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Experimental Study on Partial Replacement of Fine Aggregate by Crumb Rubber

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Abstract: Production of rubber is large in quantity across the world. For example, 110 million tons rubber is produced annually only in India. It is not possible to discharge the rubbers in the environment because they decompose very slowly and cause lots of pollution. So, it is necessary to have a relevant use of these wastages. These waste materials can be used to improve some mechanical properties of concrete such as more energy absorption, better ductility, and better crack resistance. In this paper, the 7-days 14-days and 28-days compressive strength, tensile strength and flexure strength of concretes containing crumb rubber are investigated. The purpose of this experimental investigation is to study the behaviour of strength from Crumb rubber concrete (CRC). In this investigation CRC was manufactured by usual ingredients such as cement, fine aggregate, coarse aggregate, water and polyvinyl alcohol (PVA) at various replacement levels and certain percentage of crumb rubber. The constant water cement ratio is 0.40. The mixes are cast with 20%, 25%, replacement of fine aggregate with crumb rubber with adding PVA at 4% and 6% respectively to the concrete mix and the mechanical properties such as compressive strength, split tensile strength and flexural strength are found out.

Keywords: cement, Fine aggregate, crumb rubber, coarse aggregate, PVA

I. Introduction

Waste materials resulting from vary physical and chemical processes are the most important challenges in the industrial and developing countries. Extensive investigation on wastage recycling is being implemented to minimize the environmental damages. One of the non-recyclable materials enters the environment as automotive used tires. Large quantities of scrap tires are generated each year globally. This is dangerous not due to potential environmental threat, but also from fire hazards. Over the years, disposal of tires has become one of the serious problems in environments. Land filling is becoming unacceptable because of the repaid depletion of available sites for waste disposal. Investigations show that used tires are composed of materials which do not decompose under environmental conditions and cause serious contaminations. Burning is a choice for their decomposition; however the gases exhausted from the tire burning results in harmful pollutions. In order to prevent the environmental problem from growing, recycling tire is an innovative idea or way in this case. Recycling tire is the processes of recycling vehicles tires that are no longer suitable for use on vehicles due to wear or irreparable damage. Based on examinations, another way is using the tires in concrete. This results in the improvement of such mechanical and as energy adsorption, ductility, and resistance to cracking. The accumulation of used tyres at landfill sites presents the threat of uncontrolled fires, producing a complex mixture of chemicals harming the environment and contaminating soil and vegetation. Therefore, an urgency to identify alternative outlets for these tyres, with the emphasis on recycling in line with the policy of most countries is needed. One such possible outlet is to produce tire chips and fibres components for use in concrete as aggregate or filler. Indeed, waste Tire chips and fibre is uniquely different to other waste materials, because its production method does not require any sophisticated machineries and easy to handle in economically. Hence, the successful use of waste tire chips and fibres in concrete could provide one of the environmentally responsible and economically viable ways of converting this waste into a valuable resource.

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II. MATERIALS AND METHODOLOGY

Ordinary Portland cement (OPC) is the basic Portland cement and is best suited for use in general concrete construction. It is of three types, 33 grades, 43 grades, 53 grades. One of the important benefits is the faster rate of development of strength. Cement is fine, grey powder. It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The basic composition of cement is provided in table. In the present work 43 grade cement was used for testing.

Table 1 Typical Constituents of Ordinary Portland cement

Cement	CCN	Mass%
Calcium oxide, CaO	C	61 – 67 %
Silicon oxide, SiO2	S	19 – 23 %
Aluminiumoxide,Al2O3	A	2.5 – 6 %
Ferric oxide, Fe2O3	F	0 – 6 %
Sulphate	S	1.5 – 4.5 %

Table 2 Tests on Cement

Properties	Values
Specific gravity	3.15
Normal consistency	32 %
Initial setting	30 minutes
Final setting	600 minutes

Manufactured sand (M-Sand) is a substitute of river sand for concrete construction. Manufactured sand is produced from hard granite stone by crushing. The crushed sand is of cubical shape with grounded edges, washed and graded to as a construction material. The size of manufactured sand (M-Sand) is less than 4.75mm. Crumb rubber is a term usually applied to recycled rubber from automotive and truck scrap tires. During the recycling process steel and fluff is removed leaving tire rubber with a granular consistency. Continued processing with a granulator and / or cracker mill, possibly with the aid of cryogenics or mechanical means, reduces the size of the particles further. The particles are sized and classified based on various criteria including colour (black only or black and white).The granulate is sized by passing through a screen, the size based on a dimension (¼) or mesh. Mesh refers to material that has been sized by passing through a screen with a given number of holes per inch. For example, 10 mesh crumb rubber has passed through a screen with 10 holes per inch resulting in rubber granulate that is slightly less 1/10 of an inch. The exact size will depend on the size of wire used in the screen.

Table 3 Indian Tyres Industry General Details

Total no of Tyre Companies	36
Total no of Tyre Factories	51
Tyre Production 2012 – 13 (Estimated)	110 Million
Industry Turnover (Estimated)	Rs. 31000 crores

Capacity Utilization (Estimated)	84%
Growth in Truck & Bus tyre production	15%

Table 4 Classification of crumb rubber according to practical size

Market	Mesh sizes
Moulded and Extruded Products	4 – 100 mesh
Asphalt Modification	16 – 40 mesh
Sport Surfacing	¼ ” – 40 mesh
Automotive Products	10 – 40 mesh
Tires	80 – 100 mesh
Rubber and Plastic Blends	10 – 40 mesh
Construction	10 – 40 mesh

The opening between the wires of a screen – term commonly used to describe or measure the size of crumb rubber. Crumb rubber is sized by the screen or mesh through which it passes in the production process. The finer the screen / mesh the more openings it will have per liner inch, i.e. 30 mesh means there are 30 holes or openings per liner inch. The greater number of openings, the smaller the material must be to pass through the screen. A minus" – "symbol refers to material that has passed through the screen, i.e. – 30. Technically crumb rubber sizes are expressed in two numbers. The second number is preceded by a plus (+) symbol and indicates the size particle that has been retained on the screen.

Polyvinyl alcohol, also known as PVOH, PVA, or PVAL, is a synthetic polymer that is soluble in water. It is effective in film forming, emulsifying, and has an adhesive quality. It has no odour and is not toxic, and is resistant to grease, oils, and solvents. It is ductile but strong, flexible, and functions as a high oxygen and aroma barrier. Polyvinyl alcohol is widely used to strengthen textile yarn and papers, particularly to make the latter more resilient to oils and grease. It is also used in freshwater sports fishing. PVA is added into bags that are filled with oil based or dry fishing bait and attached to the hook. As PVA is soluble in water, when the bag lands on the bed of the water, it breaks down; leaving the hook bait surrounded by pellets and ground bait. This attracts fish to the hook bait, although the PVA does cause the plastic to dissolve in water. PVA may also be used as a coating agent for food supplements and does not pose any health risks as it is not poisonous. One of the leading industrial uses for PVA is for food packaging, accounting for 31.4 percent of the global share in 2016. To combat moisture formation from foodstuff, PVA film is created to be thin and water-resistant. Its cross linking density and resistance to moisture are added benefits to its usability in this area. Polyvinyl alcohol is a resin, a natural or synthetic organic compound made of non-crystalline or viscous substance. Hence, it is often utilized as the starting point for the creation of other resins such as polyvinyl butyral (PVB) or polyvinyl formal (PVF). PVB has an adhesive quality and is a water-resistant, plastic film, which is often used to laminate safety glass for vehicles. PVF is commonly used to insulate wires. It is also interesting to note that in another growing market, the pharmaceutical market, use of polyvinyl alcohol for coating of medicinal tablets is quite prominent. Its various chemical properties have shown the benefit of its use in health applications, and in particular in pharmaceutics. However, extensive experimentation and pharmaceutical use of PVA/PVOH has been limited due to regulations on food and drugs.

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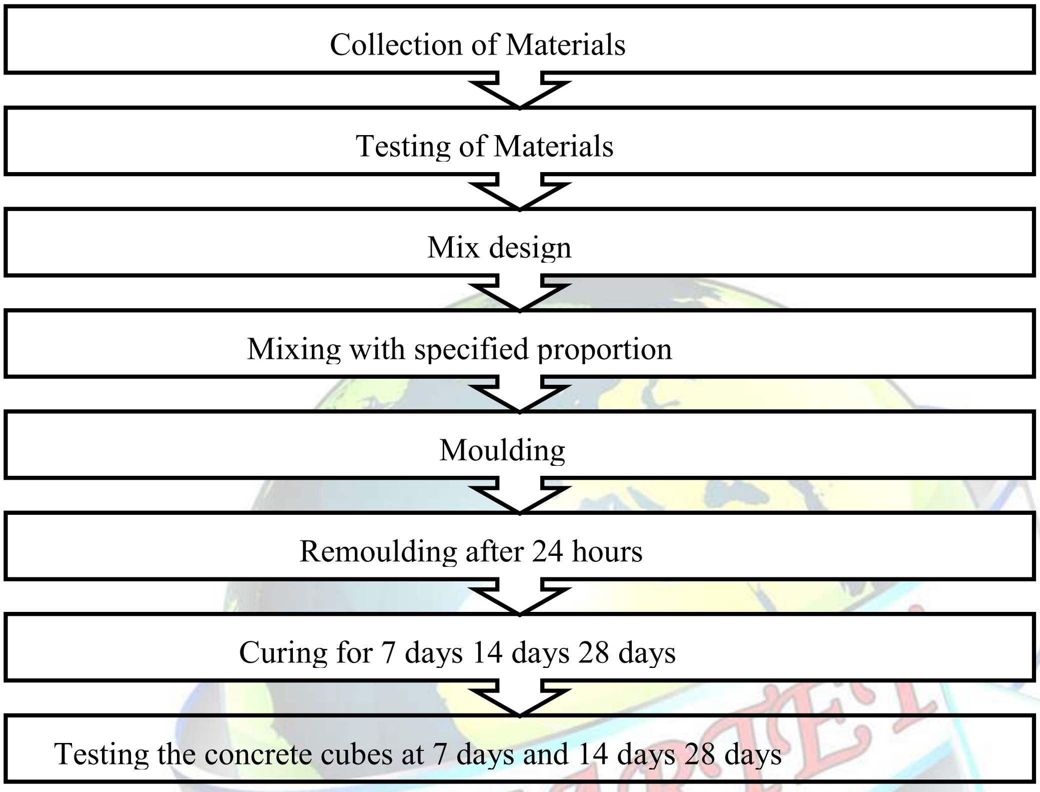
III. METHODOLOGY



IV. EXPERIMENTAL PROGRAM

1) SIEVE ANALYSIS OF FINE AGGREGATE

The M-sand having fineness modulus of 2.705 and it corresponds to grading zone II of IS; 383 – 1970 grading requirements. The specific gravity of fine aggregate is 2.44. The particle size distribution is in table 2.3. The optimum gradation of fine aggregate is determined more by its effect on water requirement then on physical packing. It is found that sand with a fineness modulus below 2.4 give the concrete a sticky consistency. Making it difficult to compact sand with a fineness of about 3.0 gives the best workability and compressive strength.

Table 5 Sieve Analysis Results of Fine Aggregate

Is sieve	Weight retained (gm)	Weight retained	Cumulative% Weight retained	Weight passing
16 mm	0	0	0	100
10 mm	0	0	0	100
4.75 mm	0	0	0	100

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2.36 mm	158	7.9	7.9	92.1
1.18 mm	195	9.75	17.65	82.35
600 micron	955	47.75	65.4	34.6
300 micron	335	16.75	82.15	17.85
150 micron	305	15.25	97.4	2.6
Pan	52	-	-	-
Total	2000	-	-	270.5

Fineness modulus = Weight Passing / 100 = 270.5/100 = 2.70

2) SPECIFIC GRAVITY OF FINE AGGREGATE

Specific gravity of aggregate is used of in the design calculation of concrete of mixes. With the specific gravity of each constituent know, its weight can be converted in to solid volume and hence a theoretical yield of concrete per unit volume can be calculated.

Specific gravity of sand G = ((W2 – W 1) / ((W4 – W1) – (W3 – W2))

Table 6 Specific Gravity of Fine Aggregate

Test No	% of passing
Wt. of pyconometer (W1) g	679.40
Wt. of pyconometer + sand (W2) g	1828.68
Wt. of pyconometer + sand + water (W3) g	2218
Wt. of pyconometer + water (W4) g	1508
Wt, of dry soil (w2 – w1)	1149.2
Specific gravity of sand	2.62

Specific gravity of sand G = 2.62

3) SIEVE ANALYSIS OF COARSE AGGREGATE (IS 2386 Part-1 1963)

The maximum size of aggregate is fixed based on sieve analysis. This influences the requirement of sand and water in concrete and also the spacing between the reinforcement. The sample is brought to an air dry condition before weighing and sieving condition. This is achieved by drying at room temperature. The air dry sample is weighed and sieved on the appropriate sieves starting the larger at the top. Each sieve is separately over a clean tray not more then.

Table: 7 Sieve analysis result of coarse aggregate

Sieve size in mm	Weight retained in gm	Percentage retained	Cumulative percentage retained	Percentage passing
80	0	0	0	100
63	650	21.67	21.67	78.33
50	1080	36	57.67	42.33
40	480	16	73.67	26.33

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25	510	17	90.67	9.33
10	200	6.76	97.34	2.66
Pan	80	2.4	99.81	0.19
		TOTAL		259.17

Fineness modulus = Percentage Passing / 100 = 259.17/100 = 2.59

4) SPECIFIC GRAVITY OF COARSE AGGREGATE (IS 2386 Part-3 1963)

Specific gravity of aggregate is used of in the design calculation of concrete of mixes. With the specific gravity of each constituent known its weight can be converted in to convert in to solid volume and hence a theoretical yield of concrete per unit volume can be calculated.

Table 8 Specific gravity of coarse aggregate

Test	Value in kg
Weight of container – (w1)	6.67
Weight of container + Aggregate(w2)	15.58
Weight of container + Aggregate + water (w3)	17.40
Weight of container + water (w4)	11.58

Gravity of aggregate = 2.80

5) ABRASION TEST OF COARSE AGGREGATE

Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works. Los Angeles abrasion test is a preferred one for carrying out the hardness property and has been standardized in India.

CALCULATION:

Original weight of aggregate sample	= W_1=5kg
Weight of aggregate sample retained	= W_2=4.130kg
Weight passing 1.7mm Is sieve	= W_1-W_2=0.87kg
Abrasion value	= $(W_1-W_2)/W_1$ x 100
	= 0.87/5 x 100
	= 17.4%

IMPACT TEST (IS 2386 Part-4 1963)

The aggregate impact test is carried out to evaluate the resistance to impact of aggregate. And the impact value is measured as percentage of aggregates passing sieve to the total weight of the sample.

CALCULATION:

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Aggregate impact value (B/A) x 100

B-Weight of fraction passing 2.36mm IS sieve.

A-Weight of oven direct sample.

Empty weight of mould	= 1.805kg
Weight of mould & aggregate	= 1.935kg
Oven dried of aggregate	=0.565kg
Weight of aggregate passed 2.36mm IS sieve	=0.130kg
Impact value	$=W_2/W_1$ x 100
	=0.06/0.588 x 100
	=10.2%

10-12 range of impact value is strong.

6) **SHAPE TEST OF COARSE AGGREGATE** (IS 2386 Part-3 1963)

The particle shape of aggregates is determined by the percentages of flaky and elongated particles contained in it. The flakiness index of aggregates is the percentage by weight of particle's whose least dimension is less than three fifths of their mean dimension.

FLAKINESS INDEX:

Total weight of aggregate passing through the gauge/Total weight of aggregate taken =130/2000 x 100=6.5%

ELONGATION INDEX:

Total weight of aggregate return on the length/Total weight of aggregate taken =1470/2000 x 100=73.5%

Table 9 Shape test of coarse aggregate

S.No	SIZE OF AGGREGATE		ELONGATION INDEX		FLAKINESS INDEX	
	Passing through IS Sieve	Retained on Is Sieve	Length Gauge	Weight Of Aggregate	Thickness Gauge Of Main Sieve	Weight Of Aggregate In Each Fraction Position The Gauge
1	63	50	-	0	33.9	0
2	50	40	81	0	27	0
3	40	31.5	58.3	0	19.5	0

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4	31.5	25	-	0	16.5	0
5	25	20	40.5	0	16.5	50
6	20	16	32.4	3.55	10.8	0
7	16	12.5	28.6	0	18.5	70
8	12.5	10	20.2	1060	8.75	10
9	10	6.3	14.7	55	4.09	10
				1470		130

Flakiness index =W x 100/v
=130 x 100/2000

=6.5%

Elongation index =1470 x 100/2000 =73.5%

V. MIX DESIGN

Mix design is the process of selecting suitable ingredient if concrete and determines their relative proportion with the object of certain minimum strength and durability as economically as possible.

DESIGN OF M30 GRADE CONCRETE

Table 10. Mix proportion for a cubic meter of concrete

Mix	Cement (kg/m ^{3})	Crumb rubber (kg/m ^{3})	Polyvinyl alcohol (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (lit/m^3)
Conventional	394	0	0	717.99	1206.82	157
20%	394	143.59	6.28	574.39	1206.82	157
25%	394	179.48	9.42	502.59	1206.82	157

VI. RESULTS AND DISCUSSION

SLUMP CONE TEST

Concrete was then placed into the frustum. The mold needs to be on a level, rigid surface, free of vibration. Concrete was then put in the moulds in 3 layers and a steel rod was jabbed into each layer of concrete 25 times to consolidate the concrete in the mold. The top concrete was then cut off and the mold was carefully lifted off. A ruler was then used to measure the new height since the previous height of the mold was known.

CALCULATION

Table 11. Slump cone test Values

Samples	Slump (mm)
Conventional	38
20%	45
25%	50

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COMPACTION FACTOR TEST

With both trap doors in the hoppers closed and the cylinder covered, the upper hopper was filled with concrete. Its trap door was then opened so that the concrete fell into the lower hopper. The trap door of the lower hopper was then opened such that the concrete fell into the cylinder. The surplus concrete on top was cut off and the mass of the concrete in the cylinder determined. (This concrete is said to be partially compacted). The concrete was then emptied and refilled with the same concrete. The cylinder was then placed in the vibrating machine and concrete was added till when it was to level, the steel rod was then used to clear off free concrete on the top. The mass of the fully compacted concrete was then measured.

CALCULATION:

CONVENTIONAL CONCRETE UPPER HOPPER:

Top internal diameter	=254mm
Bottom internal diameter	=127mm
Internal height	=279mm

LOWER HOPPER:

Top internal diameter	=229mm
Bottom internal diameter	=127mm
Internal height	=129mm
CYLINDER:	
Internal diameter	= 152mm
Internal height	=305mm
Distance between bottom to top of BH	=200mm
Distance between bottom to top cylinder	=200mm
Weight of the cylinder	=7.5kg
Weight of the cylinder + partially compacted concrete	=17.48kg
Weight of the cylinder + fully compacted concrete	=18.22kg
Compactor factor	= 0.95
20% REPLACEMENT: **UPPER HOPPER:**	
Top internal diameter	=254mm
Bottom internal diameter	=127mm
Internal height	=279mm
LOWER HOPPER:	

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Top internal diameter	=229mm
Bottom internal diameter	=127mm
Internal height	=129mm

CYLINDER:

Internal diameter	= 152mm
Internal height	=305mm
Distance between bottom to top of BH	=200mm
Distance between bottom to top cylinder	=200mm
Weight of the cylinder	=7.5kg
Weight of the cylinder + partially compacted concrete	=15.73 kg
Weight of the cylinder + fully compacted concrete	=19.195 kg
Compactor factor	= 0.84

7) HARDEND CONCRETE TESTS

COMPRESSIVE STRENGTH

The compression test is carried out with cube specimen to find out the compressive strengths of conventional and rubber replaced concretes using compression testing machine and the results are tabulated.

Table 12 Compression Strength Results

MIX PROPORTIONS	7 Days			AVG	14 Days			AVG	28 Days			AVG
SAMPLES	**1**	**2**	**3**		**1**	**2**	**3**		**1**	**2**	**3**	
Conventional	22.5	23.7	24.65	**23.61**	31.5	29.61	32.4	**31.17**	35.22	33.80	35.78	**34.93**
20%	21.6	20.32	21.7	**21.30**	26.98	31.67	27.87	**28.84**	30.08	29.13	31.66	**30.29**
25%	18.53	17.92	19.58	**18.68**	23.96	23.12	25.18	**24.08**	27.36	26.47	27.98	**27.27**

SPLIT TENSILE STRENGTH

The cylinder was then placed on the compression machine lengthwise. This was to determine the tensile strength. A pair of splints was placed on the cylinder one on top and the other one at the bottom. The machine was then switched on and the force used to split the cylinder along the centroid measured. This was repeated for the other cylinders

Table 13. Tensile Strength results.

MIX PROPORTIONS	7Day s			AVG	14 Days			AVG	28Day s			AVG
SAMPLES	**1**	**2**	**3**		**1**	**2**	**3**		**1**	**2**	**3**	
Conventional	2.7	2.86	2.83	**2.8**	3.02	3.2	3.08	**3.1**	3.6	3.72	3.68	**3.67**

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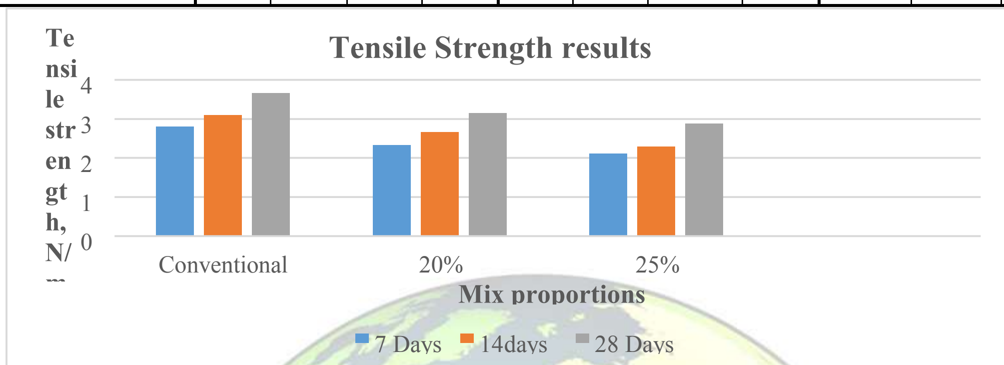
20%	2.28	2.4	2.32	**2.33**	2.8	2.53	2.65	**2.66**	3.06	3.18	3.22	**3.15**
25%	2	2.15	2.19	**2.11**	2.3	2.25	2.36	**2.3**	2.81	2.99	2.84	**2.88**

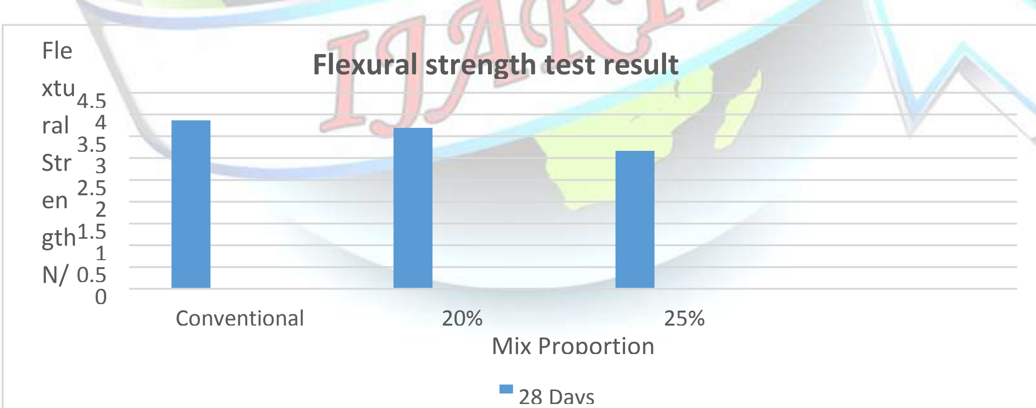


FLEXURAL STRENGTH

The flexural strength test is carried out to find out the Flexural strengths of conventional and rubber replaced and the results are tabulated

Table 14 Flexural strength test result

MIX PROPORTIONS	**28 Days**			**AVG**
SAMPLES	1	2	3	
Conventional	3.95	3.8	3.85	**3.87**
20%	3.6	3.78	3.65	**3.69**
25%	3.1	2.95	3.45	**3.17**



VII. CONCLUSION

The performance of concrete with 20% and 25% of replacement of fine aggregate with crumb rubber has been increased with the use of polyvinyl alcohol. The use of polyvinyl alcohol has increased bonding between crumb rubber and other constituents of concrete. Reduced weight, compressive and tensile strengths of rubber derived concrete do limit its use in some structural applications. The introduction of recycled rubber tires into concrete significantly increased the slump

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and workability. Even though SSS was not conducted it is evident that rubberized concrete can't resist chemical attacks arising from ground water and polluted air. It can therefore not be used in septic systems even though it has less absorption. All the mechanical properties of the Rubcrete are reduced when compared to conventional concrete upto 3 to 5% but is still better in other properties that are mentioned above. When compared to conventional concrete, replacing crumb rubber upto 15% can provide better results in compression, tension and flexure strengths.

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