Mechanical Properties of Rubber Fibre Reinforced Concrete

Subash Kumar Wadhwani[1], M. Abu Bakar Shaikh[1], Muzamil Hussain Qureshi[1], G. Mustafa Kumbhar[1], Fahad Ali Shaikh[1]

[1]*Civil Engineering Department, Mehran UET Jamshoro, Sindh, Pakistan*

Abstract: **Rubber waste generation is a huge problem in the entire world which poses enormous threats for the inhabitants in various forms endangering them critically from environmental as well as health perspective. The rubber waste generation in developing countries like Pakistan is not only a threat but a huge menace because of the absence of necessary essentialities. This research presents a sustainable approach which not only reduces rubber waste but also enhances the properties of concrete to our benefit. The rubber waste used in this research is in the form of fibres which is introduced inside the concrete mix at different percentages to alter the properties of concrete. The flexural strength test was performed for rubber fibre reinforced concrete at different rubber contents of 0.5%, 1.0%, 1.5% and 2.0% for both the mix designs of 20 MPa and 30 MPa. The number of samples i.e. beams casted for both the mix designs were 30 of dimensions 4"x4"x20". The curing period for all the samples was fixed at 28 days in normal water. Conclusively, the rubber fibre reinforced concrete provided increased flexural strength at an optimum rubber content of 2.0% for 20 MPa and 1.0% for 30 MPa.**

Keywords: **Rubber Waste, Sustainable Concrete, Mechanical Properties, Rubber Fibre Reinforcement, Rubber Fibre Reinforced Concrete**

I. INTRODUCTION

The rubber waste is such a waste that has contributed in the destruction of environment in many ways throughout the ages. It is a usual practice to get rid of rubber waste by burning it but doing so damages and changes the environment permanently. This research aims at devising such a mandatory step which would reduce rubber waste and create a unique amalgam known as "The Rubber Fibre Reinforced Concrete".

Rubber fibre reinforcement alters the performance, suitability, sustainability and durability of the concrete. It mainly enhances the ductility characteristics of the concrete which is very much essential for the flexural components of the structure.

Fig. 1

II. LITERATURE REVIEW

(Fakhri and Saberi. K, 2016), This research aims to completely modify compressive, flexure, water absorption and unit weight characteristics of normal concrete with rubber addition. The rubber so used to carry out this research is of used tires along with silica fume as an additive to enhance the strength characteristics of rubberized concrete. The rubber was replaced partially with fine aggregates in different proportions to make the roller compacted rubber concrete. The rubber was added in proportions ranging from 5% to 35%. So, with different curing periods a vast number of tests were carried out to check out the behaviour of concrete as well as the rubcrete.

(Sarangi and Choudhary, 2018), This research aims to make yet another new material namely Rubber Fibre Reinforced Concrete which is entirely made with same ingredients (cement, fine aggregates and coarse aggregates) as conventional concrete but with rubber fibres added as an additional material to improve the mechanical properties of concrete. The concrete so designed to carry out the research was of M20 grade with the number of samples up to 96 out of which 24 were beams and 72 were cubes. The initial curing was done using the normal water but exactly after 7 days the curing was done on salty water for the remainder of the days. Conclusively, the rubber fibre reinforcement in the normal concrete showed an enhanced and improved compressive strength characteristic, the flexural strength also improved with the rubber fibre reinforcement and the cracking resistance improved by a huge margin.

(Ghutham et al., 2016), In this research the rubber tires were used as fibres to reinforce the normal concrete and enhance its mechanical properties. The addition criteria of rubber as fibre reinforcement was 0.25% and 0.5% by concrete weight. The rubber adopted in this research was of cycles that was cut mechanically with human effort using different tools. The resulting concrete after comparing it with the control samples resulted differently and managed to show an enhanced workability, compressive strength, tensile strength and flexural strength.

(Helminger, 2014), This research aims to make a concrete whose ingredients will contain both rubber and steel as a fibre. The rubber was replaced partially with the fine aggregates to create the rubberized concrete and then the steel fibres were added as fibres to further reinforce the concrete and enhance its mechanical properties. The mix design to carry out this research was of 5000 psi at a curing of around 28 days. Workability was found to have decreased, unit weight also decreased with increasing rubber percentage but with fibre increment it increased, air content also increased with rubber increment, fibre addition increased compressive characteristic where as it was quite adverse for the rubber addition, split tensile increased with fibres but decreased with rubber increment, similar trend was also seen with the modulus of elasticity, toughness seemed to have improved with rubber increment.

(Xue and Shinozuka, 2013), This research aims at studying the impact, energy absorption, energy dissipation and mainly the seismic characteristics of rubberized concrete. For this purpose, the rubber in the form of crumbs was used in different proportions in the concrete replacing the fine aggregates partially. The rubcrete got improved in terms of energy dissipation therefore the damping ratio came out to be more than the damping of the normal concrete, crumb rubber addition decreased the modulus of concrete as a whole and increasing the rubber content decreased the strength characteristics whereas silica fume addition in larger contents enhanced the strength characteristics.

(Elchalakani et al., 2016), Rubber is used in this research in varying proportions i-e 10%, 20%, 30% and 40% in very fine shape that is powdered form or crumb form. The drastic reduction of strength, plastic modulus and tensile strength in rubcrete resulted due to inadequate bonding between concrete ingredients and rubber owing to the differing nature of the later. It was advised that the inclusion of silica fume up to 15% followed by the pre-treatment of rubber with NaOH and other chemical agents to improve binding characteristics of rubcrete. Various other studies referenced in this paper also suggested that the total rubber content to be used in Rubcrete should not exceed 20%, 25% and 30% because additional increase in the rubber content reduces the compressive strength and other important parameters of concrete such as modulus of plasticity and tensile strength etc to a much larger percentage.

(Kotresh and Belachew, 2014), The work of these authors focused mainly upon the bonding properties of rubber aggregate in the concrete which in turn enhanced the properties rubcrete as a whole. They have suggested that the recycling factories should provide rubber particles of sizes 20-10, 10-4.75 and 4.75 mm. Their studies further revealed that light unit weight rubcrete can be used in various non-structural (non load bearing) sides in the field of civil engineering such as architectural application, fall facades, stone baking interior construction and earth quake shock wave absorption like foundation pads, railway stations, resistance to impact or explosion, trench filing, bunkers and railway buffers. Their studies further revealed that the rubcrete provided an enhanced sound insulation, water proofing and heat insulation compared to the normal concrete. If proper design is carried out i-e the 20mm thick surface of rubcrete on top of the roof with 4.75mm rubber aggregate would provide sufficient insulation characteristics and possibly best results in this regard.

(Shah et al., 2014), This author studied on the thermal properties of rubber concrete for which he used 5%, 10% and 15% scrap rubber and replaced them by volume by coarse aggregate. He examined the thermal behaviour of rubcrete by a special hot box technique. He concluded that up to 5% rubber content didn't produce good results in regard to the thermal properties, but more than 5% rubber content gave acceptable results in regard to the thermal behaviour of rubcrete. Furthermore, he proposed that the inclusion of rubber content enhances the decreases the compressive strength, flexure strength, workability because of differing nature of rubber due to its texture and natural properties, stiffness and unit weight. However, the properties that showed a drastic increase in the rubcrete due to hike in the rubber content were, impact resistance, air content, water absorption, energy absorption and insulation properties.

(Su et al., 2014), This study was a remarkable approach towards the rubberized concrete which provided necessary information about different variety of rubber inclusion especially circulating around the sizes of rubber and their homogeneity. His work included three groups of samples of rubberized concrete which contained three homogeneously sized rubber particles i-e 3mm, 0.5mm and 0.3mm respectively each of which were separately used in the groups of samples in his research. In addition to this, he approached another trial in which he used a continuous sized grading rubber in the rubberized concrete as partial replacement of fine aggregates 20% by volume. It was realized that rubber particle size affected the water permeability and concrete workability more than the strength and fresh density. The larger the size of the rubber particles resulted in increased workability and fresh density compared to the smaller particles if used to make rubberized concrete.

III. MATERIALS & METHODS

A. Cement

Ordinary Portland cement of Lucky brand is used in this research having the following characteristics

Table 1: Properties of Cement

Properties	Result
Fineness	97.5%
Normal Consistency	0.34 (W/C ratio)
Initial Setting time	42 min
Final Setting time	8hrs. 16min

B. Fine Aggregates

Commonly available dry river sand is used having following properties.

Table 2: Properties of Fine Aggregates

Properties	Result
Fineness Modulus	4.047
Zone	Zone-1

C. Coarse Aggregates

Crushed coarse aggregate containing different sizes but having maximum size of ¾” is used

Table 3: Properties of Coarse Aggregates

Properties	Result
Fineness Modulus	3.253
Water Absorption	1.344%
Specific gravity	2.602

D. Rubber Fibres

Rubber in the form of fibres is used having following characteristics.

Figure 1: Rubber Fibres

Table 4: Properties of Rubber Fibres

Properties	Result
Length	15-30 mm
Diameter	3-4 mm
Water Absorption	1%
Specific gravity	1.184

E. Methodology

DOE mix design was incorporated for the evaluation of flexural strength of beams casted for both the 20MPa and 30MPa in this regard following results were obtained

i. 20MPa

Cement: F.A: C.A = 1: 2.89: 2.5

W/C Ratio: 0.6

ii. 30MPa

Cement: F.A: C.A = 1: 2.5: 2.3

W/C Ratio: 0.54

For all the rubber fibres percentages i.e. 0.5%, 1.0%, 1.5% & 2.0% and for plain cement concrete 3 samples were casted resulting in total number of 15 beams for 20MPa as well as for 30MPa. The size of each beam was 4”x4”x20”.
Testing of beams was done on Universal Testing Machine (UTM) on the basis of single point loading.

IV. RESULTS

For single point loading flexural strength can be evaluated as:

$$\alpha = 1.5Pl/bd^2$$

whereas l=500mm, b=100mm, d=100mm

$$\alpha = 0.00075P \ (N/mm^2)$$

i. For 20MPa

The beam samples are shown below,

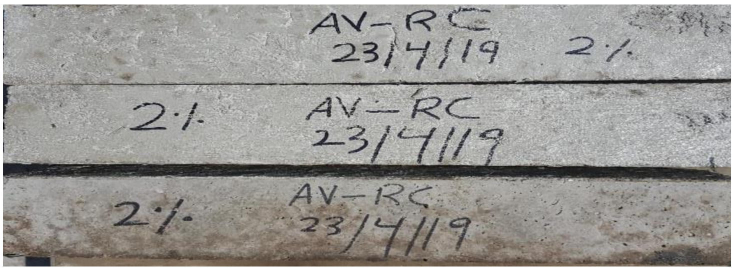

Figure 2: Beams (20MPa)

Following are the results obtained:

Table 5: Flexural Strength (20MPa)

Concrete type	Load (N)			Strength (MPa)			Average Strength (MPa)	Change in Strength from Control Sample (%)
0% RFRC (Control Sample)	3941	5881	4077	2.95575	4.41075	3.05775	3.47475	-
0.5% RFRC	7081	7351	6806	5.31075	5.51325	5.1045	5.3095	52.80235988
1.0% RFRC	7451	8016	7251	5.58825	6.012	5.43825	5.6795	63.45060796
1.5% RFRC	7806	8107	7006	5.8545	6.08025	5.2545	5.72975	64.89675516
2.0% RFRC	7991	8311	7751	5.99325	6.23325	5.81325	6.01325	73.05561551

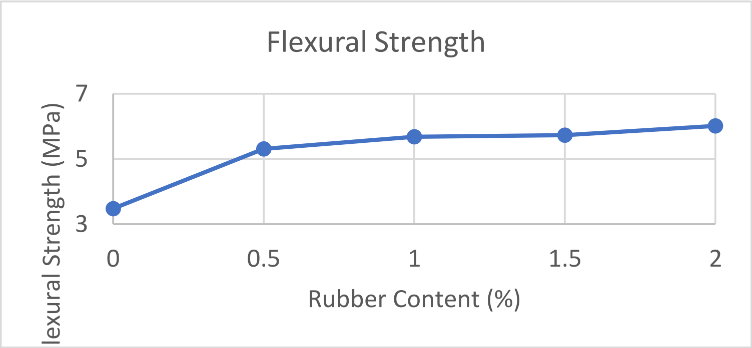

Figure 3: Flexural Strength (20MPa)

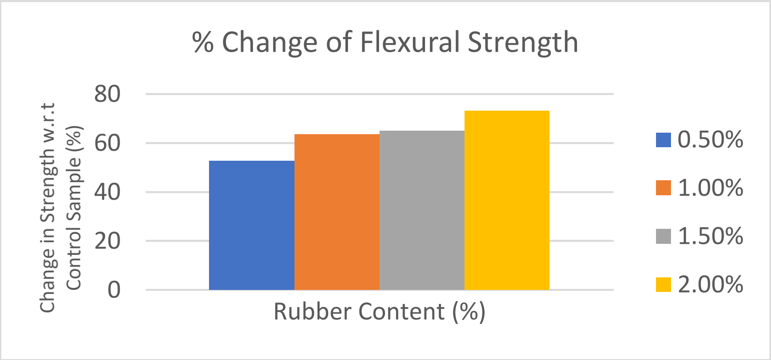

Figure 4: Change in flexural strength by adding Rubber fibres (20MPa)

Table 5 & Fig. 3 shows the flexural strength of concrete beams having different percentages of rubber fibres.

Further from the achieved results it is clearly illustrated that the Concrete flexural strength increases by adding rubber. Within the scope of our Research work we got the highest Flexural Strength at 2.0% Rubber Fibres. Fig. 4: shows Flexural strength of concrete increases by 73% by adding 2.0% Rubber Fibres.

ii. For 30MPa:

The beam samples are shown below,

Figure 5: Beams (20MPa)

Table 6: Flexural Strength (20MPa)

Concrete type	Load (N)			Strength (MPa)			Average Strength (MPa)	Change in Strength from Control Sample (%)
0% RFRC (Control Sample)	8241	7761	7980	6.18075	5.82075	5.985	5.9955	-
0.5% RFRC	7823	7706	8641	5.86725	5.7795	6.48075	6.0425	0.783921274
1.0% RFRC	9881	8871	8963	7.41075	6.65325	6.72225	6.92875	15.56584105
1.5% RFRC	8251	9131	7847	6.18825	6.84825	5.88525	6.30725	5.199733133
2.0% RFRC	6571	10384	8191	4.92825	7.788	6.14325	6.2865	4.85364023

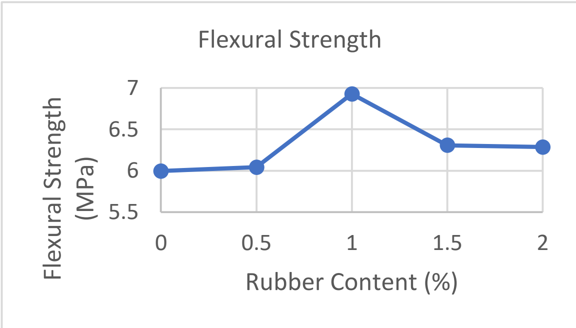

Fig. 6: Flexural Strength (20MPa)

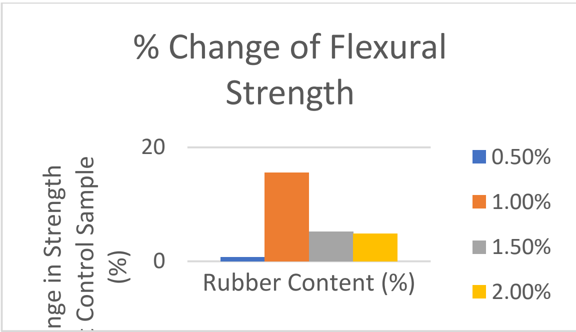

Fig. 7: Change in Flexural strength by adding Rubber fibres

Table 6 & Fig. 6 depicts the flexural strength of Concrete Beams having different percentages of Rubber Fibres.

Further from results it is clearly illustrated that the concrete Flexural strength increases by adding rubber up to 1.0%. Fig. 7 shows concrete Flexural strength increases by 15.5% by adding 1.0% Rubber Fibres.

iii. Comparison between 20MPa and 30MPa

The comparison between the flexural strength characteristic of 20 MPa and 30 MPa samples is included in the following table 7 and its illustration is shown in the figure 8

Table 7: Comparison between Flexural Strength of 20MPa & 30MPa

Rubber Content (%)	Flexural Strength (MPa)	
	20MPa	30MPa
0%	3.47475	5.9955
0.5%	5.3095	6.0425
1.0%	5.6795	6.92875
1.5%	5.72975	6.30725
2.0%	6.01325	6.2865

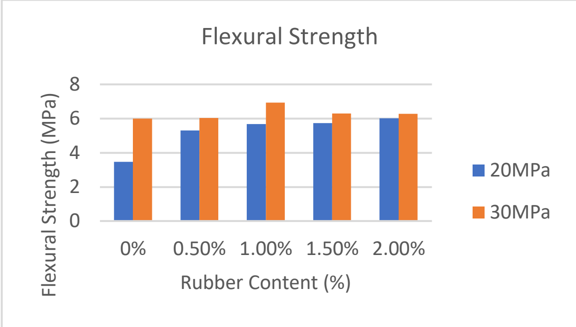

Figure 8: Comparison between Flexural Strength of 20MPa & 30MPa

Table 8 and Fig. 9 shows the Comparison of Increase or Decrease in Flexural Strength of 20MPa & 30MPa.

Table 8: Comparison between Change in Flexural Strength of 20MPa & 30MPa

Rubber Content (%)	Change of Flexural Strength (%)	
	20MPa	30MPa
0.5%	52.80235988	0.783921274
1.0%	63.45060796	15.56584105
1.5%	64.89675516	5.199733133
2.0%	73.05561551	4.85364023

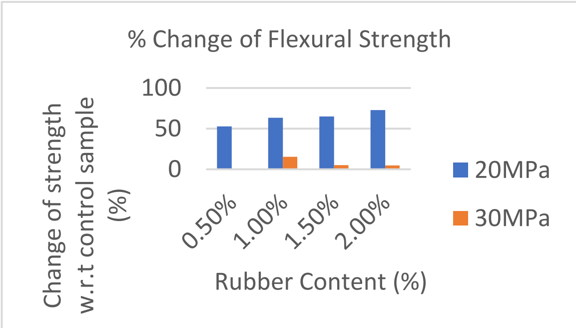

Figure 9: Comparison between Change in Flexural Strength of 20MPa & 30MPa

V. CONCLUSIONS

A. Flexural Strength Characteristics for 20 MPa

- The flexural strength increased with the increase in the rubber fibre content. The maximum flexural strength was found at 2.0% rubber fibre content. The flexural strength of concrete increased up to 73% at 2.0% rubber fibre content
- The behaviour of strength increase was not gradual.

B. Flexure Strength Characteristics for 30 MPa

- The flexural strength increased up to a certain percentage of rubber fibre content i.e. 1.0% after which any additional increase in the rubber fibre content resulted in the decrease in the flexural strength. Flexural strength of concrete increased by 15.5% at 1.0% rubber content.

VI. RECOMMENDATIONS

- The rubber fibre reinforcement could not be amalgamated with additives like silica fume etc which increases the strength of concrete up to 160%. It is a potential recommendation for the researchers
- Rubber pre-treatment with additional chemicals such as NaOH, H_2O and Silane Coupling Agents, Cement Slurry, Mortar etc also improves the internal bonding characteristics of the rubber fibres with concrete which ultimately increases the strength
- The waste tire rubber used in this research did not contain any sort of steel fibre reinforcement (already present in the tires). So, it is suggested to the researchers to use the rubber along with the steel reinforcement inside
- The rubber percentages covered in this research are 0.5%, 1%, 1.5% and 2%. A more detailed rubber percentage division beyond our limitation is highly recommended for future expansion
- Based on the results of this research (Flexural Characteristic) a potential reduction in the reinforcement of the concrete (RCC) must be studied further for economical designing purposes
- A further study in the internal bonding mechanism of rubber with the concrete is to be investigated

- Addition of de-airing agents reduces the air entrainment in the concrete matrix. It is highly recommended to study the said research gap.

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