriented.

iii. **Aspect Ratio of the Fibers:** Another important factor which influences the properties and behavior of the composite is the aspect ratio of the fiber. It has been reported that up to aspect ratio of 75, increase on the aspect ratio increases the ultimate strength of concrete linearly. Beyond 75, relative strength and toughness is reduced.

iv. **Workability and Compaction of Concrete:** Incorporation of steel fiber decreases the workability considerably. This condition unfavorably affects the compaction of green concrete mix. Even prolonged peripheral vibration fails to compact smoothly and increment in density of the concrete. The fiber volume at which this situation is reached depends on the length and diameter of the fiber i.e. Notch ratio.

v. **Volume of Fibres:** The strength of the mix matrix largely depends on the quantity of fibers used in it. The effect of volume on the toughness and strength characteristics. It is viewed that the increase in the volume of fibers, increase approximately linearly, the tensile strength and toughness of the composite. Utilization of higher percentage of fiber is probable to originate segregation and harshness of concrete and mortar.

vi. **Size of Coarse Aggregates:** Maximum size of the coarse aggregate should be restricted to 20mm, to avoid appreciable reduction in strength of the composite. Fibers also in effect, act as aggregate. Although aggregate encompass a simple geometry, their influence on the properties of fresh concrete is complicated.

vii. **Mixing:** Jute fiber content in excess of 2% by volume and aspect ratio of more than 100 are difficult to mix. It is important that the fibers are dispersed uniformly throughout the mix; this can be done by the addition of the fibers before the water is added. While mixing in a controlled way via; laboratory mixer, introducing the fibers through a wire mesh basket will assist even distribution of fibers. For casting in site or field use, other suitable methods must be adopted.

2. LITERATURE REVIEW

The idea of using cellulose fibers as reinforcement in composite materials is not a new or recent one. Man had used this idea for a long time, since the beginning of our civilization when grass and straw were used to reinforce mud bricks. In the past, composites, such as coconut fiber/natural rubber latex, was extensively used by the automotive industry. However, during the seventies and eighties, cellulose fibers were gradually substituted by newly developed synthetic fibers because of better performance. Since then, the use of cellulose fibers has been limited to the production of rope, string, clothing, carpets and other decorative products.

Over the past few years, there has been a renewed interest in using these fibers as reinforcement materials to some extent in the plastics or synthetic industry. This resurgence of interest is due to the increasing cost of plastics, and also because of the environmental aspects of using renewable and biodegradable materials.

Table – 2: Mechanical Properties of some Cellulose Fibers [7]

Fiber	Diameter (μm)	Density (g/cm^3)	Moisture content (%)	UTS[1] (MPa)	Modulus (GPa)
Cotton		1.5		500-880	0.05
Jute	200	1.45	12	460-533	2.5-13
Coir	100-450	1.15	10-12	131-175	4-6
Banana	80-250	1.35	10-12	529-754	7.7-20.8
Sisal	50-200	1.45	11	568-640	9.4-15.8
Flax		1.50		1100	100
Kraft fiber		1.54		1000	40
Sunhemp	48	0.673		200-300	2.68
Pineapple	20-80	1.44		413-1627	34.5
Palm leaf	240			98.14	2.22
Mesta	200	1.47		157.38	12.62
Kusha grass	390			150.59	5.69

[1] Ultimate tensile strength

Unlike brittle fibers, such as glass and carbon fibers, cellulose fibers are flexible and will not fracture when processed over sharp curvatures [15]. This enables the fibers to maintain the desired aspect ratio for good performance. Their non-abrasive nature permits a high volume fraction of filling [1], [2], [12], [14], [16], [19] &[22] during processing, and this results in high mechanical properties without the usual machine wear problems associated with synthetic fibers especially glass and ceramic.

Cellulose fibers are also non-toxic [17], easy to handle and present no health problems like glass fibers that can cause skin irritations and respiratory diseases when the fibrous dust is inhaled [2]. They offer a high ability for surface modification [25], are economical, require low amounts of energy for processing [24] & [14], and are biodegradable [23], [20] & [17]. In terms of socio-economic issues, the use of cellulose fibers as source of raw materials is beneficial.

Table – 3: Annual Fiber Production in India / Worldwide [19]

Fiber	India	World	Cost (U.S. $ / kg)
Coir	160,000	282,000	0.03
Banana	1632	100,296	0.10
Sisal	3000	600,000	0.05
Palmyrah	100	Not known	0.07
Pineapple	Not estimated	Not estimated	0.05
Glass			0.33
Carbon			> 16.00
Stainless steel			> 4.00

Despite the advantages mentioned above, use of cellulose fibers in thermoplastics has not been extensive. Possible reasons that contribute to unsatisfactory final properties of the composite include:

(i) Limited thermal stability at typical melt processing temperatures of about 200 ^{0}C. This limits the type of thermoplastic that can be used with the fibers [7] & [30].
(ii) Poor dispersion characteristics in the non - polar, olefinic thermoplastic melt due to strong hydrogen forces between the fibers [7] & [17].
(iii) Limited compatibility with many thermoplastic matrices [1], [13] & [14] due to their highly hydrophilic character. This result in poor mechanical properties of the composites produced.
(iv) High moisture absorption of the fibers that can affect the dimensional stability of the composite [5] & [19] and the interfacial bond strength.
(v) High biodegradability when exposed to the environment. This limits the service life of composites particularly in outdoor applications.

There are many reports on the potential use and limitation of cellulose fibers as reinforcement in thermoplastics available in the literature. These studies show that the problems mentioned above are common, independent of the type and origin of the fiber employed [3]. Other factors that may hamper increased use of cellulose fibers in plastics are problems and costs associated with the collection and storage which are not yet mechanized and standardized to produce fibers of high and uniform quality.

3. METHODOLOGY

Due to the rapid growth in construction and technology sector, the expectations from the mould able construction materials like concrete have been increased manifold. It is now a challenge for all the civil engineers to further increase the properties of concrete like strength, durability and to reduce the hairline cracks without much increase in the overall cost of the material. The experimental studies that have been carried out on concrete specimen prepared by mixing jute fibers and SBR Latex polymer on M30 grade concrete make it possible for us to determine the actual enhancement in the properties of the concrete on the addition of fibers in different proportions.

Table – 3: Batch Description – for concrete matrix.

Batch Designation		Grade of Concrete	Mix Proportions Adopted	Jute Fibers (%)	Polymer (%)
Title	Type of Concrete				
S1	Conventional	M30	1 : 1.729 : 2.45	0	0
S2	Fiber Reinforced Polymer Concrete			2	5
S3				2	10
S4				2	15
S5				2	20
S6				4	5
S7				4	10
S8				4	15
S9				4	20
S10				6	5
S11				6	10
S12				6	15
S13				6	20
S14				8	5
S15				8	10
S16				8	15
S17				8	20
S18				10	5
S19				10	10
S20				10	15
S21				10	20

Table – 4: Properties of cement used in the study.
(Source-Specifications given as per the ACC cement manufacturing company)

Physical Properties	IS: 12269 – 2013 specifications
Soundness	10mm
Fineness	225m²/kg
Compressive Strength F_{ck} 28-days	53.0 MPa
Specific gravity	3.15
Autoclave Expansion	10 mm

Table – 5: Properties of Aggregates used in the Study

Physical Properties of Aggregates	Coarse aggregates	Fine aggregates
Specific gravity	2.71	2.54
Fineness modulus	6.86	2.68
Bulk density (kg/m³)	1580	1760

Styrene Butadiene Rubber (SBR): Latex Polymer: Locally available polymer 'Cemseal Cementone' was investigated in this study. It is a type of Styrene Butadiene Rubber (SBR) latex. The composition of the Cemseal Cementone used as polymer is given in Table 3.4. Cemseal Cementonex SBR is based on Styrene Butadiene Rubber, special adhesive and bonding chemicals along with hydrophilic agents. Cemseal Cementonex SBR gives a versatile performance in many civil engineering applications. The product is a milky white liquid.

Table – 6: Properties of Polymer Used (SBR)

Type	Styrene Butadiene Rubber
Form	White Liquid
Density	1 kg/L at 25 ⁰C
Solid Content	50 %
Chloride Content	50 %

Jute Fibers: Jute has high specific properties, low density, less abrasive behavior to the processing equipment, good dimensional stability and harmlessness. Being made of cellulose, on combustion, jute does not generate toxic gases.

Due to jute's low density combined with relatively stiff and strong behavior, the specific properties of jute fiber can be compared to those of glass and some other fibers. It has a typical density of 1.3 g/cm³, elongation of 1.5 - 1.8 %, tensile strength of 393 - 773 MPa and Young's modulus of 6.5 GPa.

Jute fiber used in the study are cut in the length of 1 inch (2.54 cm) having diameter of approximately 1 mm measured with the help of Venire scale.

3.1. Mix Design of SBR latex based Concrete.

1. Determining the Target Strength for Mix Proportioning
$f'_{ck} = f_{ck} + 1.65 \times S$
$f'_{ck} = 30 + 1.65 \times 5.0 = 38.25$ N/mm²

2. Selection of Water-Cement Ratio
From Table 5 of IS: 456 - 2000, Maximum water-cement ratio = 0.45, Here taking water-cement ratio = 0.42 Say; for polymers addition.

3. Selection of Water Content
a. Maximum water content for 20 mm aggregate upto 0.45 = 186 Kg (for 25 to 50 slump), here targeting slump of 80mm, we need to increase water content by 3% for every 25mm above 50 mm i.e. increase 6% for 100mm slump.
b. Here take water-cement ratio = 0.42
c. So taking increase in water content = 4% i.e. Estimated water content for 80 mm Slump = 173.6 + (4 × 173.6/100) = 180.544 litre
d. Water content = 180.544 litres.

4. Calculation of Cement Content
a. Water cement Ratio = 0.42

b. Water content from step - 3 i.e. 180.544litres
c. Cement Content = Water content / w-c ratio" = (180.544/0.42) = 429.867 kg/m^3
d. From Table 5 of IS 456, Minimum cement Content for severe exposure = 320 kg/m3, i.e. 429.867kg/m^3> 320 kg/m^3,
e. Hence, Ok. As per clause 8.2.4.2 of IS: 456
f. Maximum cement content = 450 kg/m^3, hence Ok.

5. Estimation of SBR latex 5/100 x 429.867= 21.493 = 21.5 kg/m^3(say) As the specific gravities of the polymer and water are 1.01 and 1.00 respectively.
   Slump control factor = (21.5/1.01) + (180.544/1.00) = 201.83 kg/m^3.
   Since the total solids of the SBR latex are 47.2%, the required amount of latex is 21.5/0.472 = 45.55 kg/m^3 In which water content is 24.05kg. Therefore net mixing of water = 180.544– 24.05= 156.594 kg/m^3

6. Proportion of volume of Coarse Aggregate and Fine Aggregate Content
a. From Table 3 of IS 10262- 2009, Volume of coarse aggregate corresponding to 20 mm size and fine aggregate (Zone II) = 0.62 @ 0.5 w/c ratio; here it will 0.64 (say) for 0.42 w/c ratio

7. Estimation of concrete mix proportion calculations per unit volume
   i. Volume of concrete = 1 m^3
   ii. Volume of cement = (Mass of Cement) / (Sp. Gravity of Cement)x1000, b = (429.867) / (3.15 × 1000) = 0.136 = 0.14 m^3
   iii. Volume of water = (Mass of Water) / (Sp. Gravity of Water)x1000, c = (156.594) / (1 × 1000) = 0.157 m^3
   iv. Volume of SBR = 0.05 m^3
   v. Total Volume of Aggregates d= 1- (b+c+d) = 1- (0.14 + 0.157 + 0.05) = 0.653=0.7 m^3
   vi. Mass of coarse aggregates = d × Volume of Coarse Aggregate × Specific gravity of Coarse Aggregate × 1000 = 0.7 × 0.64 × 2. 71 × 1000 = 1214.08 kg/ m^3
   vii. Mass of fine aggregates = d × Volume of Fine Aggregate × Specific Gravity of Coarse Aggregate × 1000 = 0.7× 0.36×2.68 × 1000 = 675.36 kg/ m^3

4. RESULTS & DISCUSSIONS

The behavior of all the prepared concrete matrix 21 Nos. batches is taken as a basic study on the modeled structure. The basic tests were conducted in lab for evaluating the most wanted performance as shown in Tables that follows below of all the batches and presented a comparative study.

Table – 7: Tests Results of Constant Jute Fibers w.r.t SBR – Polymer.

Specimen	Jute fibers (%)	Polymer (%)	Slump (mm)	Compaction Factor	Compressive Strength (N/mm^2)		Flexural Strength (N/mm^2)
					7 Days	28 Days	28 Days
S1	0	0	64	0.88	24.89	38.67	4.45
S2	2	5	68	0.89	27.78	42.89	4.59
S3		10	70	0.90	30.44	46.22	4.79
S4		15	73	0.92	29.78	44.44	4.69
S5		20	77	0.94	28.44	42.00	4.55
S6	4	5	63	0.87	29.78	46.00	4.76
S7		10	65	0.88	32.89	49.11	4.94
S8		15	68	0.90	32.22	48.00	4.84
S9		20	71	0.92	31.56	46.22	4.75
S10	6	5	59	0.85	29.56	45.33	4.70
S11		10	61	0.86	31.78	47.78	4.84
S12		15	63	0.88	30.67	46.00	4.74
S13		20	66	0.89	29.78	43.11	4.65
S14	8	5	56	0.83	27.11	42.89	4.60
S15		10	58	0.84	29.11	45.33	4.72
S16		15	60	0.86	27.33	42.22	4.55
S17		20	62	0.87	26.67	41.78	4.51
S18	10	5	51	0.81	26.89	42.44	4.57
S19		10	52	0.82	27.56	43.11	4.61
S20		15	54	0.84	25.78	39.56	4.42
S21		20	56	0.85	23.78	37.33	4.28

Table – 8: Tests Results of Constant SBR – Polymer w.r.t Jute Fibers.

Specimen	Polymer (%)	Jute fibers (%)	Slump (mm)	Compaction Factor	Compressive Strength (N/mm^2)		Flexural Strength (N/mm^2)
					7 Days	28 Days	28 Days
S1	0	0	64	0.88	24.89	38.67	4.42
S2	5	2	68	0.89	27.78	42.89	4.59
S6		4	63	0.87	29.78	46.00	4.76
S10		6	59	0.85	29.56	45.33	4.70
S14		8	56	0.83	27.11	42.89	4.60
S18		10	51	0.81	26.89	42.44	4.57
S3	10	2	70	0.90	30.44	30.44	4.79
S7		4	65	0.88	32.89	49.11	4.94
S11		6	61	0.86	31.78	47.78	4.84
S15		8	58	0.84	29.11	45.33	4.72
S19		10	52	0.82	27.56	43.11	4.61
S4	15	2	73	0.92	29.78	44.44	4.69
S8		4	68	0.90	32.22	48.00	4.84
S12		6	63	0.88	30.67	46.00	4.74
S16		8	60	0.86	27.33	42.22	4.55
S20		10	54	0.84	25.78	39.56	4.42
S5	20	2	77	0.94	28.44	42.00	4.55
S9		4	71	0.92	31.56	46.22	4.75
S13		6	66	0.89	29.78	43.11	4.65
S17		8	62	0.87	26.67	41.78	4.51
S21		10	56	0.85	23.78	37.33	4.28

If the percentage of polymer is fixed, with increase in the fibers content in the mix then the value of slump goes on decreasing which indicates decrease in the workability of concrete. The same trend was observed in case of Compaction Factor also as shown below in Fig.-2 and Fig.-3.

The main reason behind this compacted workability of concrete can be attributed to the increased friction with the increase in percentage of jute fibers. Friction produced will increase the effort required to prepare the concrete. Hence workability reduces. While the addition of polymer renders the surface of aggregates smooth. They fill most of the pores of aggregates and thus provide lubricating effect with reduced friction. Hence the workability also increases.

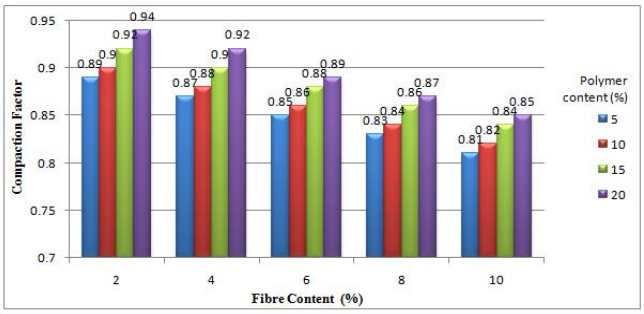

Fig. – 2: Showing Graph for Results of compaction factor at constant fiber content.

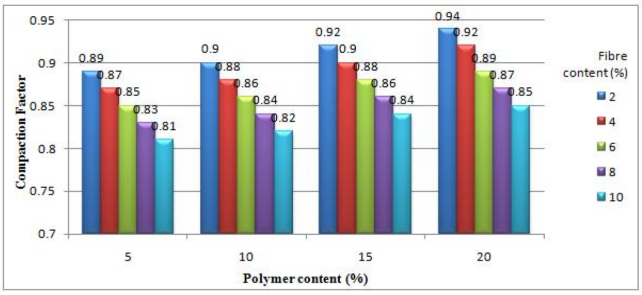

Fig. – 3: Showing Graph for Results of compaction factor at constant polymer % content.

The results of Fig. - 4 and Fig. - 5 below shows that an initial increase in the strength with addition of SBR latex polymer & jute fibers in the concrete. The best result is obtained for batch S7 with 4% jute fiber and 10% polymer. Increase in compressive strength with the increase in SBR latex polymer can be justified by the fact that it is itself a sticky and viscous liquid and imparts binding properties into the concrete when it dries. Fibers on the other hand do not contribute more to increase in the compressive strength and flexural strength of concrete.

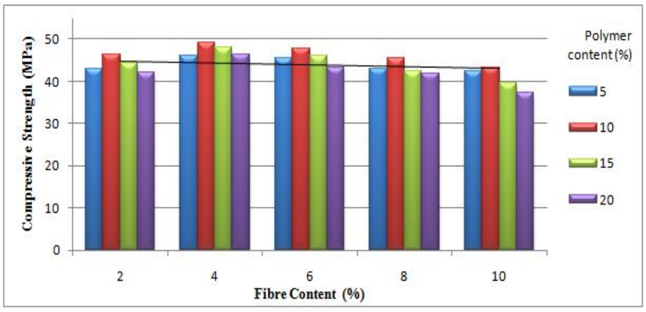

Fig. – 4: Showing Graph for Results of compressive strength at constant fiber content.

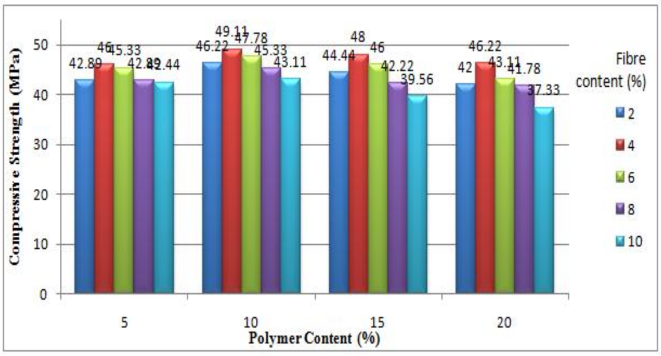

Fig. – 5: Showing Graph for Results of compressive strength at constant polymer % content.

The Flexural Strength of concrete as per Graph No. 6 and Graph No. 7 shows that there is initial increase in the strength with addition of SBR latex polymer & jute fibers in the concrete. The best result was obtained for batch S7 with 4% jute fiber and 10% polymer similar to the compressive strength at the 28 days. The increase in the flexural strength of concrete can be best justified by the fact that concrete is a brittle material. They contain pores and hairline micro cracks in them. In plain concrete specimen (batch S1) the extent of hairline cracks was observed more on the application of load. But on the introduction of fibers in the concrete the hairline cracks of concrete is reduced. This results in extra effort to initiate the tensile cracks. Hence the flexural strength of concrete increased with the increase in fiber content up to some extent

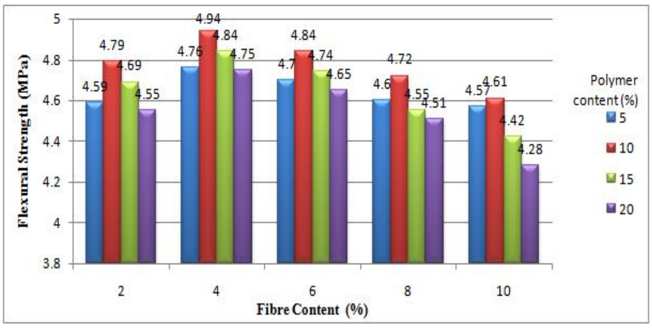

Fig. – 6: Showing Graph for Results of Flexural strength at constant fiber content.

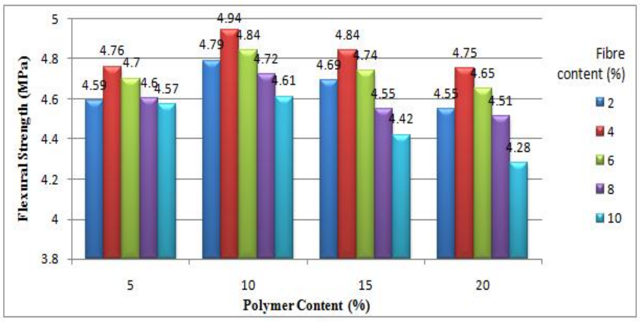

Fig. – 7: Showing Graph for Results of compressive strength at constant polymer % content.

5. CONCLUSIONS

a) With increase in proportion of polymer in the mix the workability of the fresh concrete increases whereas for fibre it decreases.

b) With the increase in proportion of polymer up to 20% in concrete mix, there is increase in slump value by 17% and increase in compaction factor value by 7%, which shows the workability of the concrete is increased.

c) With the increase in proportion of fiber up to 10% in concrete mix, there is decrease in slump value by 21% and decrease in compaction factor value by 8%, which shows the workability of the concrete is decreased.

d) Maximum compressive strength and flexural strength of concrete is found when 4% fiber and 10% polymer is used in the concrete mix.

e) Optimum use of fiber without affecting the target mean strength of concrete was found to be 10% for fiber when up to 10% polymer is used.

f) Optimum use of polymer without affecting the target mean strength of concrete was found to be 20% for polymer when up to 8% fiber is used.

g) Bulk density and weight of concrete is decreased while adding fibre in concrete.

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