Combined Effect of Recycled Tyre Steel Fibre and Crumb Rubber on Flexural Toughness of Concrete

Ndayambaje J. Claude, Richard Onchiri, Walter O. Oyawa

***Abstract:** The disposal of scarp tyres has been environmental concern over the past few decades. Plain Concrete exhibits brittle behaviour which is undesirable property for a structural material resisting dynamic forces. Using used tyre crumb rubber and steel cords extracted from used tyres as steel fibre reinforcement can enhance ductility and toughness of concrete which is environmentally beneficial and technically sound. In this study, 12.5% volume of Crumb rubber of maximum size passing sieve 4.75mm was used to replace fine aggregates and recycled tyre steel fibre (RTSF) dosages of 0.3%,0.6%,0.9% and 1.2% by mass of concrete were added in concrete to investigate flexural performance of the Recycled tyre steel fibre reinforced rubber concrete (RTSFRC). 24 Concrete beams (500x150x150mm) were manufactured to evaluate the effect of (RTSF) volume and its aspect ratios on flexural strength and Toughness of rubber concrete. The results showed that, combined crumb rubber and recycled tyre steel fibre from waste tyres improved the ductility and toughness of concrete.*

***Index Terms:** Recycled tyre steel fibre, Crumb Rubber, Recycled tyre steel fibre reinforced rubber concrete, Flexural strength, Flexural Toughness, Toughness index, Residual strength factor.*

I. INTRODUCTION

Concrete structures resisting against impact and earthquake loadings have been of most considerable focus in civil structural engineering design. Enhanced Ductility and toughness are important properties of concrete which make it exhibit linear response under blast loadings. Different studies have been done to enhance the ductility and toughness of concrete by incorporating natural and artificial waste products in concrete [1], [2]. Rubberized concrete could be considered as green materials by replacing, specified percentage of normal aggregates by recycled waste tyre materials in concrete. Badorul H (2017) reported that, incorporating crumb rubber in concrete, increases ductility and toughness of concrete, which is represented by the area under- load deflection curve up to a specified deflection criterion on the test method specified by ASTM-C1018.However, they further said that,

Revised Version Manuscript Received on December 04, 2017.

Ndayambaje J. Claude, Student, Department of Civil Engineering, Pan-African University, Institute of Basic Science, Technology and Innovation, Nairobi, Kenya, E-mail: westclauden@gmail.com

Prof. Richard Onchiri, Associate Professor, Department of Building and Civil Engineering, Technical University of Mombasa, Mombasa. E-mail: roocharo@yahoo.com

Prof. Walter O. Oyawa, Professor, Department of Civil Engineering, Jomo Kenyatta, University of Agriculture and Technology, Nairobi, Kenya, E-mail: oyawaw@yahoo.com

Compressive strength and flexural strength at first crack and at ultimate failure drastically reduce as the rubber content increases [3]. Recently, effort have been done to develop methodologies of extracting used tyre steel cord, bead wires and their use in Concrete. Concrete obtained by adding randomly distributed Recycled tyre steel fibres evidenced a satisfactory improvement of brittle concrete matrix mainly in terms of toughness and post crack strength and impact load resistance. In addition, it was proven that mechanical behaviour of concrete reinforced with fibres extracted from waste tyres is comparable to that of conventional steel fibre reinforced concrete. As consequence, Recycled steel fibre reinforced rubber concrete (RTSFRC) appears to be a potential candidate for structural concrete [4], [5].Combined effect of crumb rubber and steel cord extracted from waste tyres in concreteas reinforcement can significanly enhance the ductility and toughness properties of concrete.In this study, effect on concrete toughness and flexural strength of various (RTSF) percentages 0.3%,0.6%,0.9% and 1.2% mass of concrete combined with 12.5% of crumb rubber replacing normal sand were investigated. It was previously reported that , the aspect ratio of fibre affects fibre reinforced concrete properties such flexural strength ,tougness and tensile strength due to different preferential alignment of steel fibres in vicinity of mould surface which is most pronounce in small mould containing long fibres [6].For this reason , the effect of tyre steel fibre length on flexural strength and toughness of rubber concrete was also studied by keeping a constant value of fibre volume ratio 1.2% and varying the fibre length of 60mm,40mm and 20mm.

II. EXPERIMENTAL PROGRAM

A. Materials

The cement used in the all mixes was a locally manufactured Bamburi Portland limestone cement of class 42.5MPa having a specific gravity of 3.05. The cement conforms with EN 196 and Kenyan bureau of standards. Locally available Crushed coarse aggregates and Natural river sand with maximum size of 4.75mm were used in this study. Locally produced Crumb Rubber aggregates of maximum size passing sieve 4.75mm was used to replace normal sands. All Properties of aggregates used are summarized in table I.

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.*

Steel fibres used in the current study were from cutting of Waste tyre steel cord. These steel cord was one of the products of pyrolysis processing. They are high yield steels with tensile strength and average diameter of 1015Mpa and 1.15mm respectively. These steels were cut in three different sizes ,20mm ,40mm and 60mm for assessing the effect of the fibre length on the concrete properties, fig 1 shows the fibre used. A high-range water reducers (HRWR) SP430 was also used in all mixes to increase workability.

B. Mix Design Proportions

A 30MPa class of control mix was designed according to BS8110 and BS1988.Different ratios of Recycled tyre steel fibres 0.3%,0.6%,0.9% and 1.2% were added in rubber concrete mix with a constant volume of 12.5% crumb rubber replacing normal sand. To evaluate the effect of fibre length, three different concrete mixes of constant fibres volume (1.2%) with three different lengths(20mm,40mm,60mm) were added in 12.5-Rubber concrete mix. Material proportions for all concrete mixes are summarized in Table II. Water cement ratio was maintained constant in all mixes with a value of 0.5. The mix designation is coded as **CRm-VnLp**, where m, n and p are percentage volume of crumb rubber, percentage mass of tyre steel fibres and length of tyre steel fibre (mm) respectively.

Tables I Concrete Mix Design Proportions

Mix Designation C30	Rubber (kg/m3)	W/C Ratio	Water Content (kg/m3)	Cement Content (Kg/m3)	Fine Agg. (Kg/m3)	Coarse aggregate (kg/m3)	Admix. (l/m3)	Steel fibres (kg/m3)
CR0	0	0.5	195	390	727.75	1047.25	3.3	0
CR12.5	31	0.5	195	390	636.8	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-V1.2L40	31	0.5	195	390	636.8	1047.25	3.3	28.2
CR12.5-V1.2L20	31	0.5	195	390	636.8	1047.25	3.3	28.2

III. EXPERIMENTAL DETAILS AND PROCEDURES

A. Compressive Strength Test

Compressive strength test was carried out using cubes of 150 mm sides on 7 and 28 days of curing. A mean of 3 cubes strengths were taken as compressive strength of that mix. The testing was in accordance with BS1881: part 116 [7]. Tests were conducted in Universal testing machine (UTM) with capacity of 2000KN, the maximum load and corresponding strength could be displayed on the UTM scream

Tables II. Physical Properties of All Aggregates Natural aggregates and crumb rubber

Physical properties	Coarse aggregates	fine aggregates	Crumb rubber
Fineness modulus	5.7	3.45	2.9
Moisture content (%)	1	3	1.2
Absorption (%)	1.12	1.9	9.8
Bulk specific gravity (SSD condition)	2.65	2.5	0.83

B. Split Tensile Strength Test

Split tensile strength tests were carried out on 100mm diameter and 200mm length specimens. Specimens were Positioned with its length parallel to line of applied load in UTM machine. Testing were conducted in accordance with BS1881: part 117 [8]

C. Flexural Strength and Toughness

Flexural strength and toughness were conducted on concrete beams s of size 150x150x500mm. Four points bending test method were conducted in accordance with ASTM-C1609 [9]. Flexural test set up and specimen geometry are illustrated on figure 3. The testing was performed in oil hydraulic machine with the capability of controlling loading rate. A linear variable differential transducers(LVDT) were used to record vertical displacements (deflections) and a load cell on central top of the beams was used to monitor loadings and load-deflections data were recorded and displayed on data recording system (Data logger) prior to plot load -deflection (P-d) curves. Ultimate Flexural strength were determined based on the maximum flexural load recorded during the test. Flexural Toughness or energy absorption was presented by the area under load -deflection curves at deflection equals to supported length over 150 in accordance with JCI-SF4 and Toughness indices which is calculated as the area under the load-deflection curve up to 3, 5.5 and 15.5 multiple of first crack deflection divided by the area up to the first crack strength as according to ASTM-C1018.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

The average of three specimen flexural strengths and toughness on 28 days test was taken as flexural strength and toughness of that mix.

Fig 1. Crumb Rubber

Fig. 2. Recycled Tyre Steel Fibres of Different Lengths

IV. RESULTS AND DISCUSSIONS

A. Compressive Strength

From the results of the tests on different concrete cubes at 28 days, it was shown that, the compressive strengths decrease with the increase of crumb Rubber ratio. At 12.5%, the compressive strength decreases by 21.51%, however with the addition of tyre steel Fibres (0.3%,0.6%,0.9 and 1.2%), the strength reduced by 22.48%,17.39%,13.29% and 10.38% respectively compared to the control mix. In can be concluded that, addition of the recycled tyre steel fibres limited the reduction of compressive strength in Rubber concrete, though the improvement of this strength was minor and almost negligible.

B. Split Tensile Strength

The results of the Split tensile strength tests shown that, as the crumb rubber ratio increases in concrete mix, the split tensile strength decreases but at lower rate compared to compressive strength. At 12.5% crumb rubber ratio, the split tensile strength reduces by 17.44% at 28 days. The addition of tyre steel Fibres (0.3%,0.6%,0.9 and 1.2%), the split tensile strength reduced by 14.97%,10.42%,5.55% and 0.27% respectively compared to the control mix. The addition of the recycled tyre steel fibres up to 1.2% ratio has counterbalanced that reduction of split tensile strength in Rubber concrete.

C. Flexural Strength and Toughness.

For evaluating flexural performance of the various concrete mixtures; terms, First -crack load, ultimate failure loads and their corresponding mid span deflections were employed. first crack Flexural strength and ultimate flexural strength values were determined from First crack load and ultimate failure load using Formula for modulus of rapture given in test method ASTM-C78 in four points bending tests method according to ASTM-C1609-10.3. Flexural Toughness and Flexural toughness indices were determined in accordance with ASTM-C1609 and JSCE-SF4 respectively. Flexural toughness is represented by the area under load -deflection curve. ASTM defines First crack, as the point on the load-deflection curve at which the form of curve first became nonlinear (approximately on onset of cracking on concrete mix). In the JSCE-SF4, the first crack point is not a concern on load-deflection (P-d) curve, according to JSCE-SF4, the toughness is represented by the area under load -deflection curve up to supported span over 150.

The produced load-deflection curves for different mixes are presented on Figure 8. The results of flexural strengths, Flexural Toughness, Toughness indices and residual strengths are presented in Tables III, VI, and V respectively. From the produced load-deflection curves, it showed that the maximum flexural load supported by rubber concrete was generally lower than that of normal concrete due to inclusion of crumb rubber. The mechanism is the same as that of compressive tests though, the reduction in flexural load carrying capacity is smaller than that in compressive loads tests. At 12.5% crumb rubber ratio, the ultimate flexural strength reduced by 17.8%. addition of recycled tyre steel fibres at different percentages increases flexural load carrying capacity of rubber concrete. At 1.2% ratio of recycled tyre steel fibre, there marked 4.3% increase from a negative percentage of 17.8% of flexural strength of rubber concrete .The enhanced ductility and toughness were observed on combined Crumb rubber and the tyre steel fibre concrete beams, where the concrete beams retained more loads after reaching at first-crack level, while, in the concrete without fibres, the concretes could not carry more loads after immediate first-crack level appeared, it exhibited brittle failure, this can further be observed on the shape of the load-deflection curve which is sharper than that of (RTSFRC) curves.

The results shown in table IV, indicate that, the Flexural toughness of RTSFRC increased significantly as the fibre volume and aspect ratio increased. The maximum value was observed at 1.2% volume of fibre and aspect ratio of 52 where the increment was 258% compared to that of normal concrete. It was reported that flexural strength of fibre reinforced concrete depending on amount and shape of fibres used, can increase from 10 to 40 times that of plain concrete [10], [11].

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

To assess the level of Flexural performance of fibre reinforced concrete, ASTM-C1018-97 introduces, Toughness indices I_5, I_{10}&I_{20} and Residual strength factors $R_{5,10}$, $R_{10,20.}$ Toughness Indices enable actual performance to be compared with a readily understood reference level of performance. In this regard, the values 5,10, and 20 for I_5, I_{10}&I_{20} respectively correspond to linear elastic material behaviour up to first crack and perfectly plastic thereafter. The residual strength factors $R_{5,10}$, $R_{10,20.}$ represents the average level of strength retained after first crack as percentage of the first crack strength for deflection intervals (5.5-3) multiple of first crack deflection and (10.5-5.5) multiple of first crack deflection.100 residual strength factor corresponds to perfectly plastic behaviour, however lower values indicate inferior performance.

From the results of the current study, toughness Indices and residual strength factors of plan and rubber concrete were nearly 1and 0 respectively. The combined effect of Rubber and recycled tyre steel fibres in concrete increased the Toughness index and Residual strength factor from 1.08 to 7.68 and 55.8 respectively at fibre volume of 1.2% and fibre length of 60mm.This shows a good level of performance of RTSFRC compared to plain concrete and rubber concrete.

Table. III. Results of Flexural Strength loads and Strengths

Mix	First crack load(N)	Ultimate flexural load(N)	First crack strength(Mpa)	Ultimate strength (Mpa)
CR0	41280	41280	5.50	5.50
CR12.5	30800	33800	4.11	4.51
CR12.5-V0.3L60	28010	32208	3.73	4.29
CR12.5-V0.6L60	28900	33920	3.85	4.52
CR12.5-V0.9L60	30001	35280	4.00	4.70
CR12.5-V1.2L60	37000	43040	4.93	5.74
CR12.5-V1.2L40	36600	39500	4.88	5.27
CR12.5-V1.2L20	31300	32570	4.17	4.34

Table. IV. Results of Flexural Toughness and Stiffness

Mix	First crack deflection (mm)	Maximun deflection (mm)	Flexural stiffness (KN/mm)	Toughness (KNmm)
CR0	1.01	1.01	40.87	20.85
CR12.5	1.25	1.30	24.64	22.08
CR12.5-V0.3L60	0.91	6.71	30.78	46.76
CR12.5-V0.6L60	0.82	8.45	35.24	52.50
CR12.5-V0.9L60	0.68	9.09	44.12	61.51
CR12.5-V1.2L60	0.55	11.14	67.27	74.80
CR12.5-V1.2L40	0.71	8.54	51.55	55.60
CR12.5-V1.2L20	0.87	5.23	44.12	37.50

Fig. 3.Four-bending load test and Failure mode of RTSFRC

Table. V. Results of Toughness Indices and residual strength factors (ASTMC-1018-97)

Mix	First -crack deflection(mm)	Energy absorption in (Joule)			Toughness Index		Residual strength factor R5,10
		$\delta = \delta_{Fc}$	$\delta = 3\delta_{Fc}$	$\delta = 5.5\delta_{Fc}$	I_5	I_{10}	20(I10-I5)
CR0	1.01	20.85	20.85	20.85	1.00	1.00	-
CR12.5	1.25	20.50	22.08	22.08	1.08	1.08	-
CR12.5-V0.3L60	0.91	12.74	42.22	53.13	3.31	4.17	17.12
CR12.5-V0.6L60	0.82	11.85	43.10	67.30	3.64	5.68	40.85
CR12.5-V0.9L60	0.68	10.25	44.38	69.40	4.33	6.77	48.82
CR12.5-V1.2L60	0.55	10.10	49.41	77.60	4.89	7.68	55.82
CR12.5-V1.2L40	0.71	10.75	47.36	73.25	4.41	6.81	48.17
CR12.5-V1.2L20	0.87	12.61	44.50	53.68	3.53	4.26	14.56

The flexural stiffness or bending stifness (K) was also determined from Load-deflection curves of the concrete beams. K was detrmined as the gradient of the slope of linear part of load deflection-curves.The reduced bending stiffness value is an indication of an increase in deformability which makes a material absorb more energy and exhibit ductile response when subjected external forces. It is ovious that all Recycled tyre steel fibre reinforced rubber concrete (RTSFRC) exhibited higher ductility and Toughness compared to normal concrete.The enhancement was due to increase in ultimate deflection offered by STSFRC beams.A concrete with higher value of toughness is preferably needed in the design of earthquake resisting structure, pavements and other structures exposed to blast loadings .

V. CONCLUSIONS

The current study was to evaluate the Flexural performance of concrete made with partial replacement of normal fine aggregates by crumb rubber and reinforced with radomly distributed recycled tyre steel fibre in different volume ratio and different aspect ratio.This concrete is considred as a green material since it can substantially reduce the amount of waste tyres dumped in invironment by using Rubber tyres and tyre steel cords in concrete production.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

All the beams were subjected to four bending load tests and load-deflection data were recored .From the results of the experiments, the following conclusions were drawn:

- The compressive and Tensile sterngth decreases with the increase of Crumb rubber in concrete.Based on results of concrete made with different crumb rubber percentage volume ,12.5 % has taken as an optimun value of crumb rubber replacement normal sand where the compressive strength decreases nearly only by 20%.
- The inclusion of crumb rubber in concrete as an aggregate has resulted in reduced flexural strength at first-carck and ultimate failure under the four-bending load test.The reduction in flexural strength is generally lower than that of compressive strength of concrete made with partial replacement of normal sand by crumb rubber.

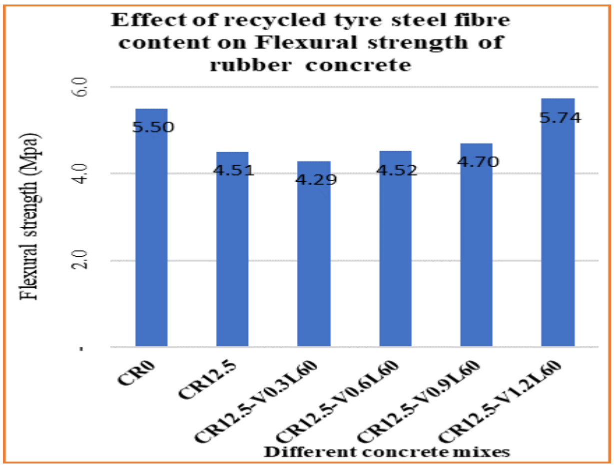


Fig. 4.comparison Flexural toughness for concrete various volume ratio of RTSF

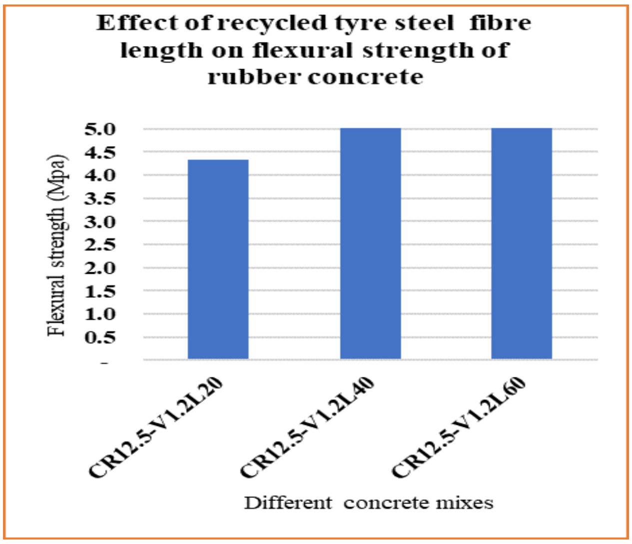


Fig.5 .comparison Flexural toughness for concretes with various aspect ratio of RTSF

- Flexural Toughness, which was determined by calculating the area under load -deflection curve up to L/150 deflection, increases with the increase in Recycled tyre steel fibre volume. It was noticed a considerable enhancement of Flexural toughness property when 12.5% crumb rubber ratio and 1.2% recycled tyre steel fibre volume ratio with aspect ratio of 52 were used in concretes where, the flexural toughness increased by 258% compared to plain concrete
- Toughness indices and Residual strength factors were determined based on ASTM-C1018.Improved values of these indices and factors were observed in concrete made with partial replacement of normal sand by crumb rubber and reinforced with rondomly distributed tyre steel fibres.At 12.5% of crumb rubber replacement and 1.2% of tyre steel fibres , toughness index I_{10} and residual factor $R_{5,10}$ were 7.68 and 55.82 repectively while the plan concrete was 1 and 0 respectively.This shows that, the RTSFRC retained more laods after first crack and exhibitting ductile failure behaviour.
- Using combined Recycled tyre steel fibres as reinforcement and Crumb rubber as fine aggregates in concrete is an innovative and green construction material with enhanced ductility and toughness properties that are prefered in construction of Pavements, earthquake resisting structures and blast load resisting structures.

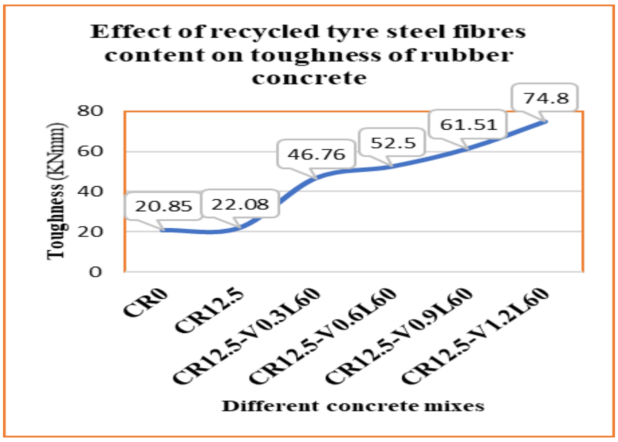


Fig. 6.comparison of Flexural toughness for concretes with various aspect ratio of RTSF

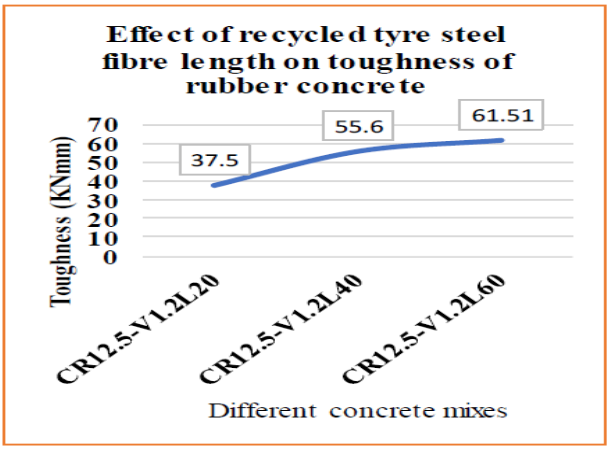
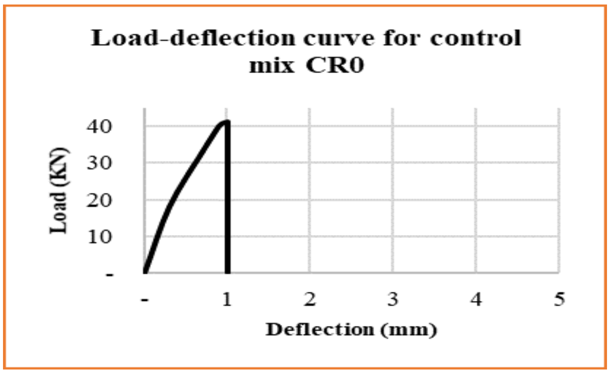
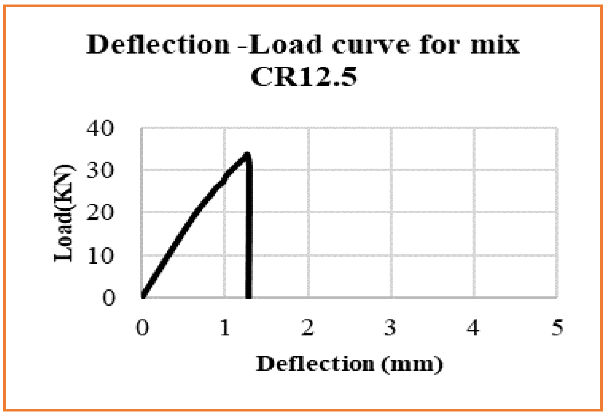


Fig.7.Comparison of Flexural toughness for concrete with various aspect ratio of RTSF

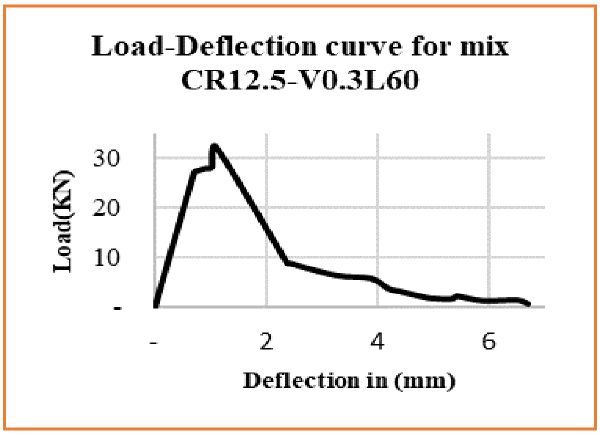
Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.



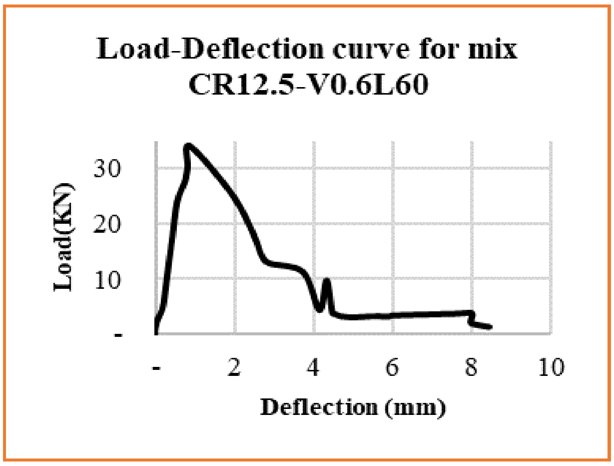
(a) **CRO**



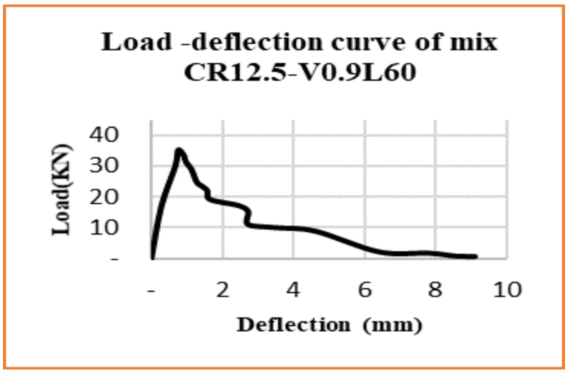
(b) **CR12.5**



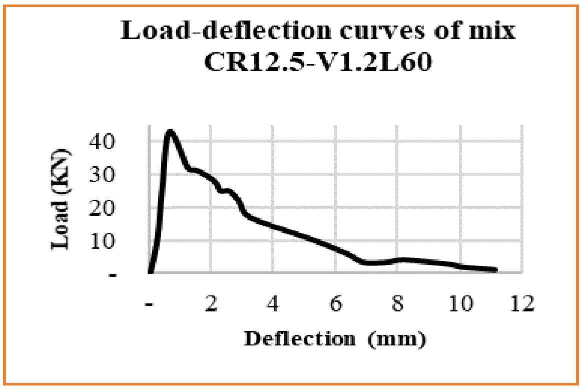
(c) **CR12.5-V0.3L60**



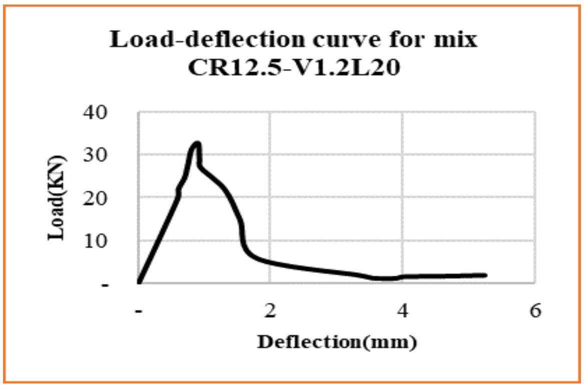
(d) **CR12.5-V0.6L60**



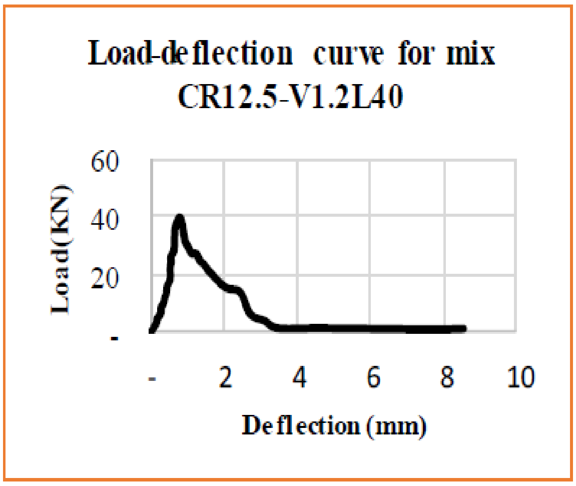
(e) **CR12.5-V0.9L60**



(f) **CR12.5-V1.2L60**



(g) **CR12.5-V1.2L20**



(h) **CR12.5-V1.2L40**

Fig.8.Load-deflection curves for various concrete beams

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

ACKNOWLEGEMENT

Much thanks to the management of Panafrican University Institute of Basic Science ,Technology and Innovation , we also thank structural engineering and materials laboratories at Jomo Kenyatta ,University of Agriculture and Technology where all the laboratory works described in this paper were conducted.

REFERENCES

1. E.-H. Z. Ismail, "Use of waste plastic in concrete mixture as aggregates replacement," Waste management, vol. 28, no. 11, pp. 2041-2047, 2008.
2. H. B. Wang, "Ductility characteristics of fibre-reinforced concrete beams reinforced with FRP-rebars," Construction and Building Materials, Elsevier Ltd, vol. 25, pp. 2391-2401, 2011.
3. A.T. N. M. Badorul Hisham Abu Bakar, "Cumulative Effect of Crumb Rubber and steel fibre on Flexural toughness of concrete," Engineering, Technology and Applied science research, vol. 7, no. 1, pp. 1345-1352, 2017.
4. Bedewi.N, Steel fibre reinforced concrete made with fibre extracted from waste tyres, Addis Ababa: department of civil engineering, Addis Abba University, 2009.
5. L. F. G. Alien M, "Use of Steel Fibre recovered from Waste tyres as reinforcement in Concrete: pull-out, Compressive and Flexural strength," Elsevier LTD, 2008.
6. A. S. o. T. M. (ASTM), "Standard Test method for Flexural Toughness and First-crack strength of Fibre -reinforced Concrete (using Beam with Third-Point Loading)," ASTM-C1018-97, West Conshohocken, 1997.
7. BSI, "Method for determination of compressive strength of concrete cubes," BS 1881-116:1983, Landon, 1987.
8. B. S. Institute, "Method for determination of split tensile strength of concrete cylinders," BS 1881:167, Landon, 1983.
9. ASTM, "Standard test method for flexural performance of fibre-reinforced concrete (using third-point- loading)," ASTM-C1609/C1609m-10, west Conshohocken, 2010.
10. ACI committee 544, "State-of-the-art report on fibre reinforced concrete," American concrete Institute, Detroit, 1982.
11. ACI committee 544, "Measurement of properties of fibre reinforced concrete (ACI 544.2R.2R-78)," American Concrete Institute, Detroit, 1978.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.