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Assessment of Mechanical and Durability Properties of Concrete Using Rubber Waste as Partial Replacement of Fine Aggregate

Tikaram Pokhrel[1], Surendra Bahadur Shahi[2], Gokarna Thapa[3]

ABSTRACT Concrete is a basic engineering material used for developing modern structures. At present,river sand is becoming expensive due to higher cost of transportation from river beds. Judiciary and Governments have therefore imposed ban on extraction of river sand from the river bed beyond a certain depth causing a shortage of fine aggregates. Consequently, concrete industry has been forced to look for alternative materials of river sand as fine aggregate. It is therefore desirable to investigate the use of cheaper, easily available and sustainable alternative materials to natural sand. Large quantities of waste rubber tyres are produced every year and accumulation of these tyres is a major problem. The engineering properties of concrete can be enhanced by using different industrial wastes as a replacement of fine aggregate. Waste rubber tyres can be used as in the concrete as replacement of fine aggregate (FA). This would not only solve the problem of accumulation of tyres but will also save natural resources.

Therefore, the present study has been carried out for workability, mechanical and durability properties of concrete containing rubber fiber as partial replacement of fine aggregate. The fine aggregate was substituted with **waste rubber fiber by 5%, 10%, 15%, and 20%** to prepare waste rubber fiber concrete. Tests were performed on concrete samples to analyze workability, compressive strength, flexural strength, water absorption, and abrasion resistance. The compressive strength is adversely affected and the other water absorption are marginally affected. The partial replacement of fine aggregate by rubber fiber is found to enhance the flexural strength and abrasion resistance properties of rubberized concrete. Results indicated that rubber fiber concrete can be used to prepare precast structures, paver blocks and for the applications where high flexural load acts.

Keywords: *Fine aggregate, Rubber fiber, Rubber fiber concrete, Flexural strength, Abrasion Resistance*

1: INTRODUCTION

1.1 Background

Concrete strength is greatly affected by the mix design parameter and the properties of its constituents. Aggregates consist of prime volume of concrete mix and its attributes affect the final product. An aggregate is treated as inert component in concrete. However, due to the increasing awareness of the role played by aggregates in determining many important properties of concrete, the traditional view of the aggregate as inert filler is being seriously questioned. Aggregate was originally viewed as a material dispersed throughout the cement paste largely for economic reasons. It is possible, however, to take an opposite view and to look on aggregate as a building material connected into a cohesive whole by means of the cement paste in a manner similar to masonry construction. [5].

The cost of concrete primarily relies on constituent material costs. It can be decreased by using alternative locally available material to natural ones. The aim of work is to determine suitable material which is economic and massively available.

Rubber concrete is addressed as concrete mix having various amounts of waste rubber. Replacing aggregate with waste rubber in concrete can hike various qualities of concrete. Also, the addition of rubber into concrete results in higher deformation characteristics.

1.2 Environmental problems

1.2.1 Stockpiles of Waste Rubber Tire

1.2.2 Fire Hazard

1.2.3 Health Hazard

Fig. 1.1 Stockpiles of waste rubber tire & fire hazard

Tyres can be recycled in the following basic ways:

a) Used whole in agricultural applications.
b) Whole tyres can be converted into new products.
c) The carbon can be extracted to make carbon black or activated carbon.
d) Hydrocarbons can be extracted to create Limonene ($C_{10}H_{16}$), Diesel fuel ($C_{16}H_{24}$) and Jet Fuel or Kerosene.
e) The steel can enter steel recycling streams.
f) Whole or shredded tyres can be burned for energy.
g) The fibre can be composted, used as filler or incorporated into cement as a reinforcing material.
h) Used whole in engineering and construction applications.
i) Baled whole, and used in bales in engineering and construction applications.
j) Tyres can be mechanically broken down (shredded, crumbed and/or granulated) and used as an input material to create new products or used in landscaping and road making applications.

In view of the above discussions, it can be summarized that waste rubber tyre can be utilized to produce modified concrete which were sustainable and economical. Experimental study is therefore needed to demonstrate the advantages of this modified concrete (waste rubber concrete).

1.3 Objectives

Main Objective:

- To evaluate the fresh and mechanical properties of concrete containing varied percentage of rubber fiber as partial replacement of fine aggregate and to evaluate durability properties and abrasion behaviour of concrete containing varied percentage of rubber fiber as partial replacement of fine aggregate.

Specific Objective:

- To evaluate the physical properties of raw materials.

1.4 Significance of work

Although ample researches have been done in the area of utilization of different kinds of rubber waste in concrete, there is a dearth of systematic experimental studies on the utilization of waste rubber fiber (RF). Researches related to concrete containing RF are still under study. Therefore, the prime aim of this study was to develop concrete mixes with maximized content of RF particles. The analysis of experimental results can contribute in the development of concrete containing rubber tyre waste and lead to a more sustainable concrete product. In this regard, a comprehensive experimental study was conducted to examine the fresh, mechanical, durability, abrasion characteristics of concrete containing RF waste.

2: LITERATURE REVIEW

Eldin and Senouci ,1993) did the research on use of rubber particles from recycled tires as concrete aggregate for engineering applications. They replaced coarse and fine aggregate of the concrete by rubber crumbs and rubber powder, respectively. By 100% substitution of coarse aggregate by rubber crumbs, the maximum compressive strength reduced by 85% and the effect of sand replacement by fine rubber grains resulted in 65% strength reduction. They also added 1-10 wt % (with respect to cement content) rubber crumbs of 4.75 mm in size in concrete and did not observe any significant change in the compressive strength. The rubberized concrete mixtures showed a ductile failure and were able to take more energy. Rubberized concrete experienced a reduction in compressive and tensile strength with increased tire particle content. Strength reduction was due to the poor bonding of cementitious products to surface of rubber particles. [15]

Topcu ,1995 did the research on the properties of rubberized concretes and reported from his study that the changes in the properties of rubberized concretes were observed in terms of both size and amount of the rubber chips. The compressive strength when tested at 28 days was 29.50MPa. It was shown that with the addition of 15, 30 and 45% of coarse rubber powders this value was reduced to 14.60, 8.91 and 5.51 MPa respectively. This represents 51, 70 and 81 percent reduction in compressive strength.[31]

Savas et al. ,1997investigated freezing and thawing durability properties for rubber modified mixtures with 10%-30% granulated rubber by weight of cement. After 300 freeze/thaw cycles, the mixtures with 10% and 15% rubber particles had a durability factor higher than 60, but the other mixtures with 20% and 30% ground rubber by weight of cement could not meet the ASTM standards. The reduction of weight of all mixtures increased with increases in freezing and thawing cycles.[28]

Khatib and Bayomy ,1999 also observed that slump of mixes was near to zero when rubber of 40% added as total aggregate volume. They also reported that mixes with fine particles has high workable than coarse tire particles. High air content was also stated in rubberized mix than control mix due to easily trapping of air by the rough surface of the tire particles. They also reported the influence of rubber particles on the fresh concrete properties. They reported that slump and unit weight of concrete mixtures decreases with increase in rubber content, and air content increases as the rubber content increases.[22]

3: RESEARCH METHODOLOGY

3.1 Raw Materials

3.1.1. Cement

Ordinary Portland cement (OPC) of grade 43 was used as per the BIS 8112 (BIS:8112 1989). The compressive strength at 28 days was found 45.7 N/mm^2. The physical properties of cement are shown in Table 3.1. The main reason for using OPC is because this cement is most widely used and is highly suitable for use in general construction when there is no exposure to sulphates in the soil or groundwater.

Table 3.1 Physical Properties of Cement

Physical properties	Cement
Consistency (%)	27.0
Initial setting time (minute)	116
Final setting time (minute)	236
28 days compressive Strength (MPa)	45.7

3.1.2 Properties of the Aggregate

The relevant tests to identify the properties of the aggregates that were intended to be used in this research were carried out. In general, aggregates should be hard and strong, free of undesirable impurities, and chemically stable.

3.1.2.1. Fine aggregate

Fine aggregate sample used in this experiment was purchased from local suppliers. River sand is a naturally occurring granular material composed of finely divided rock and mineral particles. The composition of sand is highly variable, depending on the local rock sources and conditions.

To investigate its properties and suitability for the intended application, the following tests were carried out, including sieve analysis for fine aggregate and specific gravity of fine aggregate.

Sieve analysis is a procedure for the determination of the particle size distribution of aggregates using a series of square or round meshes starting with the largest. It is used to determine the grading, fineness modulus, an index to the fineness, coarseness and uniformity of aggregates. The quality of concrete to be produced is very much influenced by the properties of its aggregates. The laboratory tests were carried out to identify the physical properties of the fine aggregate and the results are shown in Table 3.2. The sieve analysis test was performed according to the BIS 383 (BIS:383 2016). As per recommendation of BIS 383 test results was compared to the code and it comes under zone II.

Table 3.2 Sieve Analysis for Fine Aggregate

Sieve Size (mm)	Wt. Retained (gm)	% Retained	Cumulative Retained	% Passing	% passing Zone II (IS 383)
10	0	0.00	0.00	100	100
4.75	0	0.00	0.00	100.00	90-100
2.36	35	3.50	3.50	96.50	75-100
1.18	165	16.50	20.00	80.00	55-90
.6	234	23.40	43.40	56.60	35-59
.3	416	41.60	85.00	15.00	08-30
.015	135	13.50	98.50	1.50	0-10
Fineness modulus = 250.4/100 = 2.50					

The specific gravity and water absorption of fine aggregate was evaluated as per the guidelines of BIS 2386-part III (BIS:2386 1997). The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. The structure of the aggregate (size, number, and continuity pattern) affects water absorption, permeability, and specific gravity. The specific gravity test was performed in the laboratory and Table 3.3 shows the result of specific gravity of fine aggregate.

Table 3.3 Specific Gravity of Fine Aggregate

Weight of flask (W_1)	Weight of flask + aggregate (W_2)	Weight of flask + aggregate + water (W_3)	Weight of flask + water (W_4)	$W_2 - W_1$	$W_3 - W_4$	Specific gravity $(W_2 - W_1)/[(W_2 - W_1)-(W_3 - W_4)]$
963	1443	1598	1298	480	300	2.66

3.1.2.2 Coarse Aggregate

Coarse aggregate for concrete shall consist of natural gravel or crushed rock or a mixture of natural gravel and crushed rock. Coarse aggregate used in this research was purchased from nearby retailer. In a similar manner like the fine aggregate, laboratory tests were carried out to identify the physical properties of the coarse aggregate and the results are shown below in Table 3.4. Table 3.5 shows the sieve analysis test results. The specific gravity and water absorption of coarse aggregate was also evaluated as per the guidelines of BIS 2386-part III (BIS:2386 1997).

Table 3.4 Physical properties of Aggregate

Physical properties	Fine aggregate	10 mm	20 mm	Rubber fiber
Water absorption (%)	1.1	0.5	0.70	Nil
Specific gravity	2.66	2.70	2.78	1.08

Table 3.5 Sieve analysis of coarse aggregate of 10 mm size

Sieve size (mm)	Aggregate retained on each sieve (gm)	% retained	Cumulative % retained	% Passing
20	0	0	0	100
10	908	30.27	30.27	69.73
4.75	2075	69.17	99.44	0.56
Pan	17	0.57	-	-
Total	3000	-	129.71	-

Table 3.6 Sieve analysis of coarse aggregate of 20 mm size

Sieve size (mm)	Aggregate retained on each sieve (gm)	% retained	Cumulative % retained	% Passing
40	0	0	0	100
20	199	6.63	6.63	93.37
10	2776	92.53	99.16	0.84
4.75	25	0.83	100	0
Total	**5000**	**-**	**205.79**	**-**

Table 3.7 Specific gravity of coarse aggregate of 10 mm size

Weight of flask (W_1)	Weight of flask + aggregate (W_2)	Weight of flask + aggregate + water (W_3)	Weight of flask + water (W_4)	$W_2 - W_1$	$W_3 - W_4$	Specific gravity $(W_2 - W_1)/[(W_2 - W_1)-(W_3 - W_4)]$
963	1511	2771	2426	548	345	2.70

Table 3.8 Specific gravity of coarse aggregate of 20 mm size

Weight of flask (W_1)	Weight of flask + aggregate (W_2)	Weight of flask + aggregate + water (W_3)	Weight of flask + water (W_4)	$W_2 - W_1$	$W_3 - W_4$	Specific gravity $(W_2 - W_1)/[(W_2 - W_1)-(W_3 - W_4)]$
963	1710	2902	242	7	4	2.79

			3	47	79	

3.1.3 Rubber fiber

Rubber fibers were 2 mm to 5 mm in width and up to 20 mm in length (aspect ratio 4 to 10) with a specific gravity of 1.08. The particle size distribution of the RF has been shown in Table 3.9. These RF were obtained from mechanical grinding of waste rubber tyres. The grain size analysis of RF confirms to Zone II, as per BIS 383 (BIS:383 2016). The physical properties of the RF particles are presented in Table 3.4. The water absorption for RF was negligible. In this study RF was procured form the local retailer. Table 3.10 shows the result of specific gravity of RF.

Table 3.9 Sieve analysis for rubber fiber

Sieve Size (mm)	Wt. Retained (gm)	% Retained	Cumulative Retained	% Passing
10	0	0.00	0.00	100
4.75	20	2	2	98
2.36	60	6	8	92
1.18	150	15	23	77
.6	290	29	52	48
.3	300	30	82	18
.015	120	12	94	6
Fineness modulus = 261/100 = 2.61				

Table 3.10 Specific gravity test for rubber fiber

Weight of flask (W_1)	Weight of flask + aggregate (W_2)	Weight of flask + aggregate + water (W_3)	Weight of flask + water (W_4)	$W_2 - W_1$	$W_3 - W_4$	Specific gravity $(W_2 - W_1)/[(W_2 - W_1)-(W_3 - W_4)]$
963	1113	1154	1143	150	11	1.08

3.1.4 Water

The quality of the water plays a significant role in concrete production. Impurities in water may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface, and may also lead to corrosion of the reinforcement. For these reasons, the suitability of water for mixing and curing purposes should be considered. In this research, tap water at room temperature was used in all mixes.

3.1.5 Admixture
Modified polycarboxylic ether based, ASTM type F, high range water super reducing plasticizer (HRWR) procured from BASF was used to cast concrete specimens.

3.2 Mix design

Materials such as cement, sand, coarse aggregate and rubber fiber were procured and tested for physical properties. After procurement and testing of constituent materials following steps were adopted to cast the samples of waste rubber concrete:

3.2.1 Mix Proportion
A particular mix design method determines a set of mix proportions for producing a concrete that has approximately the required properties of strength and workability.

Concrete mix design method was used in this experimental study as per BIS 10262 (BIS:10262 2019). Mixes were prepared for water cement ratio of 0.45. Fine aggregate was replaced volumetric by rubber fiber at an amount of 0, 5, 10, 15, and 20%. Table 3.11 below shows the material constituents of the mix design adopted for this experimental study.

Table 3.11 Details of mixture (kg/m^3)

Mix no.	Cement	Water	Fine aggregate	Coarse aggregate		Rubber fibers	HRWR (%)
				10mm	20mm		
RF0	425	191	662	591	591	0	0.5
RF5	425	191	628	591	591	13.4	0.5
RF10	425	191	595	591	591	26.8	0.5
RF15	425	191	562	591	591	40.3	0.5
RF20	425	191	529	591	591	53.7	0.5

Details of typical mixes were also explained below for more clarity:

- RF0- Stands for the mix of M35 concrete with no sand replacement.
- RF20- Stands for the mix of M35 concrete with 20% volume of the fine aggregate of the control mix replaced by an equivalent volume of the rubber fiber aggregate.

In this study, cubes and beams specimens were cast during for different tests, whose details are shown in Table 3.12.

Table 3.12 Concrete testing

Test	Shape and dimensions of the specimens	Time duration (in days)
Compressive strength	Cube : 100mm × 100mm × 100mm	7, 28
Flexural strength	Beam : 500mm × 100mm × 100mm	7, 28
Abrasion resistance	Cube : 70mm × 70mm × 70mm	28
Water absorption	Cube : 100mm × 100mm × 100mm	28

3.2.2 Mixing of concrete and preparation of concrete specimens
It is essential that the mix ingredients are properly mixed so as to produce fresh concrete. Thorough mixing is essential for the complete blending of the materials that are required for the production of homogeneous, uniform concrete. The type of mixer used in the laboratory for this research is a pan type as shown in Fig. 3.4 below.

In this process all the material was put down in a drum which was held over a rotary pan mixer. All the dry material was put first into the chamber for a dry mix. Then half of the water was added to prepare a desirable concrete mix. The rotary mixer was rotated for 1-2 minutes at a constant speed. The remaining water with admixture was then added to mix and mixer was rotated for another 3-4 minutes. The prepared mix was discharged from the mixer and workability test was performed. The specimens (Fig. 3.5) were then cast for evaluating the hardened characteristics.

Fig. 3.4 Concrete mixing using a Pan Mixer

Fig. 3.5 Casting of concrete Specimens

All concrete requires curing in order that cement hydration can proceed so as to allow for development of strength, durability and other mechanical characteristics (as shown in Fig. 3.6). To obtain good concrete, the placing of an appropriate mix must be followed by curing in a suitable environment, especially during the early stages of hardening. Curing is the name given to procedures used for promoting hydration of cement, and consists of a control of temperature and moisture movement from and into the concrete. Curing is the process of protecting concrete for a specified period of time after placement, to provide moisture for hydration of the cement, to provide proper temperature and to protect the concrete from damage by loading or mechanical disturbance.

Fig 3.6 Curing of concrete Specimens

3.3 Testing of concrete

3.3.1. Workability Test

A concrete mix must be made of the right amount of cement, aggregates and water to make the concrete workable enough for easy compaction and placing and strong enough for good performance in resisting stresses after hardening. If the mix is too dry, then its compaction will be too difficult and if it is too wet, then the concrete is likely to be weak. During mixing, the mix might vary without the change very noticeable at first. For instance, a load of aggregate may be wetter or drier than what is expected or there may be variations in the amount of water added to the mix. These all necessitate a check on the workability and strength of concrete after producing. Slump test is the simplest test for workability and is most widely used on construction sites. The slump test was performed as per the guidelines given in the Bureau of Indian standards BIS:1199 (BIS:1199 1959). In the slump test, the distance that a cone full of concrete slumps down is measured when the cone is lifted from around the concrete. The slump can vary from nil on dry mixes to complete collapse on very wet ones. One drawback with the test is that it is not helpful for very dry mixes. The slump test carried out was done using the apparatus shown in Fig. 3.7.

Fig. 3.7 Slump Test

The mould for the slump test is in the form of a frustum of a cone, which is placed on top of a metal plate. The mould is filled in three equal layers and each layer is tamped 25 times with a tamping rod. Surplus concrete above the top edge of the mould is struck off with the tamping rod. The cone is immediately lifted vertically and the amount by which the concrete sample slumps is measured. The value of the slump is obtained from the distance between the underside of the round tamping bar and the highest point on the surface of the slumped concrete sample. The types of slump i.e. zero, true, shear or collapsed are then recorded.

3.3.2 Compressive strength

Concrete mixture was designed to produce a wide range of mechanical and durability properties to meet the design requirements of a structure. The compressive strength of concrete is the most common performance measure used by the engineer in designing buildings and other structures. The compressive strength was calculated by breaking cubical concrete specimens in a compression-testing machine. The compressive strength was calculated from the failure load divided by the cross-sectional area resisting the load and reported in units of mega Pascal's (MPa) in SI units. Compressive strength was performed on 100 mm cubes as per BIS 516 (BIS:516 1959). The load was applied at a rate of 140 $kg/cm^2/min$. Compressive strength of concrete was tested after 7 and 28 days of curing. This test is performed on compressive test machine (CTM) as shown in Fig 3.8.

Fig. 3.8 Compressive Test Machine

3.3.3 Flexure Strength

This test gives another way of estimating flexure strength of concrete. The member resisting the action is subjected to internal actions or stresses (shear, tensile and compressive). For a bending force applied downward on a member supported simply at its two ends, fibers above the neutral axis are, generally, subjected to compressive stresses and those below the neutral axis to tensile stresses.

In this test, the concrete member to be tested is supported at its ends and loaded at its interior locations by a gradually increasing load to failure (as shown in figure 3.9). Flexural strength test was conducted using four-point loading system on beams (three for each mix) of 500 × 100 × 100 mm at 7 and 28 days of curing period according to the guidelines given in BIS 516 (BIS:516 1959).

The failure load (loading value at which the concrete cracks heavily) is then recorded and used to determine the flexure strength at which the member failed, i.e. its flexure strength. The calculation of the flexure stress at failure (flexure strength) is as follows:

Flexural strength (MPa) = fl/bd^2

Where:

f = Failure Load (kg), l = Span of Specimen (mm)

d = Depth of specimen (mm), b = Width of the specimen (mm)

Fig. 3.9 Flexural Test Machine

3.3.4 water absorption
The water absorption test was carried out as per BS 1881-122 (BS:1881-122 2011). Three oven dried specimens were placed for 24 hours in water bath. The initial weight and final weight were recorded and the percentage of water absorption was determined as per the guidelines of the codes.

3.3.5. Abrasion Resistance
Abrasion resistance test will be performed on the prepared specimens (without and with Waste Rubber) as per recommended guide lines of BIS 1237 (BIS:1237 2012). The weight of the specimen shall be noted to nearest 0.1 g both prior to the abrasion test and after every four cycles. The specimen shall be fixed in the holding device such that the testing surface faces the grinding disc (as shown in figure 3.10). The contact face and the opposite face of the specimen shall be parallel and flat. The grinding disc shall be run at a speed of 30 rpm. The disc shall be stopped after one cycle of 22 revolutions. The disc and contact face of the specimen shall be cleaned of abrasive powder and debris. The specimen shall be turned 90° in the clockwise direction and 20 g of abrasive powder shall be evenly strewn on the testing track before starting the next cycle. The test cycle shall be repeated 10 times, the specimen being turned 90° in the clockwise direction and spreading of 20 g of abrasive powder on the testing track after each cycle. The abrasive wear of the specimen after 10 cycles of testing shall be calculated as the mean loss in specimen thickness.

The specimen thickness can be calculated from:

$$T = \frac{(W1-W2).V}{W1.A} \qquad \text{where;}$$

T = average loss in thickness, in mm;

W1 = initial mass of the specimen, in g;

W2 = final mass of the abraded specimen, in g;

V1 = initial volume of the specimen, in mm3 ; and

A = surface area of the specimen, in mm.

Fig. 3.10 Abrasion Testing Machine

4: RESULTS AND DISCUSSION

4.1 General
This section describes the results of the tests carried out to investigate the various mechanical and durable properties of the rubberized concrete mixes prepared in contrast with the design mixes. In the succeeding parts, the results for workability, compressive strength, impact resistance and flexure strength tests are presented. Analysis and discussions are also made on the findings.

4.2 Fresh concrete properties

4.2.1 Workability
The value for workability is a prime indicator towards the feasibility of utilisation of waste in concrete. The workability was

computed in terms of slump value. The value of the slump is obtained from the distance between the underside of the round tamping bar and the highest point on the surface of the slumped concrete sample. Fig. 4.1 shows the results of the slump test for the plain concrete and the rubberized concrete.

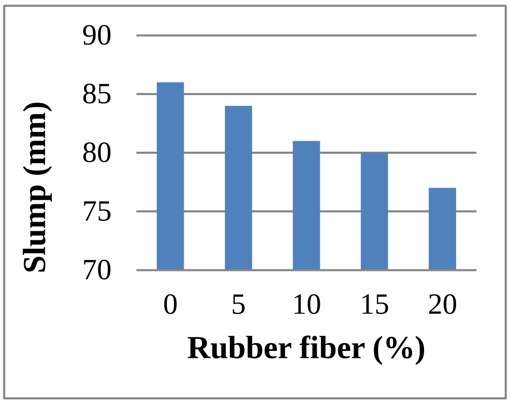

Fig. 4.1 Slump test results for concrete containing varied percentage of rubber fiber

The slump value for all the mixes containing 0 to 20% rubber fiber ranged from 77 to 86 mm. The slump value is 86 mm for control concrete whereas slump value increased to 77 MPa for higher replacement level of rubber fiber (20%) mix. Maximum slump value occurs in control sample whereas minimum slump value occurs when the replacement level of RF is 20%.

The introduction of recycled RF to concrete decreased the slump and mixes are stiffer. The rubber aggregate had a rough and irregular surface texture, which might have increased the inter-particle friction resulting in the decrease of the workability of the concrete. Alike trend of findings was observed by Gupta et al. [20] in their study on rubber fiber concrete for the different replacement percentages of rubber fiber with fine aggregates (ranging from 0-25%). The study done by Alsaif et al. [3] also reported that substitution of rubber aggregates with fine aggregate in steel fiber reinforced rubberized concrete (SFRRC) mixes significantly reduced workability.

However, the slump value for all the concrete mixtures falls in the medium workability (50-100 mm) range. Hence replacement of up to 20% replacement of fibers is acceptable in terms of workability.

4.2.2 Compressive strength

The compressive strengths of concrete specimens were determined after 7 and 28 days of standard curing. The compressive strength test was conducted on 100 mm cubes. Results of compressive strength of concrete with different percentage level of RF have been shown in Fig. 4.2. It can be observed from figure that reduction of compressive strength has been observed with the inclusion of RF in place of fine aggregate. This reduction in compressive strength is increased with the increase in percentage of RF. However, increase in compressive strength was observed with the increase in curing days. The compressive strength is MPa mm for control concrete whereas compressive strength increased to 18.83 MPa for higher replacement level of rubber fiber (20%) mix at 7 days curing. The compressive strength is MPa mm for control concrete whereas compressive strength increased to 23.27 MPa for higher replacement level of rubber fiber (20%) mix at 28 days curing. Minimum flexural strength occurs in control sample for both curing days whereas maximum flexural strength occurs when the replacement level of RF is 20% for both curing days.

The reason for the compressive strength reductions could be attributed both to a reduction of quantity of the solid load carrying material and to the lack of adhesion at the boundaries of the RF. Soft rubber particles behave as voids in the concrete matrix [4,17]. Considering the very different mechanical properties of mineral aggregates and RF, mineral aggregates usually have high crushing strength and they are relatively incompressible, whereas RF is compressible, and resilient. Rubber also has a very low modulus of elasticity of about 7MPa and a Poisson's ratio of 0.5. Therefore, RF tend to behave like weak inclusions or voids in the concrete, resulting in a reduction in compressive strength. Earlier also, reduction in compressive strength on replacement of coarse aggregate by rubber crumb was found on addition of SF in rubber concrete [36].

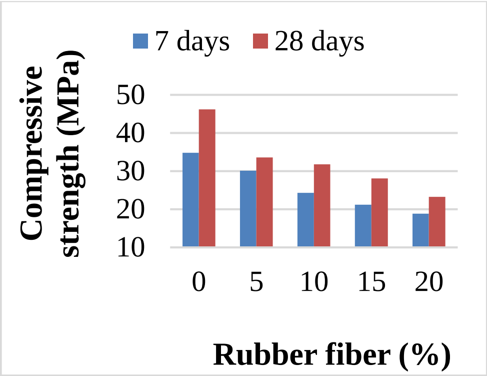

Fig. 4.2 Compressive strength results for concrete containing varied percentage of rubber fiber

4.2.3 Flexural strength

The flexural strength of concrete specimens was determined after 7 and 28 days of standard curing. The compressive strength test was conducted on 500 x 100 x 100 mm beams. Results of flexural strength of concrete with different percentage level of RF have been shown in Fig. 4.3. It can be observed from figure that increase in flexural strength has been observed with the inclusion of RF in place of fine aggregate. The increase in flexural strength is owing to fibers which provide a better bridge between propagated cracks. Moreover, the increase in flexural strength was observed with the increase in curing days. The flexural strength is 2.18 MPa for control concrete whereas flexural strength increased to 3.63 MPa for higher replacement level of rubber fiber (20%) mix at 7 days curing. The flexural strength is 3.30 MPa for control concrete whereas flexural strength increased to 4.55 MPa for higher replacement level of rubber fiber (20%) mix at 28 days curing. Minimum flexural strength occurs in control sample for both curing days whereas maximum flexural strength occurs when the replacement level of RF is 20% for both curing days.

It may be noted that, earlier also, upto 15% increase in flexural strength was reported by Ganesan et al. [16] on replacement of 15% of the sand by shredded rubber aggregate. Increase in flexural strength in the present study may be due to the effect of rubber fibers and gradual collapse of specimens under bending load.

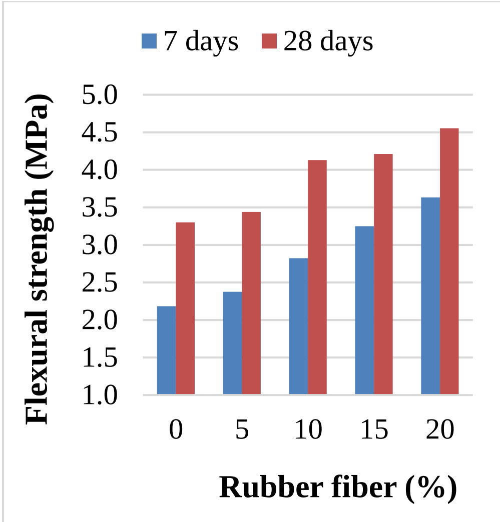

Fig. 4.3 Flexural strength results for concrete containing varied percentage of rubber fiber

4.2.4 Water absorption

The water absorption of concrete specimens was determined after 28 days of standard curing. The water absorption test was conducted on 100 mm cubes. Results of water absorption of concrete with different percentage level of rubber fiber have been shown in Fig. 4.4. It can be observed from figure that increase in water absorption has been observed with the inclusion of RF in place of fine aggregate. The water absorption is 1.03% for control concrete whereas water absorption increased to 1.49% for higher replacement level of rubber fiber (20%) mix. Minimum water absorption occurs in control sample whereas maximum water absorption occurs when the replacement level of rubber fiber (RF) is 20%.

The higher water absorption of rubber modified concrete can be attributed to the morphology of RF, which resulted in the continuities in terms of gap and cavities along the interfacial transition zone (ITZ) between cement paste (or aggregate) and rubber fiber [40]. The inclusion of fiber can induce higher porosity than control concrete which may also be the reason for the higher water absorption of rubber modified concrete.

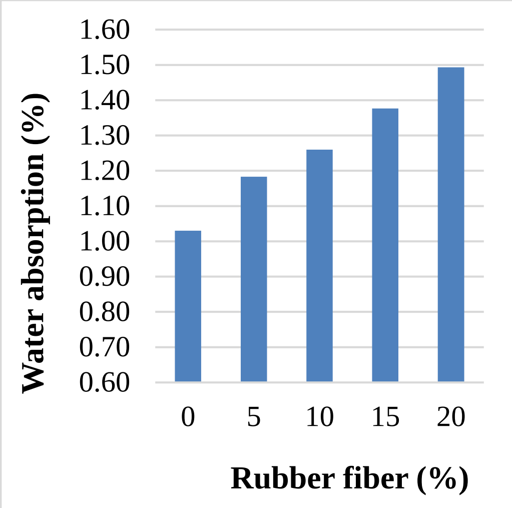

Fig. 4.4 Water absorption results for concrete containing varied percentage of rubber fiber

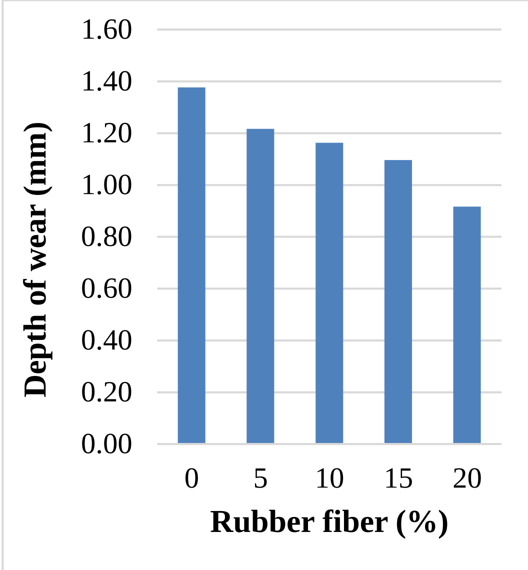

Fig. 4.5 Abrasion resistance results for concrete containing varied percentage of rubber fibe

4.2.5 Abrasion resistance

Deterioration of concrete may take place due to abrasion caused by movement of various objects on the concrete surface. Depth of wear of concrete is measured under standard testing conditions for evaluating the abrasion. The abrasion resistance of concrete specimens was determined after 28 days of standard curing. The abrasion resistance test was conducted on 70 mm cubes. Results of abrasion resistance of concrete with different percentage level of RF have been shown in Fig. 4.5. The abrasion resistance for concrete containing rubber fiber was reported in terms of depth of wear. It can be observed from figure that reduction in depth of wear has been observed with the inclusion of RF in place of fine aggregate. Depth of wear is 1.38 mm for control concrete whereas depth of wear decreased to 0.92 mm for higher replacement level of rubber fiber (20%) mix. Maximum loss in thickness occurs in control sample whereas minimum loss occurs when the replacement level of RF is 20%.

It may be noted that, earlier also, upto 81% reduction in depth of wear was reported by Gesoglu et al. [19] on replacement of 20% of the natural aggregate by rubber particles. Decrease in depth of wear in the present study may be due to ability of the rubber fiber to hold the cement paste.

5. CONCLUSION AND RECOMMENDATIONS

The objective was to evaluate fresh and hardened properties of modified concrete produced by replacement of fine aggregates by rubber fiber. Various properties of this modified concrete with varied replacement level of rubber fiber have been discussed in previous chapters. Various tests for fresh and hardened properties of waste rubber concrete were performed to assess the workability, mechanical strength, and durability of concrete along with abrasion resistance. As rubber aggregate are a product of used rubber tyres, detailed study of waste rubber concrete was carried out to ensure compatibility of this material with the concrete. From the discussion of results of rubberized concrete, following conclusions can be drawn:

I. The replacement of fine aggregate by rubber fiber decreases the workability of concrete.
II. Addition of rubber fiber resulted in decline of concrete compressive strength. Although compressive strength values considerably increased for rubber modified concrete with the increase in curing days.

III. The replacement of fine aggregate by rubber fiber increases the flexural strength of the concrete. The increase in flexural strength was observed up to 20% replacement of the fine aggregate with rubber fiber.

- *Tikaram Ram Pokhrel is currently pursuing master's degree program in structural engineering in Graduate School of Engineering, Mid-West University, Nepal,*
- *Surendra Bahadur shahi is currently working as Asst.Prof at Central Department of Civil Engineering, Mid-West University, Nepal*
- *Gokarna Thapa is Graduate of Masters in Structural Engineering from Department of Civil Engineering, Mid-West University, Nepal*

IV. The replacement of fine aggregate by rubber fiber increases the water absorption of the concrete.

V. It is also observed that abrasion resistance increases with increasing replacement level of rubber fiber. It can be also seen that rubberized concrete with replacement level more than 20%, the reduction of thickness is less than 2 mm. This type of concrete can be used in many desirable applications (paver blocks and other).

VI. It can be summarised that it is possible to use recycled rubber tyre in construction works, such as reduction in unit weight, and high abrasion resistance. Usage of waste rubber will save natural resources (fine aggregate) and also modified concrete will be economic as compared to control cement concrete.

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