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Shear Strength of Steel Fibre Reinforced Concrete Beams Cast Using Crumb Rubber as Fine Aggregate Replacement

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Abstract— *once the service life of rubber tire ends, their dumping becomes a major social, economic and most importantly environmental problem. Thus, the incorporation of the crumb rubber obtained after shredding of waste tires into concrete can be a promising green building technology towards the sustainability. The present paper aims to explore the use of concrete containing steel fibers, produced by replacing the fine aggregates with the crumb rubber. A total of 101 beams of size (500×100×100) were tested under four point bending. The results indicate a significant improvement in the shear strength, in comparison to the identical beams cast using conventional concrete.*

1. INTRODUCTION

Concrete is a composite material made of coarse aggregates, fine aggregates fortified together with cement paste that solidifies over time, having a wide variety of applications like mouldabilty, good compressive behavior, structural steadiness and also fiscal considerations. But as far as the other mechanical parameters are taken into attention like tensile and shear behavior of concrete it fails miserably. Once the concrete reaches its peak value in compression, concrete under goes dilation and exhibits strain softening which causes brittle failure of concrete due to which sudden failure occurs which can be upgraded significantly by incorporating steel fibres into concrete at the instant of producing the concrete in a mixer, forming a new type of concrete known as steel fibre reinforced concrete SFRC.

Crumb rubber is reprocessed rubber obtained from automobile scrap tires. The crumb rubber are the small sized granules of rubber manufactured by a process known as ambient grinding in which the steel and tire flex are detached leaving tire rubber with a granulose uniformity. Due to upsurge in the developmental rates of countries the usage of automobiles have increased manifold and disposal of waste materials has been a cause of grave concern for most of the nations. The dumping of used tires on land causes many stern economic and environmental problems, as reported by aforementioned studies. As per the stat from economic times around **100 million** tires are discarded in India each year and in USA around **290 million** are discarded each year as per the stat from EPA and rubber manufacturing association.. Widespread studies have also been steered on the application of the crumb rubber into concrete mixes. As a result forming a new type of concrete having an inclusive variety of applications and is known as crumb rubber concrete (CRC). It exhibits different properties than that of conventional concrete as it decreases bulk density of concrete making concrete light weight, increases increases the abrasion resistance of concrete, lowers the values of water absorption and sorptivity of concrete, improves sound absorption characteristics of concrete, and enhances freezing-thawing resistance of concrete. But the only detriment of incorporating crumb rubber into concrete is that it reduces the mechanical attributes i.e. strength parameters like compressive strength, thus to avoid such kind of strength reduction, steel fibres are infused in concrete giving rise to a new form of concrete known as steel fibre reinforced rubberized concrete (SFRRC). Current studies divulge that the SFRRC holds decent impact and toughness resistance with enhanced ductility and sound insulation, and can have a good impact on the shear strength of concrete beams.

Crumb rubber concrete is a young building material with a past history of less than thirty years and different studies are currently being pursued in this domain as M.K. Ismail et.al (2017) utilized crumb rubber and steel fibers in concrete beams, deprived of shear reinforcement, the strength attributes of the developed beams were measured. The strength parameters were elevated significantly improving the beam's toughness, ductility and cracking behavior. X.Jian-he et.al (2015), produced green concrete by utilizing the recycled concrete and crumb rubber (CR) obtained from the waste tires that would be a promising technology towards the sustainability in the modern concrete construction world. An investigational study was directed to examine the influence of the rubber content on the compressive and flexural behaviors of RSRAC. The RSRAC displayed good compressive behavior and flexure behavior when compared to conventional concrete. A.Amin et.al (2016), as far as the custom of SFRC in practice and research analysis is considered, it is yet to figure out the common application of SFRC in shear critical structural elements. However the bulk of studies emphasize on using SFRC in different members without any conventional reinforcement, thus having fibers only. But in actual building construction with SFRC, structural members infused with SF are also reinforced with conventional reinforcing steel for shear ligatures. It was verified that steel fibres, if infused in adequate amounts, possibly can substitute the least extent of transverse (ligature) shear reinforcement. Though the strengths of the beams with SF'S only and with the least quantity of conventional shear ligature reinforcement were equivalent, the post peak response of the specimen comprising of SF'S only happened to be more brittle.

The current paper ambitions to understand the effect of CR with/ without SFs on the shear capacity of concrete beams with no shear reinforcement, with shear span to depth ratio kept constant I.e. 1.0. The results of an experimental study conducted to quantify the effects on shear strength by varying the volume fractions of crumb rubber and steel fibre.

2. EXPERIMENTAL PROGRAMME

This section endows a frame of work that is done during the experimental exploration that includes materials which are used, testing methods and other different procedures which are employed for the research work.

2.1 Materials used

Portland pozzolana cement (PPC) conforming to IS (1489-1991) Part-I, having enhanced properties over OPC like it yields a lesser amount of heat of hydration, offers resistance to sulphate attacks at a greater extent, low shrinkage on drying, water tightness, etc. with a specific gravity of 3.14. The 20mm sized coarse aggregates were engaged in the experimental study.The coarse sand in nature with a zone II grade is utilized in the current experimental study. The specific gravity of coarse and fine aggregates is 2.68 and 2.62 respectively. The water absorption percentage is 1% and 0.5% for coarse aggregates and fine aggregates respectively conforming to IS (383 1970). End hooked steels fibers having a length of 50mm are employed in the current work marketed from Ludhiana branded as dramix steel fibers.

The crumb rubber varies in size starting from some microns and geos on increasing upto 40mm. A size of 18 meshes CR that equals to 1mm were engaged in current study. Water being a vital constituent of concrete as it vigorously endures hydration I.e. reaction among the cement and water Tap water is employed in the current work.

Figure 1 Steel-fibers

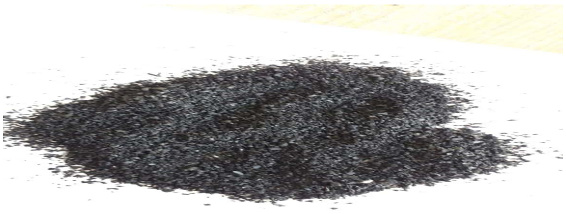

Figure 2 Crumb rubber

2.2 Mix proportions and specimen preparation

Two different concrete mixes were used in the study (grades M25 and M20). These were designed as per code provisions of IS (10262-2009) and IS (456-2000).

The different batches of concrete were made in a revolving drum-type mixer having a capacity of $0.06m^3$. Mixing being a vital step in the making of concrete, it is done to produce a homogenous mass of concrete, with a proper design mix, the next highly significant step is casting, in which fresh concrete is placed in an organized manner to attain the favorable results. In the current research rectangular metallic beam moulds of size 500x100x100 were casted. A description of total beams cast during the current work is given in the table below, also a figure is displayed which shows the casting of samples,

Figure 3 Casting of samples

Figure 4 Casted samples

Table 1 Details of casting of beams

Concrete batches	Crumb rubber (%age)	Steel-fibre (%age)	No. of beams
CM-1	**0**	**0**	**3**
CR-CM	**5%, 10%,15% and 20%**	**0**	**3**
CR-SF-1	**5%, 10%,15% and 20%**	**0.25%**	**3**
CR-SF-2	**5%, 10%,15% and 20%**	**0.5%**	**3**
CR-SF-3	**5%, 10%,15% and 20%**	**1%**	**3**

The table above illustrates concrete batches casted with different volume fractions of crumb rubber and steel fibers. CM-1 specifies beams cast with conventional concrete I.e. without any addition of crumb and steel fibre. CR-CM specifies beams cast with specified volume fractions of crumb, however without infusing steel fibers. CR-SF-1, CR-SF-2 and CR-SF-3 specifies beams cast with said volume fractions of crumb rubber also infused with steel fiber fractions of 0.25%, 0.5% and 1% respectively.

After the samples are casted and dried for 24 hours, the next important practice is curing done for 28 days. The figure displays beams in a water pool,

Figure 4 Curing of samples

2.3 Test procedures

Consistency of concrete is an important parameter of concrete which gives an idea about the workability and to measure that slump test is the easiest way to compute the consistency of freshly prepared concrete.

Figure 5 Slump test of concrete

After 28 days of curing in a water pool, the beam samples were tested tested under four-point loading applied via universal testing machine, with a constant shear-span to depth ratio (a/d=1). Fig 6 illustrates a typical setup used in this study. Shear strength of concrete beams reinforced with steel fibre and fine aggregates partially replaced by crumb rubber were evaluated, and the shear stress is calculated by dividing the ultimate load by the beam cross-sectional area (BxD).

Figure 7 Beam under 4-point loading

3. ANALYSIS OF RESULTS

As described in the preceding chapters, a series of samples of concrete beams were casted and different tests were conducted on both the freshly prepared concrete and on the hardened concrete. The slump test was carried on the fresh concrete and the shear test was steered on the beam specimens.

3.1 Slump test

The table and bar chart below depicts the value slump.

Table 2 Slump value of concrete

Mix M25	Percentage of Rubber	Percentage of Steel-Fibre	Slump-Value (mm)
CM-1	0	0	76
CR-CM	5,10,15 and 20%	0	78,81,83,and 90
CR-SF-1	5,10,15 and 20%	0.25	65,72,76, and 81
CR-SF-2	5,10,15 and 20%	0.5	60,66,67, and74
CR-SF-3	5,10,15 and 20%	1	50,53,58, and 65

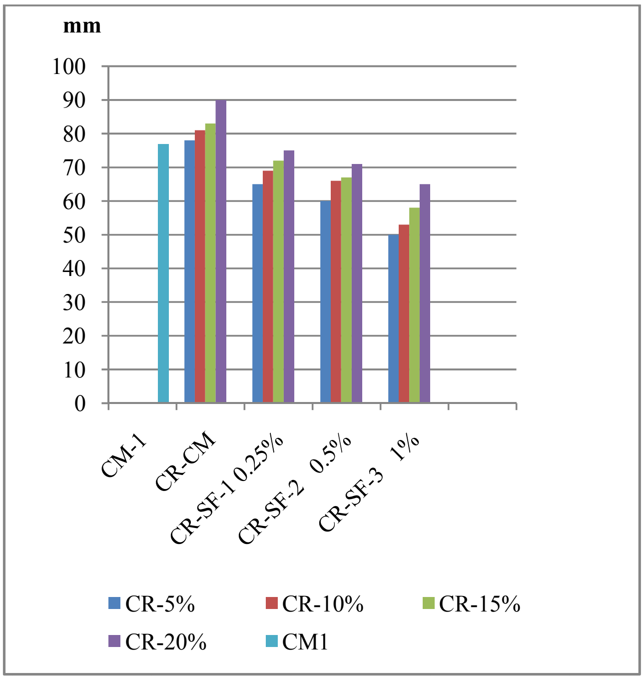

Figure 8 Bar chart of slump test

3.2 Shear test

The shear test was steered with shear-span/depth (a/d=1) constant throughout, to assess the feasibility of infusing the steel fibers into the concrete with the replacement of fine aggregates by rubber crumb at different volume fractions on the shear strength parameter of concrete.The load-displacement curves and tables showing the peak load, average shear stress and type of failure are given below,

Table 3 Peak load, shear stress and type of failure of beams cast with incorporation of only crumb rubber

Beam Designation	Rubber (%age)	Peak Load (KN)		Avg. shear stress		Type of Failure
		M25	M20	M25	M20	
CM-1	0%	18.6	14.5	1.86	1.45	Flexure
CR-CM-1	5%	17.9	13.5	1.79	1.35	Flexure
CR-CM-2	10%	15.5	11.7	1.55	1.17	Flexure
CR-CM-3	15%	14.5	9.4	1.45	0.94	Flexure
CR-CM-4	20%	13.5	7.2	1.35	0.72	Flexure

The table 3 above illustrates the shear stress values of different beams, with and without incorporation of crumb rubber. The results indicate addition of crumb rubber causes slight decrease in the strength initially but with increasing volume fraction of crumb rubber further decrease has been observed. Concrete being a brittle material thus fails in flexure and crumb rubber shows no influence on the brittleness of concrete thus also fails in flexure.

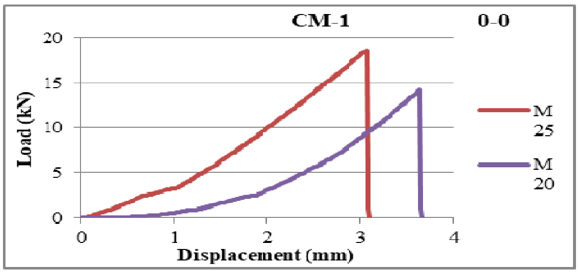

Figure 9 Load vs displacement curve for CM-1

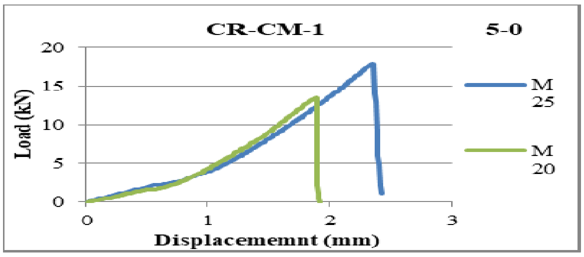

Figure 10 Load vs displacement curve for CR- CM-1

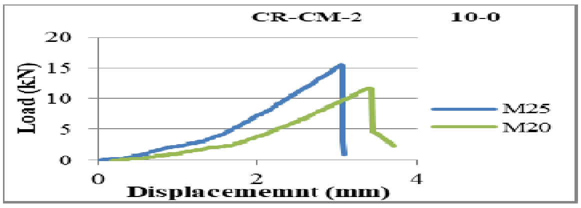

Figure 11 Load vs displacement curve for CR- CM-2

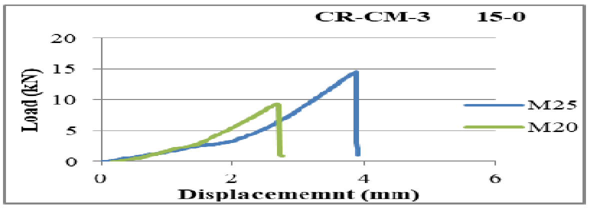

Figure 12 Load vs displacement curve for CR- CM-3

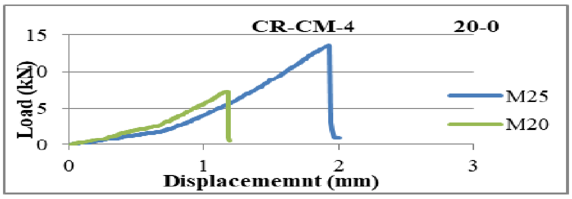

Figure 13 Load vs displacement curve for CR- CM-4

Table 4 Peak load, shear stress and type of failure of beams cast with incorporation of CR and SF (0.25)

Beam type	Steel-Fibre %age	Rubber %age	Peak Load (kN)		Avg. shear stress		Type of Failure
			M25	M20	M25	M20	
CR-SF-1	0.25 %	0%	23.4	16.7	2.34	1.67	Shear
		5%	19.2	16.7	1.92	1.67	Flexure
		10%	19.1	16	1.91	1.6	shear-flexure
		15%	19	15.8	1.9	1.58	Shear
		20%	18.6	13.4	1.86	1.34	Flexure

The table 4 above illustrates the beams CR-SF-1 cast with incorporation of crumb rubber and infused with steel fibre fraction of 0.25%. The results show a better performance in shear as compared with conventional concrete and concrete incorporated with rubber only. The results of both the grades i.e. M25 and M20 are given in the table. The sudden failure of beam has changed towards a ductile one with increased deflections and shear stress. The load vs displacement graphs are as under,

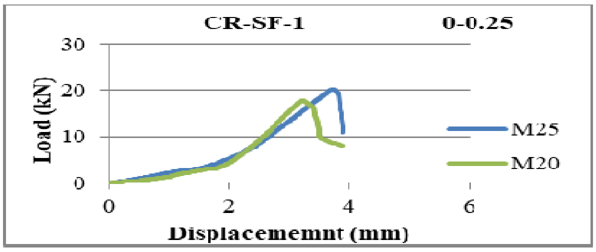

Figure 14 Load vs displacement curve for CR-SF-1 (0-0.25)

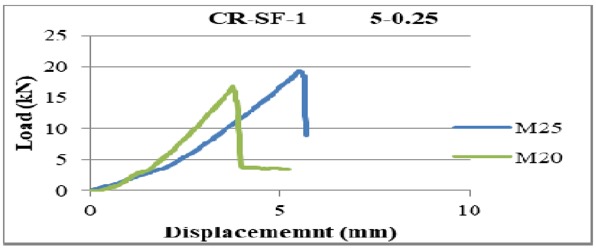

Figure 15 Load vs displacement curve for CR-SF-1 (5-0.25)

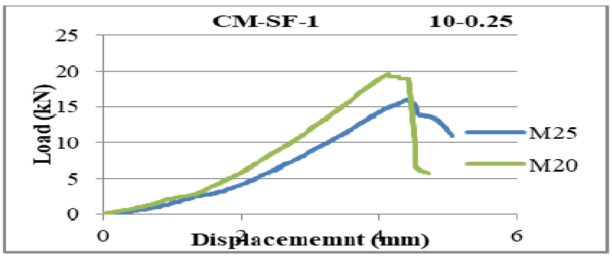

Figure 16 Load vs displacement curve for CR-SF-1 (10-0.25)

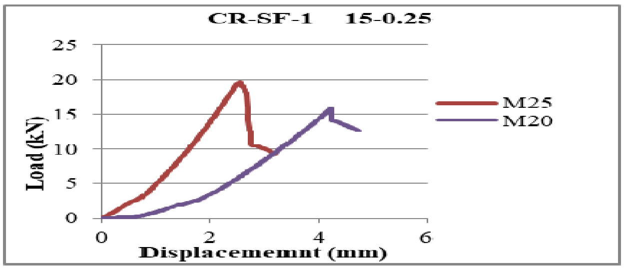

Figure 17 Load vs displacement curve for CR-SF-1 (15-0.25)

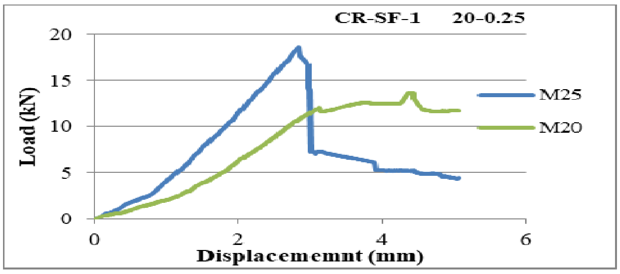

Figure 18 Load vs displacement curve for CR-SF-1 (15-0.25)

Table 5 Peak load, shear stress and type of failure of beams cast with different volume fractions of crumb rubber and steel-fibre (0.5%)

Beam type	Steel-Fibre %age	Rubber %age	Peak Load (kN)		Avg. shear stress		Type of Failure
			M25	M20	M25	M20	
CR-SF-2	0.5%	0%	26.8	21.4	1.86	2.68	Shear
		5%	21.8	20.6	1.79	2.06	Shear
		10%	21.4	20	1.55	2.0	Flexure
		15%	20.6	18.2	1.45	1.82	Flexure
		20%	19.3	17.9	1.35	1.79	Shear-Flexure

The table 5 illustrates the beams cast with incorporation of crumb and infused with steel fibre fraction of 0.5%. With further increase in the fibre content an enhanced performance in shear is attained with higher values of shear stress as compared with conventional concrete and concrete incorporated with rubber only. The results of both the grades I.e. M25 and M20 are given in the table. A more ductile conduct is achieved with increased deflections and failure in the shear zone.

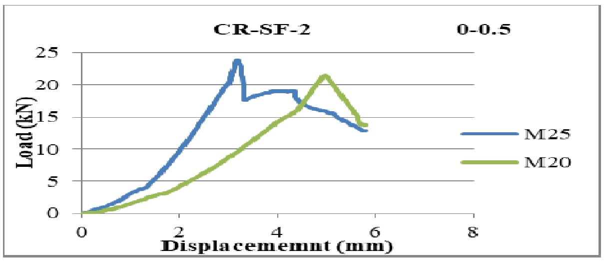

Figure 19 Load vs displacement curve for CR-SF-2 (0-0.5)

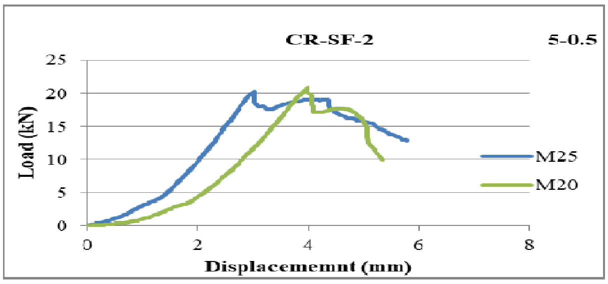

Figure 19 Load vs displacement curve for CR-SF-2 (5-0.5)

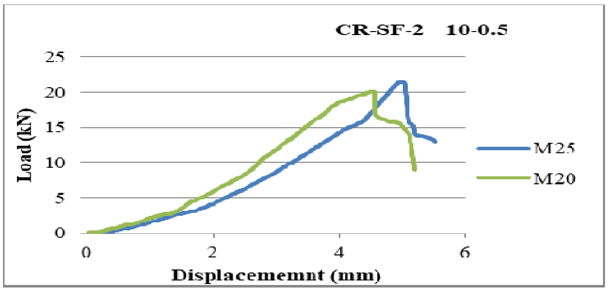

Figure 20 Load vs displacement curve for CR-SF-2 (10-0.5)

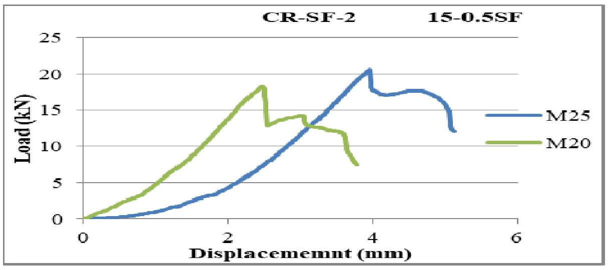

Figure 21 Load vs displacement curve for CR-SF-2 (15-0.5)

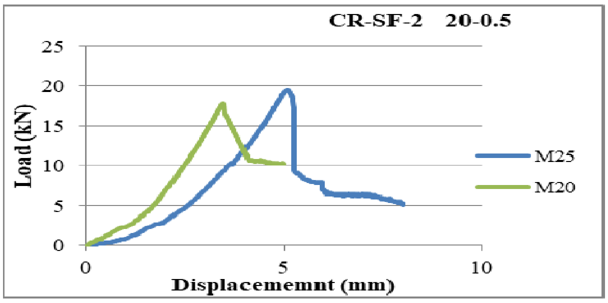

Figure 22 Load vs displacement curve for CR-SF-2 (20-0.5)

Table 6 Peak load, shear stress and type of failure of beams cast with different volume fractions of crumb rubber and steel-fibre (1%)

Beam type	Steel-Fibre %age	Rubber %age	Peak Load (kN)		Avg. shear stress		Type of Failure
			M25	M20	M25	M20	
CR-SF-3	1%	0%	28	23.2	1.86	2.32	Shear
		5%	27.5	21.9	1.79	2.19	Flexure
		10%	26.6	19.5	1.55	1.95	Shear-Flexure
		15%	21.8	19	1.45	1.9	Shear
		20%	21.9	18.5	1.35	1.85	Shear

The table above illustrates the beams cast with incorporation of crumb at different volume fractions of 0, 5, 10, 15, and 20% and infused with steel fibre fraction of 1%. The fibre content of this mix is maximum and again showing good results for shear stress. The tests were done for the both grades and display a better performance of shear, with further increase in the peak load, limiting the sudden failure towards a much better ductile conduct. The load vs displacement graphs are given below.

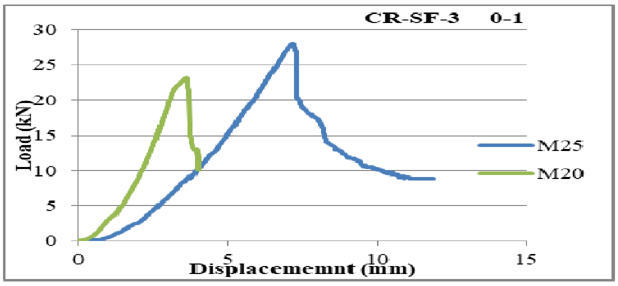

Figure 23 Load vs displacement curve for CR-SF-3 (0-1)

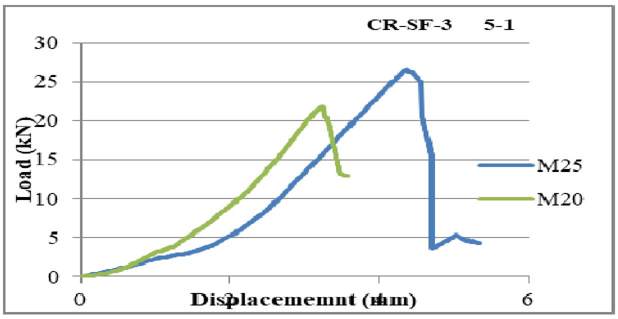

Figure 24 Load vs displacement curve for CR-SF-3 (5-1)

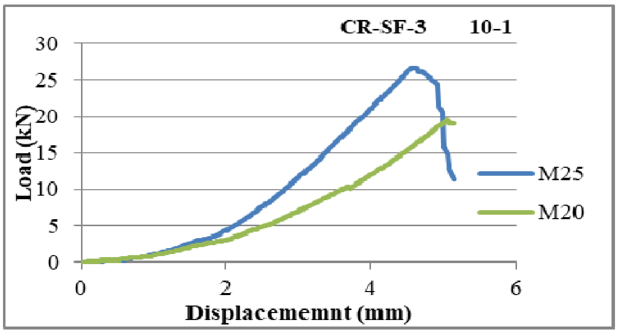

Figure 25 Load vs displacement curve for CR-SF-3 (10-1)

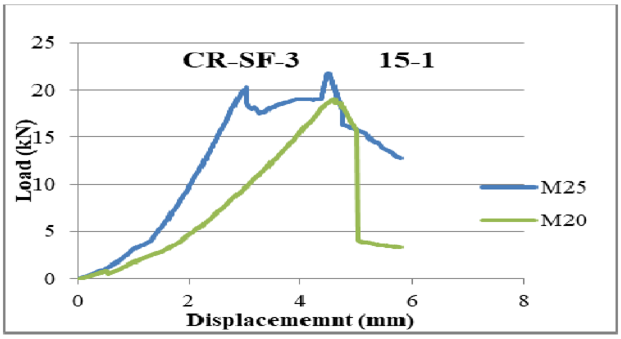

Figure 26 Load vs displacement curve for CR-SF-3 (15-1)

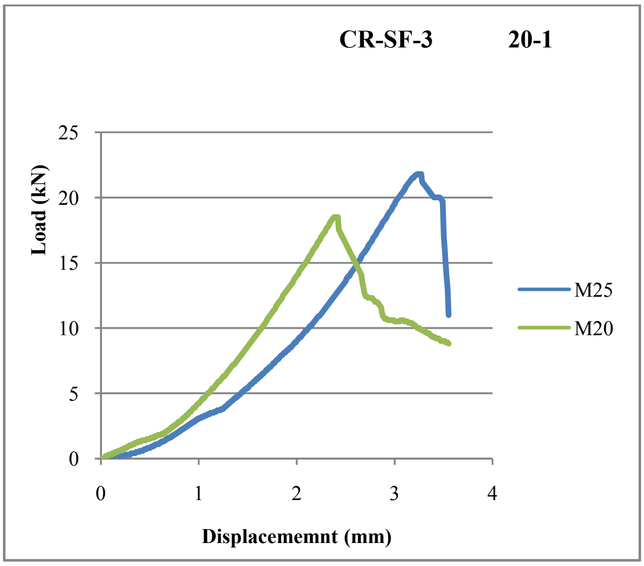

Figure 27 Load vs displacement curve for CR-SF-3 (20-1)

Figure 28 Beam failure (flexure)

Figure 29 Beam failure (flexure)

Figure 30 Beam failure (shear)

Figure 30 Beam failure combinations of (flexure and shear)

3.3 Failure of beams

The beam failure commences at the ultimate load and in the current study two types of failures have been observed, one is flexure and the other is shear or a combination of two and are depicted as,

4 Conclusions

The primary conclusions made from this investigation are as follows.

- With the incorporation of crumb rubber into concrete, a high workability for all tested concrete was attained.

- The shear test performed on concrete infused with steel fibre displays the relative ductility which lacks in plain concrete. Steel fibres improves post cracking capacity, resisting the relative sliding of the shear surfaces and thus lead to a greater shear strength.
- Beams incorporated with only crumb rubber, show a brittle as well as flexural mode of failure, but after infusion of steel fibre into the concrete the brittle failure is limited, and gives rise towards the ductile conduct with narrowed crack widths.

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