Cumulative effect of Recycled Tyre Steel Fibre and crumb rubber on impact resistance of concrete

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Abstract

Structures such as Rigid pavement, water-retaining structures and industrial floors maybe subjected to various environmental and loading conditions. Concrete is very sensitive to strain rate loading; hence Concrete structures exhibit different response under static loadings and dynamic or repeated loadings. Due to brittle property and low tensile strength of concrete, induced tensile stresses in concrete when dynamic forces and concrete plastic shrinkage loads are applied, cracking patterns are created in concrete which ultimately affect the durability of concrete structures. Combining crumb rubber and recycled steel cord extracted from waste tyre as fibre reinforcement in concrete can enhance the ductility property and impact energy storing capacity of concrete and again limiting the crack initiation and propagation in concrete structures. Application of recycled waste tyre products in concrete production will solve the disposal problem of used tyres which are dumped in environment. The overall objective of this study, is to assess the combined effect of recycled tyre steel fibre and crumb rubber on impact energy resistance of concrete. Concrete Compressive and tensile strengths of rubber concrete with 5%, 10%,12.5%,15% and 20% rubber content were tested on 7 and 28 days. The resulted optimum crumb rubber which is 12.5% replacement of fine sand and different dosages of recycled tyre steel fibre (RTSF) of 0.3%,0.6%,0.9% and 1.2% by mass of concrete were mixed in *concrete to investigate impact resistance of Recycled tyre steel fibre reinforced rubber concretes (RTSFRC). To determine effect of fibre aspect ratio , the steel cord were cut into three different lengths,20mm,40mm and 60mm. 32 concrete cylindrical discs of 150mm diameter and 64 ±0.5mm samples were casted and tested on 28 days using Drop-weight test method described in ASTM-D1557.The effect of the fibre volume fraction and its aspect ratio on impact resistance were evaluated. The results indicated that, the Combining crumb rubber and recycled steel fibres enhance significantly the impact resistance of concrete.*

Key words: Recycled tyre steel fibre(RTSF), Crumb Rubber, Recycled tyre steel fibre reinforced rubber concrete(RTSFRC); Impact energy; compressive strength; split Tensile strength, drop-weight test; Number of blows.

1. INTRODUCTION

In the last few decades, there has been an increase of vehicular density due to global development and increase of population density. This has led to production of huge amount of waste tyres. Over 1.5 Billion tons of waste tyre are produced annually on the world (BMZ, 2014).The disposal of the waste tyre has raised environmental concern due to problem associated with dumping waste tyre in environment. Using recycled tyre rubber in concrete as aggregates has improved some properties of concrete such as ductility, and impact resistance, however, compressive, tensile and flexural strengths decrease (M. A. Yazdi, 2015).It was reported that incorporating Steel fibres in concrete can enhance mechanical property , toughness, fatigue resistance, impact resistance, ductility, post-cracking behaviour and durability of concrete (ACI committee 544.R5-10, 2010) (Carpenteri.A,Bringheti.R, 2010).Concrete with the above mentioned enhanced properties is preferred in construction of airport runaway pavements, Industrial flooring, bridges ,military buildings and hydraulic structures where impact loading is enormous. Under impact loading, plain concrete exhibits excessive cracking and undergoes brittle failure mode with a relatively low impact energy absorption capacity. Fibre reinforced concrete is best candidate for concrete structures resisting impact loads and limiting initiation and propagation of plastic shrinkage cracks which usually affect durability of concrete structures (ACI committee 544.R5-10, 2010).

Recently, effort have been made to develop methods of extracting waste tyre steel cord, bead wires and their application in Construction industry. Concrete obtained by adding randomly distributed Recycled steel fibres evidenced a satisfactory improvement ductility property, toughness, post crack strength and impact resistance. In addition, it was stated that mechanical behavior of concrete reinforced with steel fibres extracted from waste tyres is comparable to that of conventional steel fibre reinforced concrete (M, L. F. G. Alien,F.leuzzi,GCentonze, 2009).As consequence, Concrete made with Recycled tyre steel fibre(RTSF) and Crumb rubber appears to be a promising candidate for Construction of structures resisting dynamic loading.

In the current study, weight drop test method described in ACI committee 544 was used to determine the performance of recycled tyre steel fibre reinforced rubber concrete in terms of Impact energy at first crack and ultimate failure. Different (RTSF) percentage mass of concrete, 0.3%,0.6%,0.9% and 1.2% were added to rubber concrete of optimum value of rubber content which was found to be 12.5%. The effect of crumb rubber content on Compressive and Split tensile strength was also studied at 7 and 28 days of curing. Since it was reported that aspect ratio of a fibre affects its performance in concrete so, the tyre steel cord were cut into three different lengths, 20mm,40mm and 60mm.

The result of this research indicate that, combining Crumb rubber and recycled Tyre steel fibre in concrete has substantially enhanced the first crack and ultimate crack impact energy.

2. MATERIAL AND METHOD

2.1. Materials

2.2.1. Cement

The cement used in all mixes was a locally manufactured Bamburi Portland limestone cement of class 42.5MPa having a specific gravity of 3.10. From the tests results, the cement conforms with European standard (EN) 196-1 and Kenyan bureau of standards.

2.2.2. Aggregates

Locally available Crushed coarse aggregates of size ranging 5- 15mm and Natural river sand with maximum size of 4.75mm were used in this study. Crumb rubber were produced by crushing and granulating waste tyre rubber into fine rubber of a maximum size passing sieve 4.75mm. All Properties of aggregates used are summarized in table 2.

2.2.3. Steel fibres

Steel fibres used in this research were from cutting of recycled high strength tyre steel cord from waste tyres. These steel cords were one of the products of pyrolysis processing of waste tyres. The steel cords were having carbon black on its surface. Due to the tyres were heated in the absence of the oxygen (non-reactive environment) the tyre steel cords Tensile strength was not affected with a mean value of 1015MPa and average diameter of 1.15mm. These steel cord were cut into three different sizes, 20mm, 40mm and 60mm using grinding machine and metal cutting discs. Crumb rubber and tyre steel fibre used can be seen on Fig.1 and Fig.2 respectively.

2.2.4. Water and Superplasticizer

Due to impracticability of the RTSFRC, a high-range water reducers (HRWR) SP430 was used in all mixes to increase workability. Potable water was used in all mixes at 0.5 Water/cement ratio.

Fig.1 Crumb rubber

Fig. 2 Recycled tyre steel fibre

2.2. Method

2.2.1. Mix design proportions

A 30MPa class concrete control mix was designed to achieve a slump value of 30-60mm according to BS8110 and BS1988.Crumb rubber of 5%,10%,12.5%,15% and 20% replacing fine aggregates were added in concrete, and their Compressive strength and split tensile strength were determined on 7 and 28 days of curing according to BS1881: part 116 (BSI, 1987), (BSI, 1983) respectively .An optimum value of Rubber content 12.5% was mixed with different parcentages of Recyled tyre steel fibres by 0.3%,0.6%,0.9% and 1.2% of the mass of concrete with three different fibre lengths 20mm,40mm and 60mm and their corresponding Compressive, Split tensile strength and Impact energy were detrmined. Material proportions for all concrete mixes are summarized in Table 1. Water/cement ratio was maintained constant in all mixes with a value of 0.5. The mix designation is coded as CR*m*-V*n*L*p*, where *m*, *n* and *p* are percentage volume of crumb rubber, percentage of Recycled tyre steel fibres and length of Recycled tyre steel fibre (mm) respectively.

2.2.2. Sample preparation and test procedure

Table.1 Mix design proportions

Mix Designation C30	Rubber (kg/m^3)	W/C Ratio	Water Content (kg/m^3)	Cement Content (Kg/m^3)	Fine Agg. (Kg/m3)	Coarse aggregate (kg/m^3)	Admix. (l/m^3)	Steel fibre (kg/m^3)
CR0	0	0.5	195	390	727.75	1047.25	3.3	0
CR5	12.4	0.5	195	390	691.3	1047.25	3.3	0
CR10	24.8	0.5	195	390	654.9	1047.25	3.3	0
CR12.5	31	0.5	195	390	636.8	1047.25	3.3	0
CR15	37.2	0.5	195	390	618.6	1047.25	3.3	0
CR20	49.6	0.5	195	390	582.2	1047.25	3.3	0
RC12.5-V0.3L60	31	0.5	195	390	636.8	1047.25	3.3	7.2
CR12.5-V0.6L60	31	0.5	195	390	636.8	1047.25	3.3	14.4
CR12.5-V0.9L60	31	0.5	195	390	636.8	1047.25	3.3	21.6
CR12.5-V1.2L60	31	0.5	195	390	636.8	1047.25	3.3	28.2
CR12.5-V0.9L20	31	0.5	195	390	636.8	1047.25	3.3	21.6
CR12.5-V0.9L40	31	0.5	195	390	636.8	1047.25	3.3	21.6

Pyhsical properties of Cement and all aggregates used were detremined according to BS410. Workability of all mixtures was detrmined according to BS1881 (BS1881-102, 1983), and high range water reducer SP430 was added in all mixes to increases the practicability of fibre rubber concrete.

Concrete cubes of 150x150x150mm and concrete cylinders of 100mm diameter and 200mm height were casted, cured and tested for compressive and Split tensile strength using Universal testing machine at 7 and 28 days in accordance with BSI 1987-116 and BS1987-117 respectively.

Impact energy was studied according to ASTM-D1557.A Drop -weight test method was used. The equipment for testing was manufactured in JKUAT mechanical department laboratory. The equipment has (1) a standard manually operated 4.54kg compaction hammer with a drop height of 457mm, (2) a 63.5mm diameter of hardened steel ball (3) and a Flat base plate (ACI committee5 44, 1978). The testing specimen were concrete discs with 150mm diameter and 63.5±0. 5mm.This was achieved by sawing a full size concrete cylinder as described in ASTM-C31 and C470.The hardened metal ball was placed on top of the sample and 4.54kg hammer was released from height of 457mm to hit the ball placed on the specimen. The number of blows required to cause the first crack and ultimate failure were recorded. White paint was smeared on concrete specimen surface to facilitate identification of first crack. The test equipment and testing method can be seen on Fig.6.The equation from Eq1-5 were used to calculate Impact energy.

$$E_I\,(dynamic) = {}^1\!/_2\, xmxV^2xN \ldots\ldots\ldots\ldots Eq.1$$

$$E_I\,(Static) = {}^1\!/_2\, xmxHxgxN \ldots\ldots\ldots\ldots Eq.2$$

$$V = gt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.3$$

$$H = {}^1\!/_2\, gt^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.4$$

$$m = W / g \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.5$$

where E_I - Impact Energy(N-m)
m - Drop hammer mass
V -Impact speed (m-s)
H -Height of drop mass(mm)
N-Number of blows

Substituting the value of height of fall, in Eq.3 and Value of Eq7 in Eq.1, the Impact energy required for one blow of the hammer is obtained in Eq.9.

$$457 = {}^1\!/_2 \times 9810 \times t^2 \ldots\ldots\ldots\ldots\ldots\ldots Eq.6$$

$$t = 0.3052 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.7$$

$$V = 9810 * 0.3052 = 2994.01\, {}^{mm}\!/_{s} \ldots\ldots\ldots\ldots Eq.8$$

$$U = {}^1\!/_2 \times 45.4 \times 2994.01^2. = 20.742KNmm \ldots\ldots\ldots Eq.9$$

Table. 2 Physical Properties and grading of Aggregates

A. Sieve Analysis			
Sieve size	**%passing**		
	Coarse aggregates	**fine aggregates**	**Rubber crumb**
19mm	100	-	-
12.5mm	94.45	-	-
9.5mm	13.3	-	-
4.75mm	-	99.6	100
2.36mm	-	97.1	98.6
1.18mm	-	84.7	92.4
600µm	-	50.7	71.4
300µm	-	31.1	29.6
150µm	-	7.2	9
fineness	5.7	3.45	2.9
B. physical properties			
Dry -rodded density(kg/m3)	1456.6	1659.3	615
Dry-loss density (Kg/m3)	1296.2	1518.7	592
Bulk specific gravity (SSD condition)	2.61	2.48	0.83
Aggregate Crushing Value (%)	19.1	3	1.2
Aggregate Impact value (%)	7.6	-	-

3. RESULTS AND DISCUSSION

3.1 Compressive strength

The results on compressive strength at 7 and 28 days showed that, Compressive strength drastically decreases as the rubber content increases. At 5%,10%,12.5%,15% and 20% Crumb rubber volume fractions, the decrease in compressive strength were 4.76%;13.39%;19.84%;25.64% and 41.07%; and 4.78%;15.55%;21.51% ;32.13% and 42.69% at 7 and 28 days respectively. This decrease was similar to what Mohammad Reza sohrabi **(2011)** reported.

It was noticed that at 12.5% crumb rubber replacement to normal sand, the decrease in compressive strength was nearly by only 20%. For that reason, only 12.5% Crumb rubber fraction was mixed with different percentages of recycled tyre steel fibres. The addition of Recycled Tyre steel fibre to this rubber concrete at fraction of 0.3%,0.6%,0.9% and 1.2%, the Compressive strength reduced by 21.15%,16.85%,13.37%,8.73%; and 22.48%,17.39%,13.29%, and 10.38% at 7 and 28 days respectively. This means that, there has been a little improvement on Compressive due to inclusion of RTSF in rubber concrete. Fig.4 shows the comparison of the results on compressive strength of rubber concrete.

3.2 Split tensile strength

The results on Split Tensile strength at 7 and 28 days indicated that, split tensile strength decreases as the rubber content increases. At 5%,10%,12.5%,15% and 20% Crumb rubber volume fractions, the decrease in Split tensile strength were 3.38%;10.30%,17.31%,22.02%, and 31.70%; and 1.20%;10.77%;17.44%;23.75% and 33.36% at 7 and 28 days respectively. The combination of 12.5 Crumb rubber with 0.3%,0.6%,0.9% and 1.2%, the split tensile strength reduced by 15.25%,7.43%,1.17% and 0.30%; and 14.97%,10.42%,5.55% and 0.27% at 7 and 28 days respectively. It was noticed that the rate of decrease in split tensile strength as the crumb rubber content increase was slightly lower than that of compressive strength. The comparison of the results on split tensile strength of rubber concrete are shown in Fig.3.

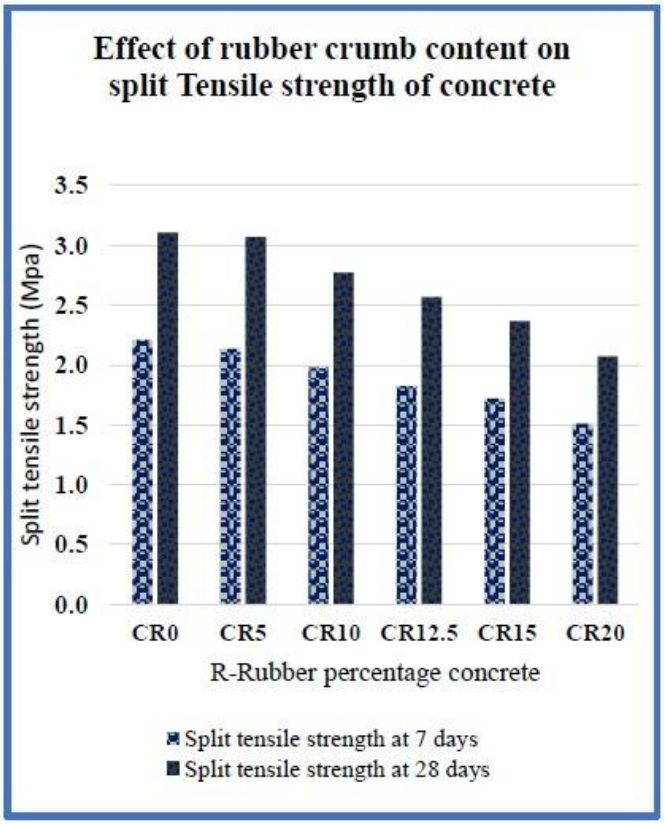


Fig.3 comparison on split tensile strength

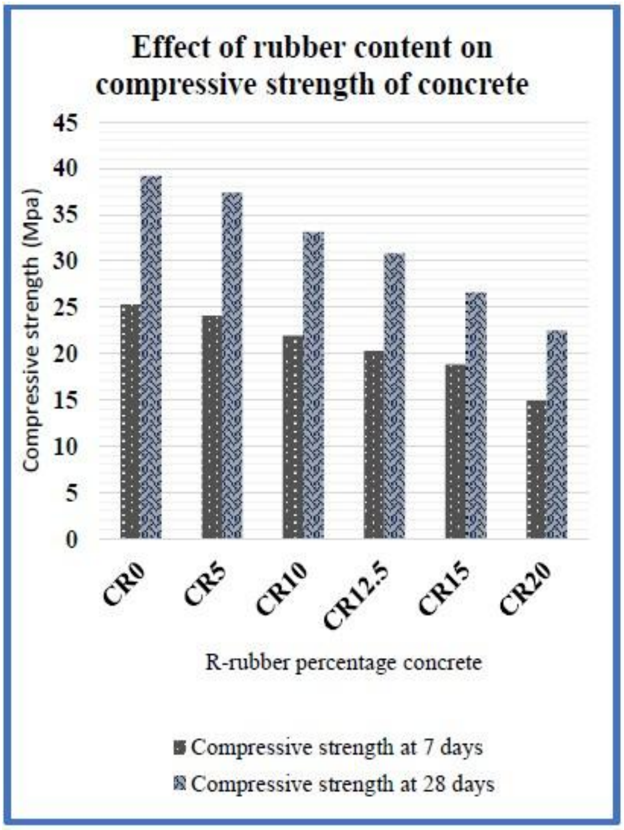


Fig.4 Comparison on Compressive strength

3.3. Impact resistance

In assessment of the performance of the recycled tyre steel fibre reinforced rubber concretes against the plain and rubber concrete, Number of blows to produce first visible crack and a total failure of the sample specimen were recorded. Impact energy stored in each sample under Drop weight test were calculated using eq.1.This test were performed in accordance with ACI committee 544.It is the simplest and the cheapest method of impact resistance test. The results of number of blows required to bring the sample specimen at first crack and at Ultimate failure and their corresponding impact energies under drop -weight impact test is summarized in Table.3.

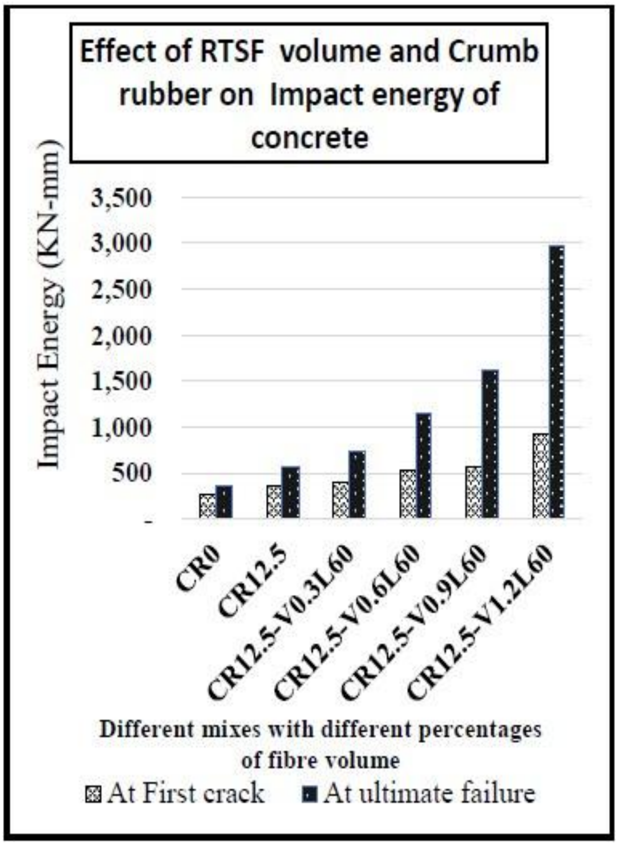
Table. 3 Results on Impact energy

Mix designation	Number of blows at First visible crack	Number of blows at Ultimate failure	Impact Energy at first visible crack (KN-mm)	Impact energy at ultimate failure (KN-mm)	Relative % gain in Impact Energy at first crack (%)	Relative % gain in Impact Energy at Ultimate failure (%)
CR0	13.25	17.00	274.88	352.68	-	-
CR12.5	17.00	27.00	352.68	560.14	28.30	58.82
CR12.5-V0.3L60	19.25	35.25	399.36	731.30	45.28	107.35
CR12.5-V0.6L60	26.00	55.50	539.40	1,151.40	96.23	226.47
CR12.5-V0.9L60	27.00	78.25	560.14	1,623.37	103.77	360.29
CR12.5-V1.2L60	44.75	143.00	928.38	2,966.68	237.74	741.18
CR12.5-V1.2L40	37.00	104.00	767.60	2,157.58	179.25	511.76
CR12.5-V1.2L20	22.25	83.50	461.60	1,732.29	67.92	391.18

During impact test, plain concrete exhibited brittle failure as can be seen in table.3, after appearance of the first crack, only 3 blows were required to bring the sample to complete failure, while for the concrete sample made with 12.5% of rubber volume replacement and 1.2% Recycled tyre steel fibre reinforcement, 98 blows were required to bring the sample specimen to a total failure of the sample. For 1.2% tyre steel fibre with length of 60mm Rubber concrete, Ultimate energy increased from 58.82 to 391.18%. This indicate that RTSFRC stored much more impact energy than that of plain concrete and rubber concrete alone after post crack level. The results conform with the report that, Impact energy can increase 5 to 10 times that of plain concrete depending on fibre volume and its aspect ratio (Fousil Fouad Wafa, 1990). The comparison of the results of impact energy is shown in Fig.7-10

Fig. 5 Ultimate Failure mode of the spacemen

Fig.6 Sample spacemen and Impact test equipment



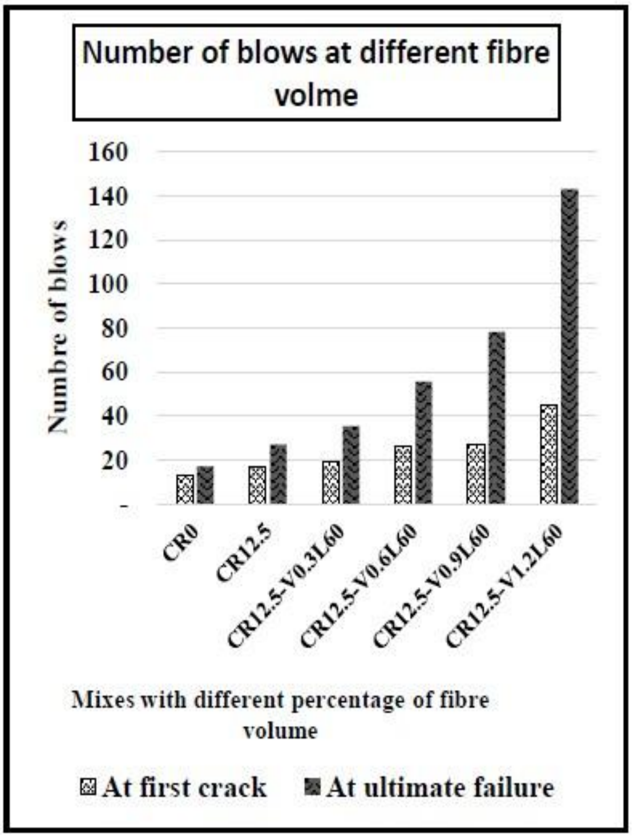


Fig.7 Comparison on Impact energy at different fibre volume

Fig. 8 Comparison on Number of Blows at different fibre Volume

To evaluate the contribution of aspect ratio of fibre on impact energy, the steel cords were cut into 3 different sizes,20mm,40mm, and 60 mm. These fibers were mixed in concrete at constant value of fibre volume which was 1.2% and results showed that, for the mixture CR12.5-V1.2L20, CR12.5L40 and CR12.5-V1.2L60, the impact energy increased by 67.92 %, 179.25 %, and 237.74 %; and391.18 %,511.76 and 741.18 at First crack and ultimate failure respectively. This indicates that the fibre with 60mm length performed better than the rests, where the maximum impact energy was at the mixture CR12.5-V1. 2L60.The Results showed that, Impact energy increases with increase in fibre volume and of aspect ratio. Fig 9 and Fig 10 show the comparison of the results of impact energy and number of blows respectively at different fibre aspect ratio.

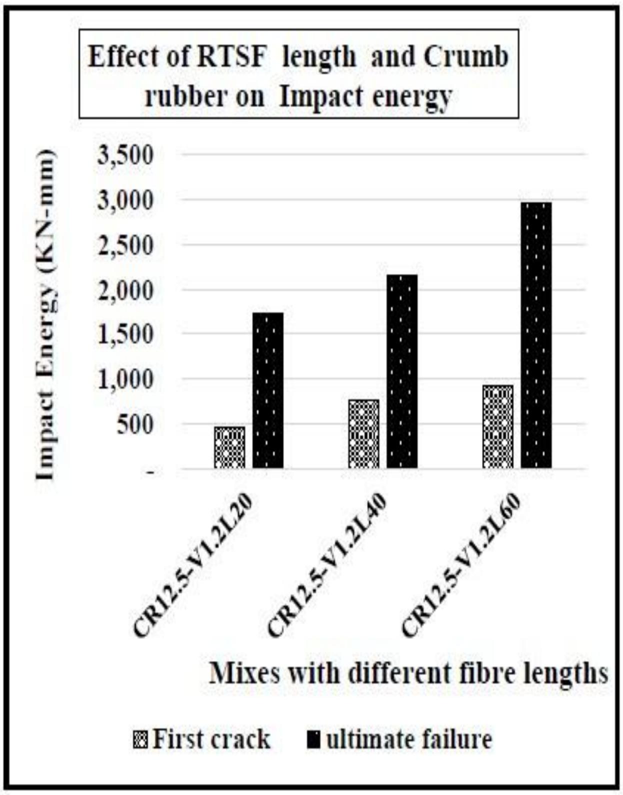


Fig.9 Comparison on Impact energy at different fibre aspect ratios

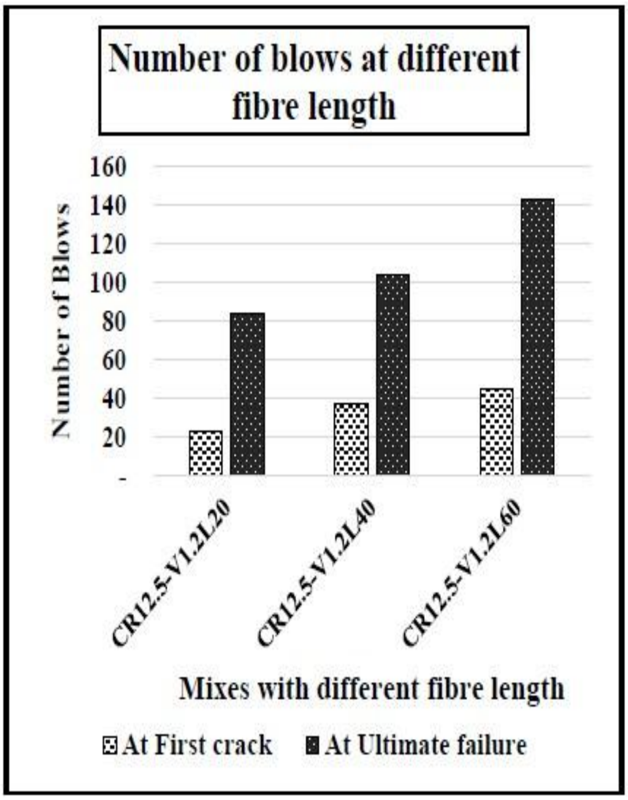


Fig.10 Comparison on Number of Blows at different fibre aspect ratios

4. CONCLUSION

Both Compressive strength and Split tensile strength of concrete decrease substantially as the crumb rubber content replacing normal sand increases in concrete. This reduction was reported to be caused by the weak bond between cement paste and rubber aggregates. Though Compressive and tensile strength slightly increased when different fibre volume were mixed with 12.5% of rubber replacement, this increase is negligible in design consideration.

The impact energy is highly enhanced when 12.5% rubber crumb is combined with 1.2% volume of recycled tyre steel fibre with length of 60mm. Ultimate impact energy of RTSFRC was much more increasing than the first crack impact energy as the fibre volume increases. This can be the reason of fibre diameter which is relatively big which may cause a crack to appear earlier. But after the appearance of first crack, the presence of the fibre prevents further increase of the crack width and length hence increase in post -crack strength under impact loads.

Conclusion can be taken that, combining steel fibre from waste tyre at 1.2% mass of concrete and 12.5% of Crumb rubber volume in concrete resulted in better performance on impact strength at both first crack and ultimate failure level. RTSFRC can best fit in construction of Road pavement, airport runaway and industrial floors when high class of concrete is designed. And applying waste tyre products in construction industry, will save environment by reducing the huge amount of waste tyres dumped in environment.

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