STRUCTURAL PERFORMANCE OF RC DUAL CONCEPT BEAM WITH CRUMBED RUBBER AND HIGH FIBRE REINFORCED CONCRETE

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Abstract - *Crumbed Rubber Concrete (CRC) is a promising new material in the construction industry, produced as the fine aggregate gets partially or fully replaced by crumbled scrap tyre rubber. Crumb rubber is a material obtained by reducing scrap tyres or other rubbers into the form of granules. CRC is a good thermal insulating material, having high heat resistant capacity than the normal concrete. Also it exhibits higher toughness. In dual layer concept, tension zone comprised with High Fibre Reinforced Concrete (HFRC) and compression zone with rubberised concrete. Dual core concept, strength criteria is evaluated by varying the shape of the HFRC core. Composite concept means a beam with hollow concept, by the inclusion of steel tubes as core which helps the provision of pipelines and other service lines without any damages. CRC beams can be designed in most economic manner, with high strength without affecting the structural performance. Analyzing the flexural performance of composite beam with dual layer, core and composite concept using ANSYS software. Also study the behavior of CRC beam under stiffness and impact resistance.*

Key Words: **Crumbed Rubber Concrete (CRC), High Fibre Reinforced Concrete (HFRC), Dual Layer, Dual Core, Hollow Core, ANSYS Workbench**

1. INTRODUCTION

Rubber aggregates obtained by the reduction of scrap tyres to aggregate sizes using two general processing technologies such as mechanical grinding and cryogenic grinding. Where mechanical grinding is one of the most commonly used process. With the rapid development of transportation and industries, a great amount of scrap tyre rubber is produced. These may cause the chances of accumulation of tyres on the landfills, which may results in severe environmental issues. Burning of these wastes can cause global warming which is a crucial problem faced by the world today. Hence to overcome these hazardous issues, recycling of scrap tyre rubber becoming more and more important with the global expanding of environmental problem. Researches shows that using tyre rubber in concrete mixtures can inversely affect the compressive strength, flexural strength and workability but concrete mixed with crumbed rubber has better toughness, impact strength, greater heat insulation and sound insulation properties than normal concrete. Also it can enhance other properties such as propagation, energy absorption, ductility and durability.

Crumbed Rubber Concrete (CRC) is having advantages that it is highly eco-friendly and economical, but taking into account of the strength characteristics, CRC won't give better performance than normal concrete. This inherent internal flaw in CRC can be healed by blending it with fibre. Hence, here introducing three concepts. In dual layer concept, tension zone comprised with High Fibre Reinforced Concrete (HFRC) and compression zone with CRC. Dual core concept increases the energy absorption and reduces crack on the beam. Composite concept means a beam with hollow concept, by the inclusion of steel tubes as core which helps the provision of pipelines and other service lines without any damages. In this study, investigating the flexural performance of composite beam with dual layer, core and composite concept using ANSYS Workbench 16.1 software. Also study the behavior of CRC beam under ductility, stiffness and impact resistance.

1.1 Scope and Objectives of the Study

This project work is restricted to static analysis of dual layer, core and hollow core concept beams under flexural and impact loading. The work is focused on CRC and HFRC. Adopting locally available waste material for construction enhances economical and environmental benifits. The work is limited to modelling and analysis of beams using ANSYS.

The main objective of this study to develop and analyse different types of composite beams with CRC and HFRC are follows;

- To investigate the flexural performance of composite beams under three concepts (dual core concept, dual layer concept and hollow core concept).
- To investigate the performance of best composite beam under low velocity impact.
- To evaluate the impact force resistance, impact stiffness of the composite beam subjected to impact loading.

1.2 Software used

ANSYS software is mainly meant for the analysis of system, on the other hand which enables design alterations, which is

basically not possible on other softwares. Whatever work is done through the experiments, those can be easily replicated by using this software. ANSYS have mainly nine softwares comprising thirty platforms. From these nine softwares Workbench can be used for structural projects. ANSYS workbench 16.1 is a finite element analysis tool that is used in conjunction with CAD systems under variety of conditions. This mainly focuses on geometry, setting up the finite element model, analysis, solving, and results. It is a software environment for performing structural, thermal, and electromagnetic analyses. The first step is input all the data needed for the analysis. Then meshing is done and modelling was carried out. Then apply different types of load and boundary condition. Using this the overall accuracy can be improved. One of the main advantage of workbench software can be considered as the 60% of work will be done automatically.

2. FINITE ELEMENT MODELLING AND ANALYSIS

2.1 General

In this paper fourteen beam models are considered under the whole three concepts. Simply supported beam with 100 x 200mm in cross section and span of 1800mm are taken. Reinforcement details provided are taken from Agampodi S.M. Mendis et.al (2). A nominal cover of 20 mm is provide for the beam. 10mmφ deformed bars are provided for the flexural reinforcement and transverse reinforcement given in the form of stirrups as 6mmφ @ 100mm c/c straight bars. Roller support is provided on left side and hinged support is provided on right side. The material properties are inputted in the engineering data of ANSYS. Next step is the preparation of geometry of the model with available engineering data.

Sketching, dimensioning and modelling is done in the geometry preparation. Once the geometry of the model is prepared, next step is to convert the geometry into model. The modelling portion involves the application of boundary conditions generation of meshing, bonding and loads. Loading is done as displacement controlled manner. The connection provided between CRC and HFRC layer are bonded connection. ANSYS WORKBENCH autogenerate mesh in fine size for the model. The element type of mesh for concrete is chosen as "solid 186 element" and for reinforcement "beam 188 element" is opted.

2.2 Dual layer concept

Investigating the flexural performance of dual layer composite beams with different depth ratios. The dual layer is made as the tension zone is comprised with HFRC and compression zone is comprised with crumbed rubber concrete. Here the strength criteria is evaluated by varying

the thickness of the fibre. The material properties of the CRC [2] and HFRC (1) are shown in table-1.

Modelling is done by varying the percentage of HFRC below the neutral axis. Such as;
1. 25% HFRC below neutral axis and CRC
2. 50% HFRC below neutral axis and CRC
3. 75% HFRC below neutral axis and CRC
4. 100% HFRC below neutral axis and CRC

Here percentage of HFRC is provided below the neutral axis and the remaining portions are provided with CRC. Total depth of the entire beam is taken as 200mm [2]. The isometric view of each model is shown below;

Material	Poisson's Ratio	Yield Strength (MPa)	Young's Modulus (MPa)	Density (kg/m³)
CRC	0.15	4.36	31500	2370
HFRC	0.14	11.18	43000	7800
Longitudinal Reinforcement	0.15	550	2 x 10⁵	7850
Transverse Reinforcement	0.15	500	2 x 10⁵	7850

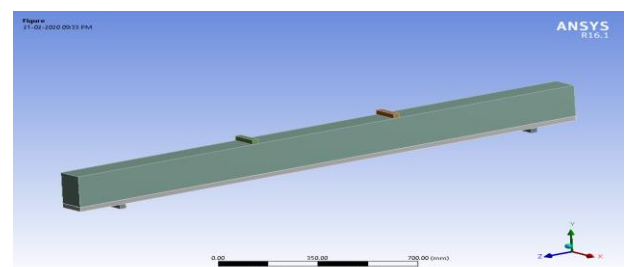**Table -1:** Material properties of dual layer concept

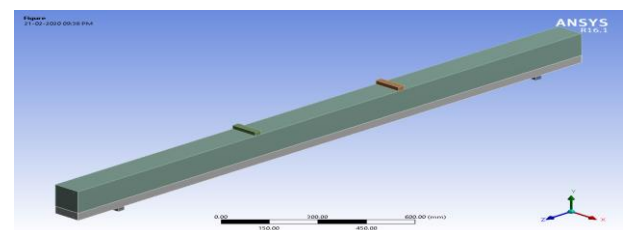**Fig -1**: Model of 25% HFRC below neutral axis and CRC

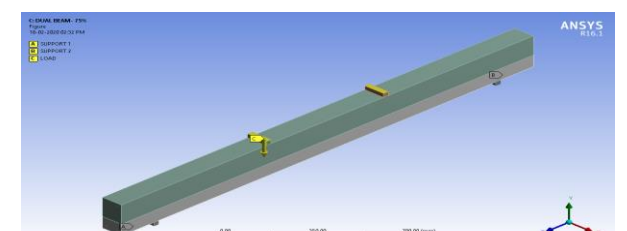**Fig -2**: Model of 50% HFRC below neutral axis and CRC

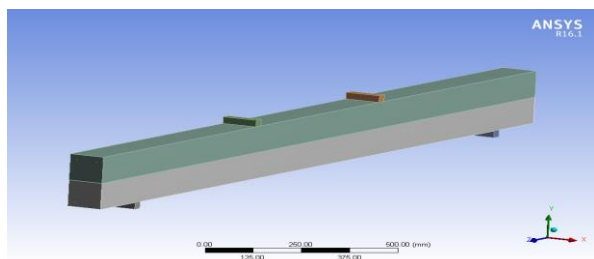**Fig -3**: Model of 75% HFRC below neutral axis and CRC

Fig -4: Model of 100% HFRC below neutral axis and CRC

From the structural analysis conducted the total deflection obtained maximum for the model are shown in figure below. Maximum total deflections are shown in figure at which the model fails and the corresponding load carrying capacity is obtained as the maximum strength upto which the beam can withstand.
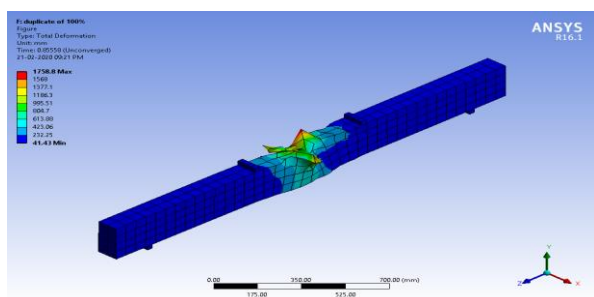

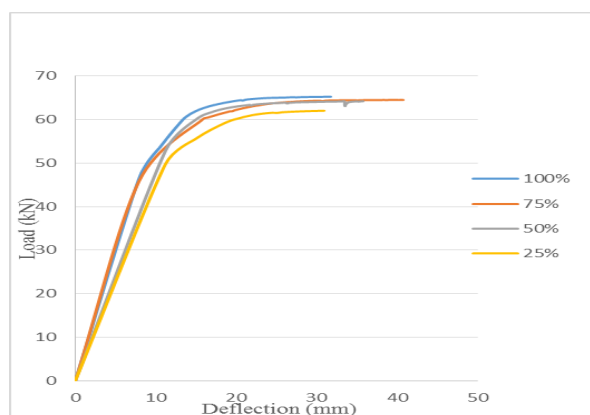**Fig -5**: Total deflection of 100% HFRC below neutral axis

Chart- 1: Load-deflection curve of dual layer concept

From the chart-1 it can be figured out the beam with 100% HFRC below neutral axis and CRC is having higher load carrying capacity compared to other dual layer models. And the maximum load at which beam fails and comparisons made are shown in table-2. Among the four models load carrying capacity of model-100% HFRC below neutral axis with CRC is obtained as 65.232kN and are greater compared to other models in dual layer concept. Hence, out of four models from dual layer concept, model with 100% HFRC below neutral axis is taken as the best model.

Model	HFRC depth (mm)	CRC depth (mm)	Deflection (mm)	Load (kN)
25%HFRC +CRC	25	175	30.921	62.01
50%HFRC +CRC	50	150	35.775	64.184
75%HFRC +CRC	75	125	40.099	64.488
100%HFRC+CRC	100	100	31.751	65.232

Table -2: Comparison of dual layer composite beams

2.3 Dual core concept

In this study investigating the flexural performance of dual core composite beams. The concept is based on different core shapes introduced within the beam. The dual core occupies two cores, in which the outer core comprises CRC and the inner core comprises HFRC. Here the strength criteria is evaluated by varying the shape of the HFRC core. In this concept the weight and ratio of HFRC is considered to be same and the area made to be constant for the core. The beam is modelled in ANSYS WORKBENCH by providing required design alterations as per the concept. And the modelling is done based on different core shapes such as,

1. CRC with rectangular HFRC core
2. CRC with elliptical HFRC core
3. CRC with trapezoidal HFRC core

Geometry of the model considered is similar to that of above concept. Here design alterations are made to the inner core. The area of HFRC core is taken as the area of 50% HFRC layer from dual layer concept. i.e., 5000mm². The isometric view of each model is shown below;
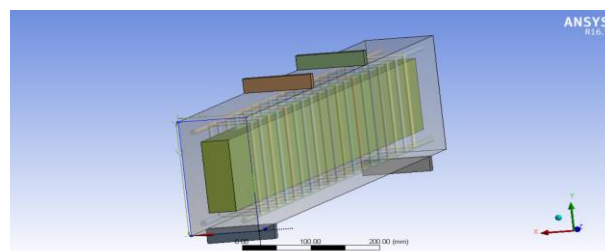

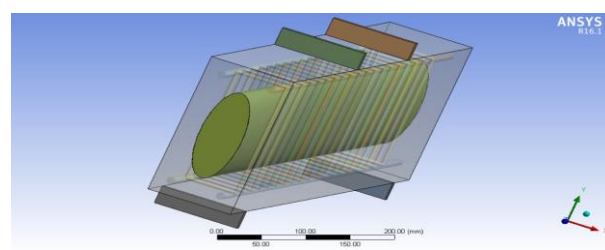**Fig -6**: Model of CRC with rectangular HFRC core

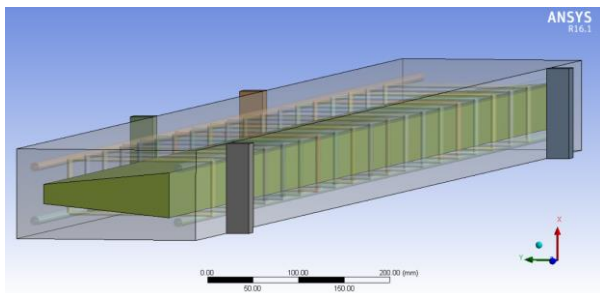**Fig -7**: Model of CRC with elliptical HFRC core

Fig -8: Model of CRC with trapezoidal HFRC core

From the chart-2 it is observed that CRC beam with rectangular core is having higher load carrying capacity compared to other dual core models. And the maximum load at which beam fails and comparisons made are shown in table-3. Out of three models compared from dual core concept, model with rectangular core is adopted as the best model.
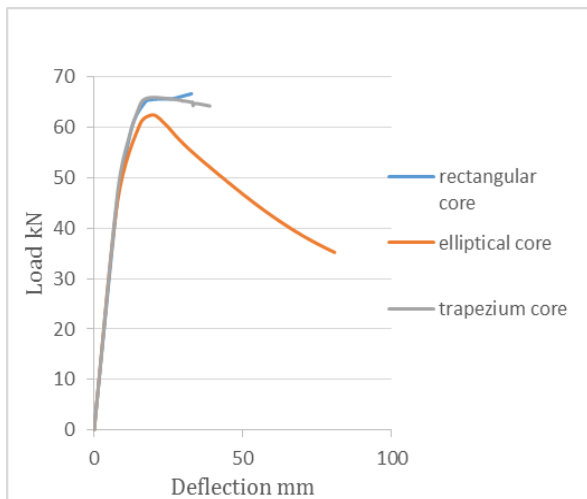

Chart- 2: Load-deflection curve of dual core concept

Model	Core area (mm²)	Beam area (mm²)	Deflection (mm)	Load (kN)
Rectangular core+CRC	5000	20000	30.921	62.01
Elliptical core+CRC	5000	20000	35.775	64.184
Trapezoidal core +CRC	5000	20000	40.099	64.488

Table -3: Comparison of dual core composite beams

2.4 Hollow core concept

In this study investigating the flexural performance of hollow core composite beams. Hollow core is created by the inclusion of steel tube as core inside the beam, which also helps in the provision of pipelines and other service lines without any damages. The steel core is bounded by CRC as outer portion in the beam. Hot Rolled Steel (HRS) and Cold Formed Steel (CFS) are used as steel core. In hot rolled steel core, the strength criteria is evaluated by varying the thickness of the steel core. Whereas, in cold formed steel core, strength criteria is evaluated by introducing C-sections and SIGMA sections connecting face to face (F2F) and back to back (B2B). The area of the core will be constant Here the modelling is done based on inclusion of hot rolled steel and cold formed steel core such as,

1. CRC with Hot Rolled Steel core
   - Steel core of 3mm
   - Steel core of 4mm
   - Steel core of 5mm
2. CRC with Cold Formed Steel core
   - C sections face to face connected
   - C sections back to back connected
   - Sigma sections face to face connected
   - Sigma sections back to back connected

In this the beam is modelled with a hollow core bounded by CRC as outer portion. Here design alterations are made to the hollow core in which hollow core is adopted as either HRS or CFS. The material properties adopted for HRS is the properties of mild steel and for CFS are shown in table-4 [10]. Dimensions provided for the model is fixed based on the area of 50% HFRC layer from dual layer concept. i.e., 5000mm². The isometric view of each model is shown below;

Material	Poisson's Ratio	Yield Strength (MPa)	Young's Modulus (MPa)	Density (kg/m³)
CRC	0.15	4.36	31500	2370
HRS	0.3	250	2E+05	-
CFS	0.3	612	2E+05	-
Longitudinal Reinforcement	0.15	550	2 x 10⁵	7850
Transverse Reinforcement	0.15	500	2 x 10⁵	7850

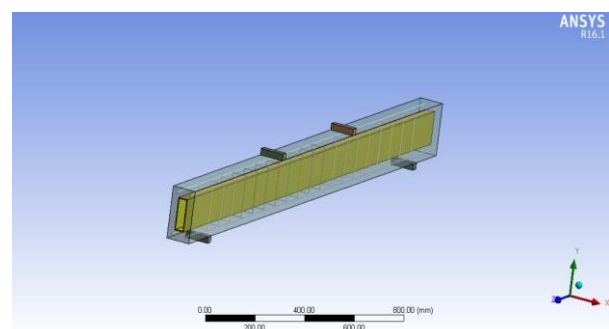**Table -4:** Material properties of hollow core concept

Fig -9: Model of CRC with HRS core of 3mm
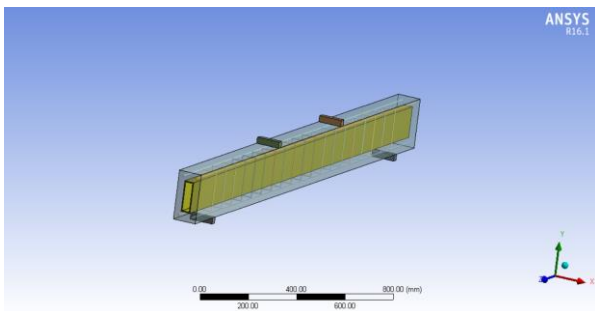
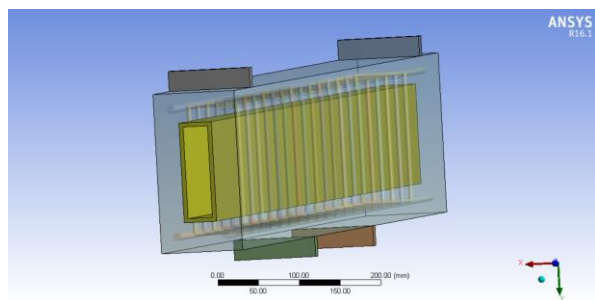**Fig -10**: Model of CRC with HRS core of 4mm

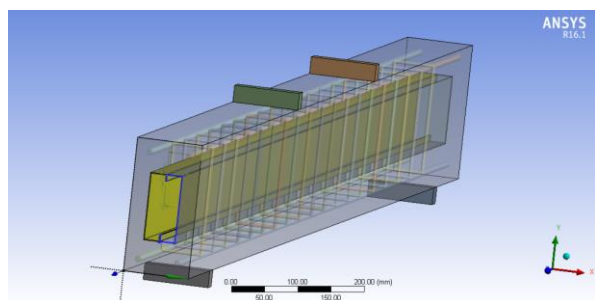**Fig -11**: Model of CRC with HRS core of 5mm

Fig -12: Model of CRC with CFS C section core F2F
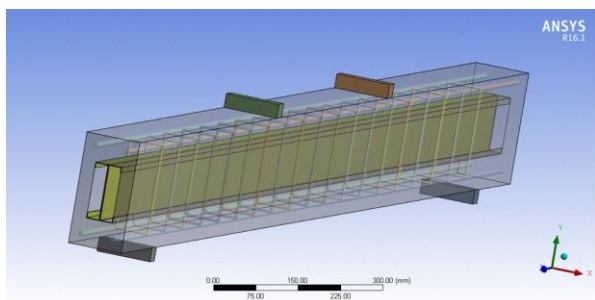

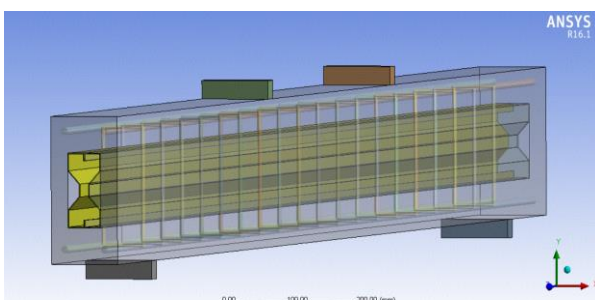**Fig -13**: Model of CRC with CFS C section core B2B

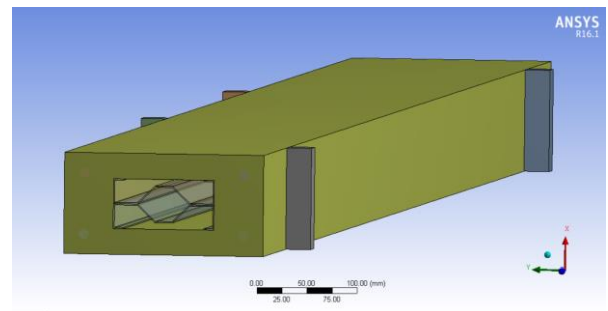**Fig -14**: Model of CRC with CFS SIGMA section core F2F

Fig -15: Model of CRC with CFS SIGMA section core B2B

From the chart-3 it has been found that beam with HRS core of 5 mm thickness is having higher load carrying capacity compared to other hollow core models. And the maximum load at which beam fails and comparisons made are shown in table-5. Out of seven models from hollow core concept, model with HRS core of 5mm thickness is found to be the best model with load carrying capacity 102.54kN.
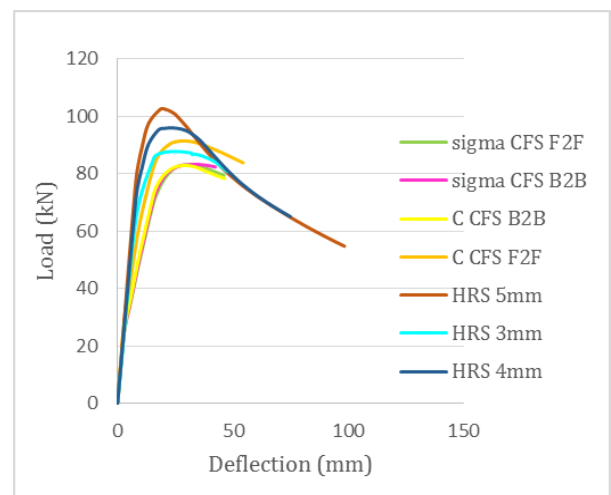

Chart- 3: Load-deflection curve of hollow core concept

Model	Load (kN)	Deflection (mm)
SIGMA CFS F2F	83.164	31.179
SIGMA CFS B2B	83.312	34.614
C CFS B2B	82.961	29.858
C CFS F2F	91.491	27.342
HRS 3mm	87.781	24.676
HRS 4mm	96.016	22.546
HRS 5mm	102.54	20.68

Table -5: Comparison of hollow core composite beams

3. RESULT AND DISCUSSIONS

3.1 Selection of best model among three modelling concept based on load carrying capacity

One best model is chosen from each concept based on the maximum load carrying capacity. And the next step is to select a best model from the best models already chosen up in the three concepts. From dual layer concept, CRC with 100%HFRC below neutral axis is obtained as the best model. From dual core concept, CRC with rectangular core is obtained as the best model. And finally from hollow core concept, CRC with HRS core of 5mm is obtained as the best model.
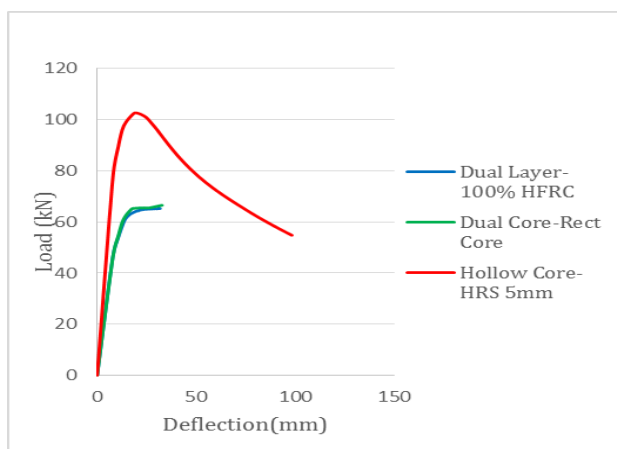

Chart- 4: Load-deflection curve of dual layer, dual core and hollow core composite beams

From the chart-4 it is observed that CRC with HRS core of 5mm from hollow core concept is having greater load carrying capacity, 102.54kN compared to other models.

3.2 Selection of best model among three modelling concept based on impact loading

Impact analysis is conducted on the models chosen from the three concepts. The analysis is conducted by a mass of 500kg is made to fall on the centre of beam from a height of almost 10 feet, which thus produces a velocity of 6.5m/s. The deformation shows how much the beam is bend. The deformation thus obtained indicates impact resistance and impact stiffness of the beam. The results shows the model which is having lesser deformation provides higher stiffness and provides greater resistance to impact.

The figure-16 shows the impact load applied to the centre portion of hollow core concept-HRS 5mm core with CRC model. It is observed that the minimum deformation obtained for the hollow core concept-HRS 5mm core with CRC model is 37.943mm.
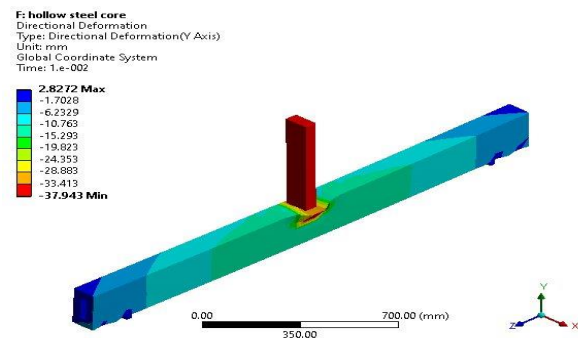

Fig -16: Deformation of hollow core concept-HRS 5mm core with CRC model

When comparison is made with other two models from chart-5, this model is having higher impact stiffness and greater resistance to impact. i.e. from the graph it is shown that the curve of HRS 5mm core model is having lesser deformation compared to other models. Hence this model is selected as the best model under impact loading. And the minimum deformation values of above three models are shown in the table-6.
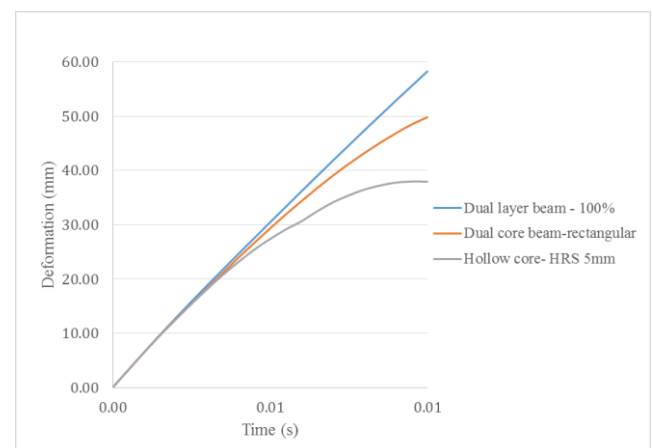

Chart- 5: Deformation by impact load

Model	Deformation(mm)
Dual Layer-100%HFRC	58.313
Dual Core- Rectangular Core	49.87
Hollow Core- HRS 5mm	37.943

Table -6: Deformation values of dual layer, dual core and hollow core composite beams

4. CONCLUSIONS

Crumbed Rubber Concrete (CRC) is one of the finest innovations that man has ever made in the construction sector. In this study, three new concepts were developed to investigate the structural performance of RC dual concept beam with crumbed rubber and high fibre reinforced concrete such as dual layer concept, dual core concept and hollow core concept. Based on the obtained results the following conclusions can be drawn,

- Rubberised concrete is highly economic and eco-friendly as it is consumed from locally available scrap tyres.
- By the replacement of aggregate by crumb rubber, the beam can be developed as light weight.
- But by the application of rubberised concrete alone in beam won't give better strength compared to normal concrete.
- The introduction of HFRC with CRC in beam confederates improvement in structural performance compared to the normal concrete.
- Based on flexural performance, among the three best models from the three concept, the model of hollow core concept- HRS 5mm core shows greater load carrying capacity, i.e. 102.54kN thereby strength of the concrete is augmented to great extend compared to normal concrete.
- Based on the impact loading also the model of hollow core concept-HRS 5mm core shows lesser deformation, i.e. 37.943mm which highly endorse for greater impact stiffness and offers higher resistance to impact compared to other models.

ACKNOWLEDGEMENT

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