Impact Load Test on Conventional and Roller Compactor Steel Fiber Reinforced Concrete Pavement

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Abstract. The effect of compaction method on steel fiber reinforced concrete pavement (SFRC) has been simulated in this study, a locally manufactured steel roller compactor is designed to simulate steel roller compactor which is commonly used in site for compaction. 0.8 % volume fraction (V_f) of steel fiber content is used and compacted using roller compactor in three cases category, case 1: load 10 kg and no. of cycles are 8, 16, 24 cycles. Case 2: initial stage: load 10 kg and no. of cycles are 4, 8, 12 cycles and finial stage: load 25 kg and no. of cycles are 4, 8, 12 and finally Case 3: load 25 kg and no. of cycles are 8, 16, 24 cycles. The obtained beam specimens were tested using a locally manufactured impact load apparatus and test results has been compared with steel fiber reinforced concrete beam specimens compacted using conventional compaction method. Test results show that the optimum steel fiber roller compacted concrete beam specimen under impact load test gives 17 blows for first crack and 173 blows for failure while steel fiber reinforced concrete beam specimen compacted using conventional method gives 15 blows for first crack and 110 blows for failure. Material properties have also been improved when using roller compactor by about 9.74%, 8.84% and 4.76% for compression strength, tensile strength and modulus of elasticity respectively.

Keywords: Steel fiber reinforced concrete (SFRC) · Roller compactor · Steel fiber roller compacted concrete (SFRCC) · Impact load test

Abbreviations

SFRC	Steel Fiber Reinforced Concrete
RCC	Roller Compacted Concrete
SFRCC	Steel Fiber Roller Compacted Concrete
PCC	Portland Cement Concrete Pavement

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NCCLR	National Center for Construction Laboratories and Research
f'_{cu}	Compressive Strength
f_t	Splitting Tensile Strength
E_c	Modulus of Elasticity
W/C	Water Cement Ratio
σ_t	Splitting Tensile Strength
P	Applied Compressive Load
L	Length of Cylinder
D	Diameter of Cylinder
ν	Velocity of the Wave, km/sec
L	Distance between Transducers, mm.
t	Traveling Time, μsec
ρ	Density (kg/m^3)
υ	Poisson's Ratio
ν	Pulse Velocity (km/s)
V_f	Volume Fraction of Steel Fiber
U	Impact Energy
fr	Modulus of rupture

1 Introduction

Roller compacted concrete (RCC) is a zero-slump concrete mixture containing of Portland cement, sand and dense-graded aggregate particles. Since it contains a comparatively small quantity of water content, it cannot be placed by the same techniques used for conventional Portland cement concrete (PCC) mixtures. For pavement applications; RCC is usually placed using an asphalt paver as for density is attained through compaction using vibrating roller compactor [1].

Roller-compacted concrete pavements (RCCP) suffers from a number of difficulties. In particular, the application of tie bars or slip bars is challenging, because of the heavy compaction by vibratory roller compactor. As a result, it is known that RCCP is prone to cracking due to drying shrinkage or thermal stress which prevents the placing of pavement slabs with long joint spacing. Nevertheless using steel fiber in concrete pavement offers higher crack resistance and flexural strength, if roller-compacted concrete (RCC) could be given the properties of SFRC, it would offer benefits as a heavy traffic pavement applications concerning its rapid construction and shorter lead time. To achieve adequate bonding between the new and old layer at cold joint, the optimum layer thickness for SFRCC ranges from 20 to 30 cm. the test results shows that with increment of volume percentage of steel fiber in SFRCC mixture from 25–75 %, compressive strength increase from 42.22 MPa to 43.55 MPa, splitting tensile strength increase from 3.89 MPa to 4.95 MPa and flexural strength increase from 6 MPa to 7.4 MPa [2].

The flexural strength of SFRCC for a given consistency is 12.5% to 52.3% higher than that of conventional RCC. The flexural toughness of SFRC with hooked fibers is

0.31 to 1.88 MPa higher than with indented fibers. The toughness of SFRC with long fibers is 1.42 to 2.99 MPa higher than with short fibers. However, accumulation of experimental results with various fiber contents is still needed [3].

2 Material Characteristics

2.1 Cement

Iraqi Portland cement (type V) of Tasluja Factory is used in the present paper. Tables 1 and 2 show the chemical composition and physical properties of the cement used. This cement is tested and checked according to Iraqi Standard Specification [4].

Table 1. Chemical composition of cement (All chemical tests were made by National Center for Construction Laboratories and Research (NCCLR))

Compound composition	Chemical composition	Percentage by weight	IQS 5:1984 limits
Lime	CaO	62.22	–
Silica	SiO_2	22. 1	–
Alumina	Al_2O_3	5.49	–
Iron Oxide	Fe_2O_3	3.53	–
Magnesia	MgO	2.24	≤ 5
Sulfate	SO_3	1.07	≤ 2.5
Loss on Ignition	L.O.I	0.09	≤ 4
Insoluble residue	I.R	0.32	≤ 1.5
Lime saturation factor	L.S.F	0.86	0.66–1.02
Main Compounds (Bogue's equation) percentage by weight of cement			
Tricalcium Silicate (C3S)	38.55		
Dicalcium Silicate (C2S)	33.15		
Tricalcium Aluminate (C3A)	8.58		
Tetracalcium Aluminoferrite (C4AF)	10.73		

Table 2. Physical properties of cement (All chemical tests were made by National Center for Construction Laboratories and Research (NCCLR))

Physical properties	Test result	IQS 5:1984 limits
Fineness using Blain Air Permeability Apparatus (m^2/kg)	310	250 min.
Soundness using Autoclave Method	0.19%	≤ 0.8
Setting Time using Vicat's Instruments		
Initial (hrs:min.)	1:65	45 m min.
Final (hrs:min)	2:46	10 h. Max.
Compressive Strength for Cement Paste Cube 70.7 mm) at		
3 days (MPa)	16.4	15 min.
7 days (MPa)	27	23 min.
28 days (MPa)	35	additional

2.2 Fine Aggregate

Natural river sand from Al-Sudoor region is used. Tables 3 and 4 show the grading and physical properties of the fine aggregate respectively that are performed by the National Center for Construction Laboratories and Research (NCCLR).

Table 3. Grading of fine aggregate AASHTO T-27.

No.	Sieve size (mm)	% Passing by weight	
		Fine aggregate %	AASHTO T-27-9
1	4.75	96	90–100
2	2.36	90	85–100
3	1.18	83	75–100
4	0.60	70	60–79
5	0.30	31	12–40
6	0.15	6.0	0–10

Table 4. Physical properties of fine aggregate. (All Test made by National Center for Construction Laboratories and Research (NCCLR))

No.	Physical properties	Test results	Limits of iraqi specification SCRB, 2003	Test No.
1	Specific gravity	2.65	–	*AASHTO T 84*
2	Sulfate content	0.08%	$\leq 0.5\%$	
3	Absorption	0.75%	–	*AASHTO T 84*

2.3 Coarse Aggregate

Crushed gravel brought from Al-Niba'ee region is used. The grading and physical properties of coarse aggregate are shown in Tables 5 and 6 respectively. The mid-range of specification is used of aggregate gradation as plotted in Fig. 1.

Table 5. Grading of coarse aggregate.

Sieve size (mm)	Coarse aggregate gradation % passing by weight	
	AASHTO M 43, Size No. 67, 2003	Selected gradation of aggregate
25	100	100
19	90–100	95
12	–	–
9.5	20–55	37.5
4.75	0–10	5
2.36	0–5	2.5

Table 6. Physical properties of coarse aggregate (All Test made by National Center for Construction Laboratories and Research (NCCLR)).

No.	Physical properties	Test results	Limits of specification	Test No.
1	Specific Gravity	2.6	–	AASHTO T- 85
2	Sulfate Content	0.087%	≤ 0.1%	AASHTO T-290
3	Absorption	0.63%	–	AASHTO T- 85
4	Percent of Passing no.200 by Weight	0.05%	≤ 1%	ASTM C 33/03
5	%Organic Impurities	0.2%	≤ 2%	ASTM C33/03

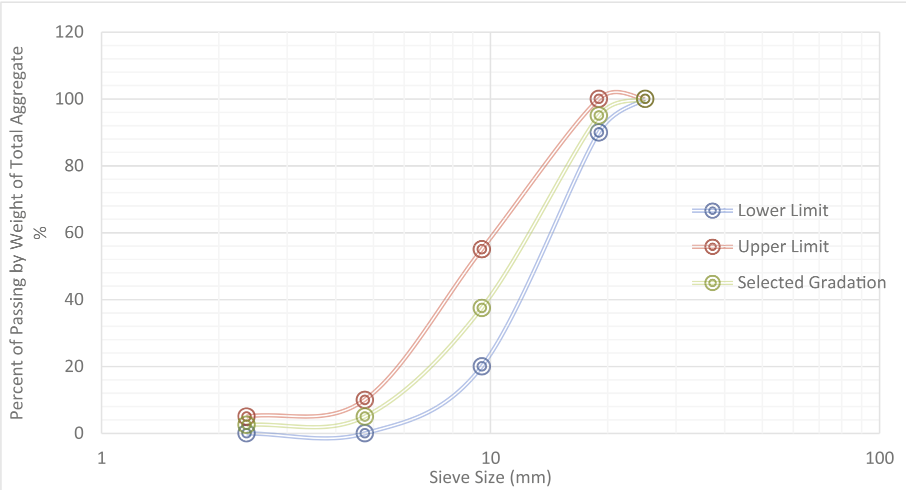

Fig. 1. Specification limits and gradation of coarse aggregate.

2.4 Water

Potable water of Baghdad is used for casting and curing.

2.5 Steel Fiber

Dramix steel fibers manufactured by Bekaert Corporation are used at a 0.4 % and 0.8 % (V_f). Table 7 gives properties of the steel fibers.

2.6 Fluidifying Additives

Sika ViscoCrete-5930, is a third generation of superplasticizers for concrete and mortar, is used. It meets the requirements for superplasticizers according to ASTM C 494 Types G and F and BS EN 934 Part 2: 2001. Main properties of the used superplasticizers are shown in Table 8.

Table 7. Properties of steel fiber (Supplied by the manufacturer).

Commercial Name	Configuration	Property	Specifications
Dramix ZC 50/0.5	Hooked Ends 	Density	7860 kg/m^3
		Ultimate Strength	1130 MPa
		Modulus of Elasticity	$200x10^3$ MPa
		Strain at Proportion Limit	5650 $x10^{-6}$
		Poisson's Ratio	0.28
		Average Length	50 mm
		Nominal Diameter	0.5 mm
		Aspect Ratio (L_f/D_f)	100

Table 8. The properties of fluidifying additive (Supplied by the manufacturer).

Appearance	Turbid liquid
Density	1.08 kg/lt _0.005
Basis	Aqueous solution of modified polycarboxylate
Packing	5 kg, 20 kg, 200 kg drums
Benefit	• Strong self-compacting behavior
	• Extremely high water reduction
	• Excellent flow ability
	• Increase high early strengths development
	• Improve shrinkage and creep behavior
Shelf life	Shelf life at least 12 months from date of production

2.7 Subgrade Soil Layer

The subgrade soil consist of a layer of low-plasticity silt and clay (ML and OL) according to Unified Soil Classification System USCS or (A-4) according to AASHTO M 145, which is simulated and contains inside a steel box of 800 mm length, 800 mm width and 350 mm depth and is compacted using 9 kg steel manually operated compacter with rectangular base plate with dimension of 100 × 350 mm, the soil is compacted in three layers at which each layer is compacted inside the box separately. The soil is brought from Bab-Almoadam overpass project. The physical and index properties of soil are shown in Table 9 and are carried in (NCCLR) according to the limits of the Iraq Standard Specification (***SCRB, 2003-R5***).

2.8 Concrete Proportions

A common concrete matrix is used in all mixes. The mixing proportion of (cement: sand: aggregate) is 1:2:2 by weight and the water–cement ratio (W/C) is 0.4 with superplasticizer of 0.02% by weight of cement. This mix is based on several trial mixes in order to achieve the most appropriate mix to produce good workability and uniform mixing of concrete without segregation. Steel fiber reinforced concrete is obtained by

Table 9. Physical and chemical properties of subgrade (All Test made by National Center for Construction Laboratories and Research (NCCLR)).

Index property	Index value	Limit of *SCRB specification R5, 2003*	
Laboratory/Field no.	2685	Other layers	Finishing layer (upper layer)
Max. Dry Density (gm/cm^3)	1.763	–	>1.7
Moisture Content (%)	11.7	–	–
Liquid Limit % (L.L)	35	<70	<55
Plasticity Index % (P.I)	7.2	<45	<30
California Bearing Ratio for 95% Compaction (%)	4.1	–	>4
Swelling Ratio (%)	0.9	–	–
TSS (Total Soluble Salts) (%)	2.895	<20	<10
Organic Matter (%)	0.460	<12	<12

adding steel fibers with volume fraction of 0.8% V_f to the fresh non-fibrous concrete mix, and remixed.

3 Experimental Work

3.1 Molds Preparation

Six wooden plywood molds are designed and fabricated for casting all beams. The molds are made of 700 mm length, 100 mm width and 100 mm height and their side pieces are connected by bolts which can easily be removed to strip off the hardened beams after casting. All molds have been well connected, cleaned, oiled, before pouring of concrete mixture into them.

3.2 Mixing

In order to obtain a homogenous concrete mixture with sufficient workability a certain producer used. All batching is done by weight. The concrete is mixed using electrical mixture. The interior surface of the mixture is cleaned and moisturized before placing the materials. First both coarse and fine aggregate placed and mixed for several minute in the mixer after that cement is added, The materials are mixed until a uniform color is obtained, Afterwards half of the water quantity is added and mixed for several minutes too. The fluidifying agent (Visco Crete -5930) quantity is split into two halves, first half is added to the remain water and moved by a sticker till homogenous mixture obtained before adding to the mixer and mixed for 5 min, finally the rest of the fluidifying agent (Visco Crete -5930) quantity is added to the mixer and mixed for about 3 min. When steel fiber is added to the mix it is uniformly distributed by several nodes in the mixer cover.

3.3 Casting, Compaction, and Curing

After mixing the SFRC mixture poured into molds in two layers, when each layer laid; the sides of the molds is hammered by rubber driver, to shake the mix and consolidate it into the molds. Then is compacted using a table vibrator compactor in case of normal compaction for about 40 s for each layer. During compaction air bubbles would appear on the surface as an indication of dispossessing unwanted air.

Afterwards the surface of SFRC is leveled off and finished with a trowel, then the specimens are covered to prevent evaporation of water. After 24 hours, the specimens were stripped from the molds and cured in a water bath with 25° temperature for about one month. Since water temperature would be below the desire temperature degree heater is used in cold weather to achieve adequate curing. After that they are took out from the water bath, finally specimens are tested.

Steel fiber concrete mixture is also used for roller compacted concrete with 0.8% V_f of steel fiber known as SFRCC, after mixing, the steel fiber concrete mixture is poured in one layer into the beam mold and hammered by rubber driver, to shake the mix and consolidate it into the molds. Compaction is carried out as shown in Plate 1 by different weight and number of passes as shown in Table 10, the compaction is done in three different cases as in the following:

Table 10. Steel fiber roller compacted concrete cases.

Case 1		Case 2				Case 3	
		Initial stage		Final stage			
Load	No. of cycles	Load	No. of cycles	Load	No. of cycles	Load	No. of cycles
10	8	10	4	25	4	25	8
10	12	10	8	25	8	25	16
10	24	10	12	25	12	25	24

1. Case 1: load 10 kg and no. of cycles are 8, 16, 24 cycles.
2. Case 2: initial stage: load 10 kg and no. of cycles are 4, 8, 12 cycles.
   finial stage: load 25 kg and no. of cycles are 4, 8, 12 cycles.
3. Case 3: load 25 kg and no. of cycles are 8, 16, 24 cycles.

Three cube and cylinder specimens are prepared for each beam specimen for conventional SFRC and for SFRCC with certain load and number of passes. As far for cube and cylinder specimens compaction for SFRCC; a locally manufactured apparatus is used, as shown in Plate 2, the steel fiber reinforced concrete mixture is poured into cubes in one layer of 100 mm hammered on sides and compacted, as for cylinders steel fiber reinforced concrete mixture which is applied in two layers each layer of 100 mm, and each layer is hammered and compacted individually. Weight to be applied onto cubes and cylinders differs from weight applied on beam specimens and it is calculated depending on stress applied in contact area between roller compacter and concrete mixture surface.

Plate 1. Roller Compacted Concrete.

Plate 2. Compaction of Cubes and Cylinders Specimens.

4 Strength and Mechanical Properties of Hardened Concrete

4.1 Compressive Strength (f'_{cu})

The compressive strength test is carried out in Material Laboratory of Faculty of Engineering in Al- Mustansiriya University for both fibrous and non-fibrous concrete [5] using a standard cubes specimens with dimensions 100 × 100 × 100 mm for length, width, and height respectively, loaded uniaxially using the universal testing machine (ELE, Digital Elect 2000).

4.2 Splitting Tensile Strength (f_t)

Indirect tensile strength is carried out in Material Laboratory of Faculty of Engineering in Al- Mustansiriya University on non-fibrous, and fibrous concrete specimens [6] using standard cylinders specimens with 100 mm diameter and 200 mm height. The test is carried out by placing a cylinder specimen horizontally in the compression testing machine and load is applied until failure occurs. The splitting tensile strength is calculated from the following equation:

$$\sigma_t = \frac{2P}{\pi L D} \tag{1}$$

Where:
σ_t: Splitting tensile strength (MPa),
P: Applied compressive load (N),
L: Length of cylinder (mm),
D: Diameter of cylinder (mm).

4.3 Modulus of Elasticity (E_c)

4.3.1 Equation Method

Measurements of static modulus of elasticity of concrete (E_c) is determined by obtained compressive strength of concrete and SFRC of cube specimens by conducting compressive strength test and then using the following equation [7];

$$E = 4.73\sqrt{f'c} \tag{2}$$

Where:
E: Elastic modulus (MPa),
$f'c$: Compressive strength of Cylinder (MPa).
While $f'c$ can be obtained using the following equation [8];

$$f'c = 0.8\,fcu \tag{3}$$

Where:
$f'c$: Compressive strength of Cylinder (MPa)
fcu: Compressive strength of Cube (MPa)

4.3.2 Ultrasonic Test Method

Portable Ultrasonic Non-destructive Digital Indicating Test (PUNDIT) is used to determine young modulus for concrete beam, cube and cylinder specimens. The device contains two transducers, one as transmitter and the other one as receiver, which used to send and receive frequency. The time that the wave takes to travel is read out and the velocity of wave transport can be calculated using the following equation; [9]

$$v = \frac{L}{t} \tag{4}$$

Where;
v = Velocity of the wave, km/sec.
L = Distance between transducers, mm.
t = Traveling time, μ sec.

Then following equation is used to determine young modulus for concrete; [10]

$$E = \rho\, v^2 \frac{(1+\upsilon)(1-2\upsilon)}{(1-\upsilon)} \tag{5}$$

Where;
E: Elastic modulus (MPa),
ρ: Density (kg/m^3),
v: Pulse velocity (km/s), and
υ: Poisson's ratio.

4.4 Impact Load Measurement

4.4.1 Manufactured Apparatus: Impact Load Device

The apparatus for the drop-weight test, as shown in Plate 3, is manufactured in local market to simulate the load repetition applied to concrete pavement on field. The equipment consists of a 2 kg steel cylinder shaped weight load, with diameter of 60 mm and length of 100 mm manually operated falling from 1,450 mm height of steel pipeline containing six holes on its sides near the base plate to prevent air from accumulating and effect the free drop weight from falling with respect to gravity. The distance of base plate edges is 200 mm.

Plate 3. Impact Load Apparatus.

4.4.2 Crack Width Measurement

Crack width is measured using steel roller package containing several steel rulers each with certain width, the rulers width ranging from 0.05-1 mm, the rulers are inserted in the crack and fitted then their sum is calculated to obtain the total crack width.

4.5 Roller Compacted Concrete

4.5.1 Manufactured Apparatus: Roller Compacter

The apparatus is manufactured in local market and designed to simulate steel roller compactor which is commonly used in the site for compaction as shown in Plate 4. A solid cylinder of 100 mm diameter, 100 mm length and 4.5 kg weight is fixed to the chase and connected from one side to steel column of 200 mm length where load would be applied and from the other side to the roller compactor holder. Finally the overall length of the apparatus is 1000 mm.

4.5.2 Cubes and Cylinders Compactor

The apparatus is manufactured in local market to compact the SFRC mixture in cube and cylinder specimens as shown in Plate 5, a steel bar of 600 mm length with circular base plate at bottom of 95 mm diameter and two steel plates distance 300 mm from the bottom plate at which load is entered between them.

Plate 4. Roller Compactor Apparatus.

5 Results and Discussion

5.1 Material Properties

Compressive strength, tensile strength and modulus of elasticity are measured at 0.8 % V_f of SFRCC, Figs. 2 and 3 show the compressive and tensile strength results respectively along with Table 11, it can be notice that beam (E2) has the maximum compressive and tensile strength results which was 62.39 MPa and 10.34 MPa respectively, that can be concluded; compacting SFRC in two layers and increasing load applied magnitude for each layer compaction gives maximum strength for SFRC. While beam specimen (F3) which has the second higher compressive and tensile strength which was 56.43 MPa and 9.51 MPa respectively.

It can be concluded from the previous results that compacting SFRC cube and cylinder specimens in two layers while increasing load magnitude gives maximum values for compressive and tensile strength at which equivalent loads to the loads on beams is applied on cube and cylinder specimens by determining stress values.

The modulus of elasticity is measured using equation method and ultrasonic device and from the obtained results that shown in Table 12; beam specimen (E2) has the maximum value of modulus of elasticity followed by beam specimen (F3); according to compaction technique of applying different incremental loads at two stages (first layer

Plate 5. Cube and Cylinder Specimens Compactor.

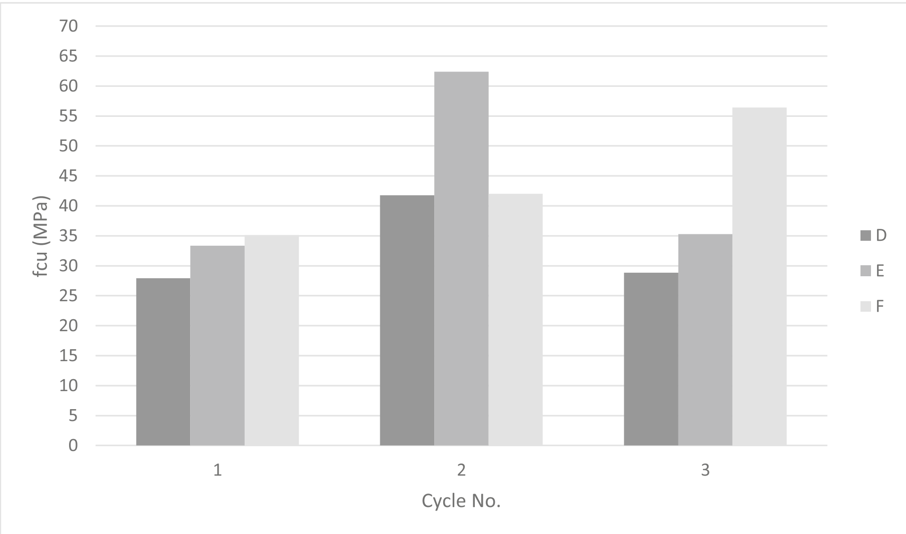

Fig. 2. Compressive strength results for roller compacted concrete cube specimens.

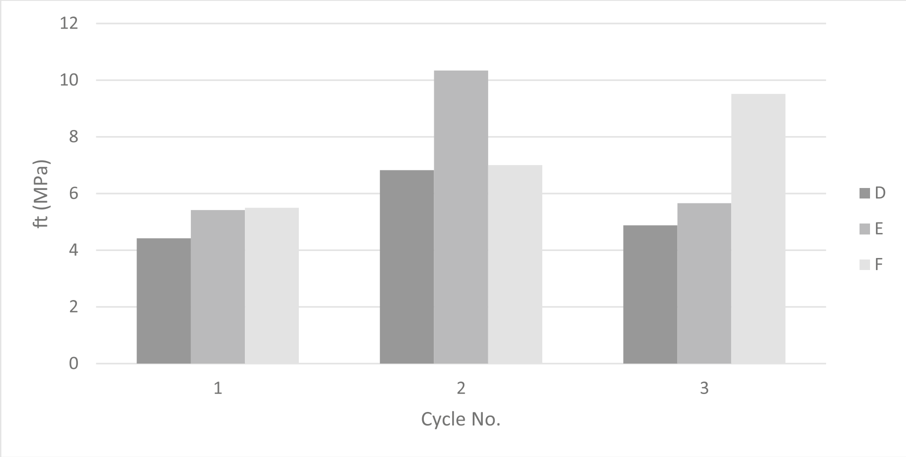

Fig. 3. Tensile strength results for roller compacted concrete cylinder specimens.

Table 11. Compressive and indirect tensile strength tests results for SF-RCC.

Sample		Compressive strength *Fcu* (MPa)	Indirect tensile strength *Ft* (MPa)
D	D1	27.93	4.42
	D2	41.76	6.82
	D3	28.85	4.88
E	E1	33.37	5.42
	E2	62.39	10.34
	E3	35.29	5.66
F	F1	35.1	5.5
	F2	42.01	7
	F3	56.425	9.51

Table 12. Modulus of elasticity results for SF-RCC.

Sample		Ec equation (GPa)	Ec ultrasonic (GPa)		
			Cube	Cylinder	Beam
D	D1	22.36	33.75	43.63	16.98
	D2	27.34	39.11	46.73	32.78
	D3	22.72	34.01	45.66	30.92
E	E1	24.44	38.46	46.08	37.68
	E2	33.42	45.45	54.00	47.23
	E3	25.13	38.78	46.73	38.41
F	F1	25.06	40.13	46.51	38.22
	F2	27.42	44.63	48.06	33.75
	F3	31.78	45.04	48.98	46.36

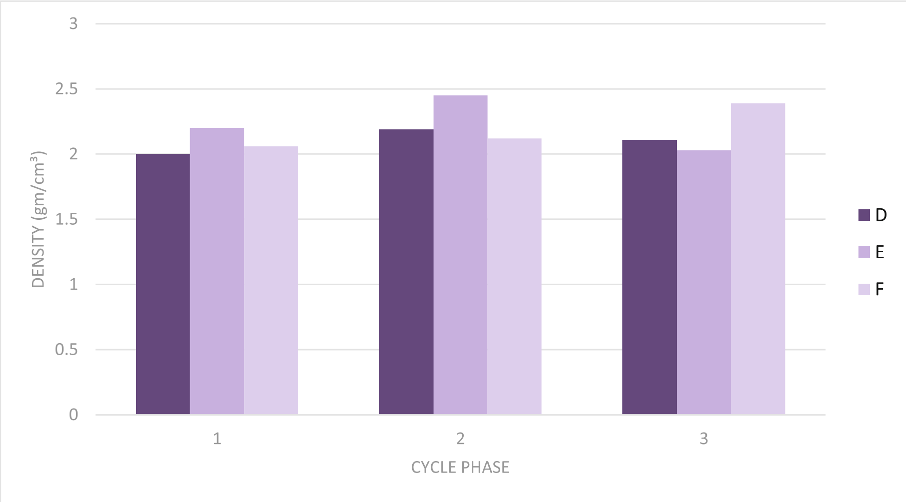

Fig. 4. Density for SFRCC beam specimens results.

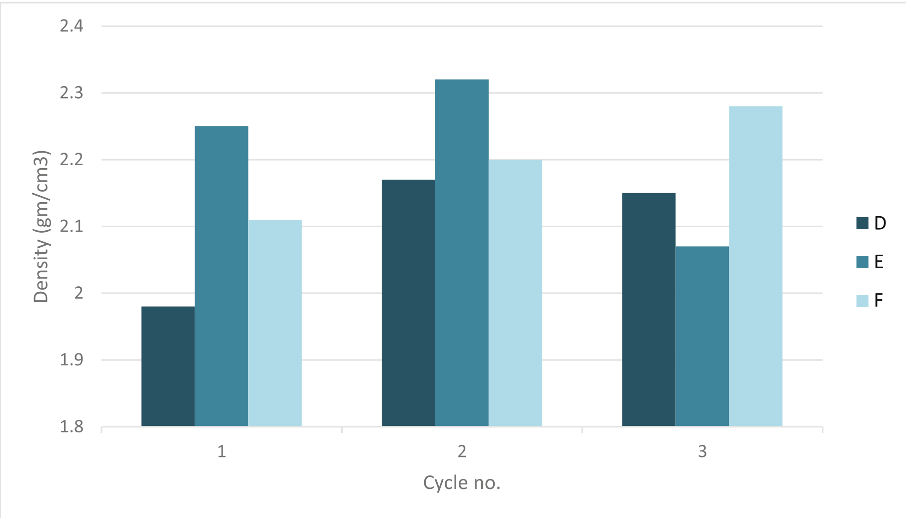

Fig. 5. Density for SFRCC cube specimens results.

with 10 kg and 8 passes) and (second layer with 25 kg and 8 passes) enhance the ability of SFRC pavement to deformed elasticity and increased it's stiffness.

Density of SFRC beam, cube and cylinder specimens are illustrated in Figs. 4, 5 and 6 respectively along with Table 13. It can be concluded that beam specimen (E2) has the maximum density followed by beam specimen (F3), which clarify that

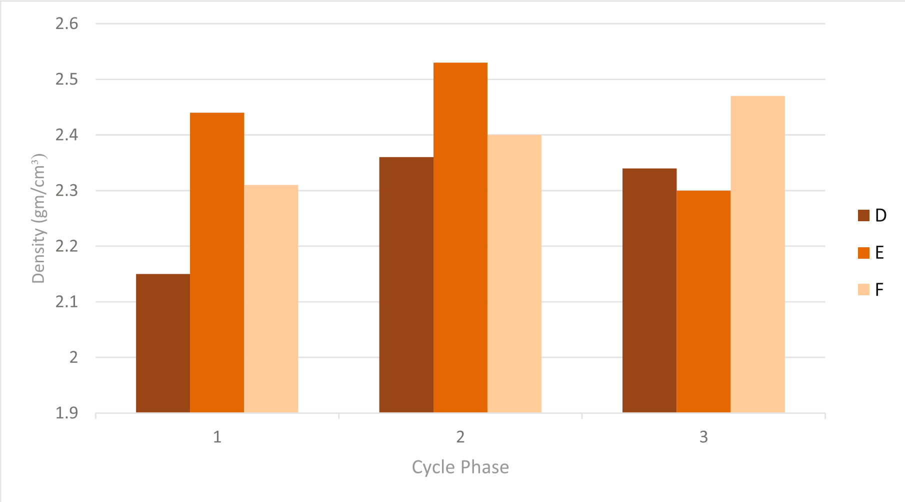

Fig. 6. Density for SFRCC cylinder specimens results.

Table 13. Density tests results for SF-RCC.

Sample		Density of beams (gm/cm^3)	Density of cubes (gm/cm^3)	Density of cylinders (gm/cm^3)
D	D1	2	1.98	2.15
	D2	2.19	2.17	2.36
	D3	2.11	2.15	2.34
E	E1	2.2	2.25	2.44
	E2	2.45	2.32	2.53
	E3	2.03	2.07	2.3
F	F1	2.06	2.11	2.31
	F2	2.12	2.2	2.4
	F3	2.39	2.28	2.47

$$\text{Density of Beam} = \frac{Weight\ of\ Beam(gm)}{Volume\ of\ Beam(cm^3)}.$$

$$\text{Density of Cube, Cylinder} = \frac{Weight\ in\ Air}{Weight\ in\ air - Weight\ in\ Water}.$$

compaction technique of applied different incremental loading at two stages (first stage: 10 kg, 8 passes) and (second stage: 25 kg, 8 passes) enhance density of SFRC and eventually increase all material properties of SFRCC.

Compressive strength, tensile strength and modulus of elasticity are measured and compared between beam specimens that have been compacted conventionally of 0.8% V_f (C) and (E2) that has been compacted using roller compactor as shown in Figs. 7 and 8 for compressive and tensile strength test results respectively and in Table 14 for modulus of elasticity test results.

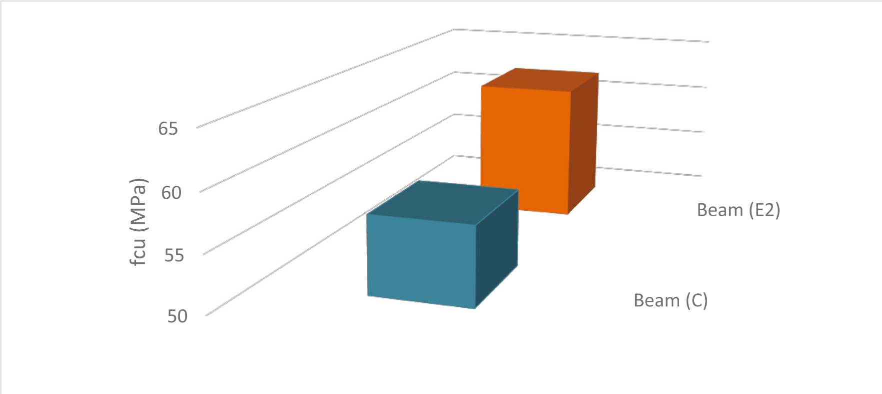

Fig. 7. Comparison of Compressive Strength Results for Cube specimens (C) and (E2).

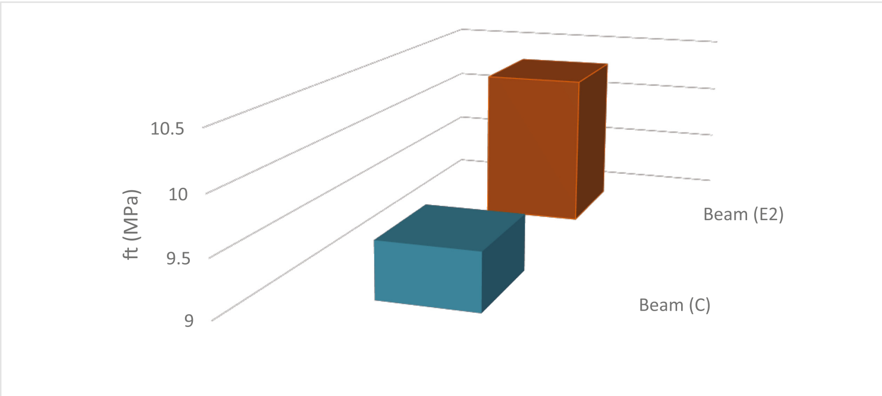

Fig. 8. Comparison of Tensile Strength Results for Cylinder specimens (C) and (E2).

Table 14. Comparison of modulus of elasticity results for (C) and (E2).

Sample	Ec equation (GPa)	Ec ultrasonic (GPa)		
		Cube	Cylinder	Beam
C	31.90	44.63	51.39	43.94
E2	33.42	45.45	54.00	47.23

According to the previous test results compressive strength increased from 56.85 MPa for cube specimen (C) to 62.39 MPa for cube specimen (E2) resulting in increasing of about 9.74%, while tensile strength increased from 9.5 MPa for cylinder specimen (C) to 10.34 MPa for cylinder specimen (E2) resulting in increasing of about 8.84% while modulus of elasticity for Ec equation increased by about 4.76% and for ultrasonic test results increased by factor of increasing 1.84%, 5.08% and 7.49% for

Table 15. Comparison of Density Results for specimens (C) and (E2).

Sample	C			E2		
	Beam	Cube	Cylinder	Beam	Cube	Cylinder
Density	2.43	2.21	2.45	2.45	2.32	2.53

cube, cylinder and beam specimens respectively, that shows compacting SFRC using roller compactor improve material properties strength of SFRC rather than compaction using vibrator table.

Density Comparison between beam, cube and cylinder specimens of (C) and (E2) cases are shown in Table 15. Comparison shows that, density is increased by about 0.82%, 4.98% and 3.27% for beam, cube and cylinder specimens respectively, which confirms the conclusion that, compaction of SFRC using roller compactor is more efficient and gives higher strength to SFRC pavement rather than using conventional vibratory compaction technique.

Comparison also has been carried out between modulus of rupture and pavement thickness for both beam specimens (C) and (E2) at which modulus of rupture (fr) is calculated using the most commonly equation that relate compressive strength of plain concrete to modulus of rupture [11];

$$fr = 0.62\sqrt{f'c}. \tag{6}$$

Where:
fr = Modulus of rupture (MPa)
f′c = Compressive strength (MPa)

While modulus of rupture for SFRC is calculated using the following equation; [12]

$$fr = 0.99\sqrt{f'c} + 3.83V_f \tag{7}$$

Where:
fr = Modulus of rupture (MPa)
f′c = Compressive strength (MPa)
V_f = Volume fraction of steel fiber

Thickness has been determined using (AASHTO Method) [13] as shown in Table 16 test results show that SFRC pavement thickness would be decreased by about 4.09%; when using roller compactor instead of conventional compaction technique.

Table 16. Comparison of Thickness Results for specimens (C) and (E2).

Sample	Modulus of rupture (*fr*) (MPa)	Thickness (mm)	Percentage of decrease (%)
C	9.74	178	–
E2	10.06	171	4.09

5.2 Impact Load Test

9 Specimens of roller compacted steel fiber reinforced concrete beams with 0.8 % V_f are tested using impact load apparatus. Each beam specimen is compacted using different load and number of load cycles as illustrated in Table 17.

Table 17. Impact energy results for roller compacted SFRC beam specimens.

Beam	No. of blows		Impact energy (kN. mm)	
	First crack	Failure	First crack	Failure
D1	3	27	87.09	783.81
D2	4	38	116.12	1103.14
D3	5	36	145.15	1045.08
E1	4	32	116.12	928.96
E2	17	173	493.51	5022.19
E3	7	35	203.21	1016.05
F1	5	33	145.15	957.99
F2	8	39	232.24	1132.17
F3	10	70	290.3	2032.1

Impact load test results are shown in Figs. 9 and 10 for first crack and failure respectively. It can be noticed that beam specimen (E2) is reported for maximum number of blows of first crack which is 17 blows; in which beam specimen (E2) is compacted in two layers of 50 mm each, 10 kg with 8 passes is applied on the first layer and 25 kg with 8 cycles is applied on the second layer. While beam specimen (F3) is reported to be the next beam for maximum number of blows for first crack which is about 10 blows, beam specimen (F3) is compacted in one layer of 100 mm, load applied is 25 kg and 24 passes.

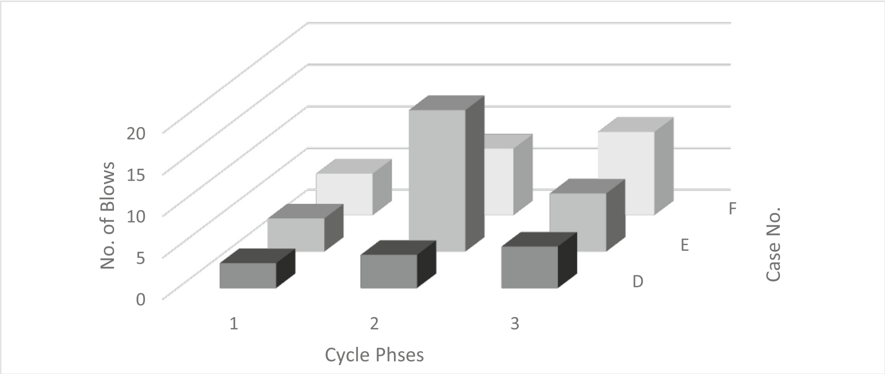

Fig. 9. Impact load test results for roller compacted concrete beams at first crack.

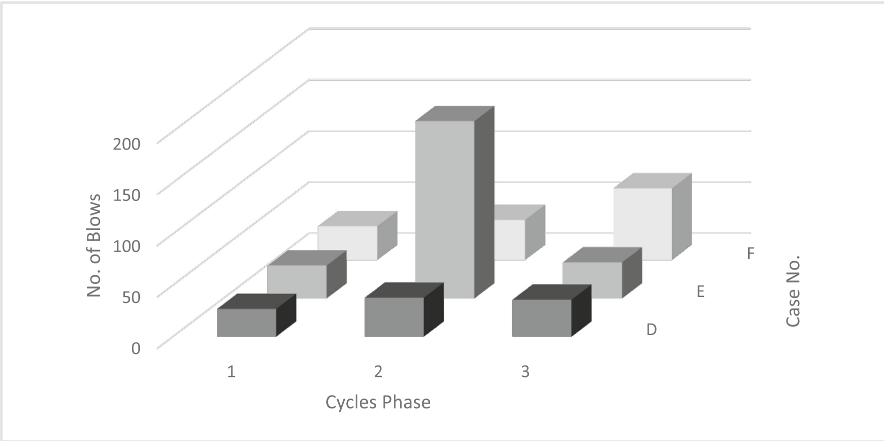

Fig. 10. Impact load test for roller compacted concrete beam specimens at failure.

As it can be seen that beam specimen (E2) has maximum number of blows 173 blows at failure due to its high strength as compared to the others; this indicated that compaction in two layers with different incremental loading value is more efficient and enhance high strength and performance with long life by increasing load magnitude at failure, reduce first crack appearance and hence minimal maintenance. Plate 6 shows all beam specimen for roller compaction technique.

Plate 6. Failed Beam Specimens Roller Compacted SFRC under Impact Load Test.

Impact energy is illustrated in Table 15 at which energy required to introduce first crack and failure to beam specimen (E2) is higher than the others, due to its high

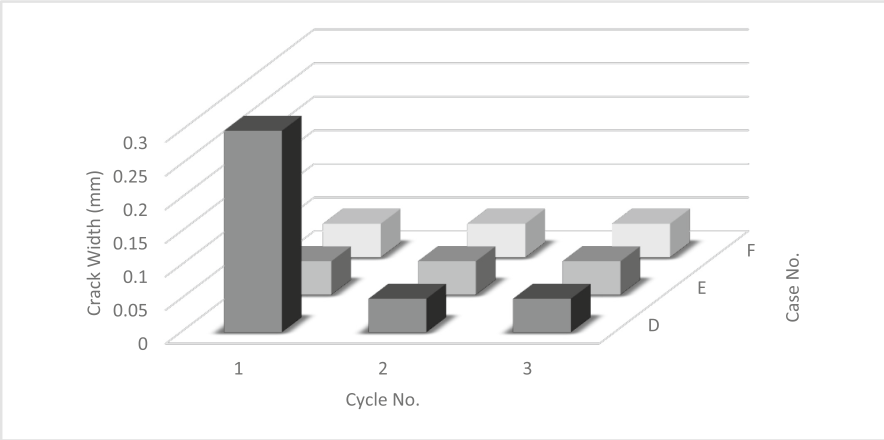

Fig. 11. Crack width results for impact load test on roller compacted concrete beam specimens at first crack.

number of blows which directly proportional to impact energy which is 493.51 kN.mm at first crack and 5022.19 kN.mm at failure. At which (U) is equal to 29.03 kN.mm [14].

As for Crack width results for first crack and failure are shown in Figs. 11 and 12 respectively. It can be notice from the obtained results that cracks width at first crack have no significant difference except beam specimen (D1) that difference may be reported as a results of low applied loading 10 kg and number of passes 8 cycles as compared to the other specimens.

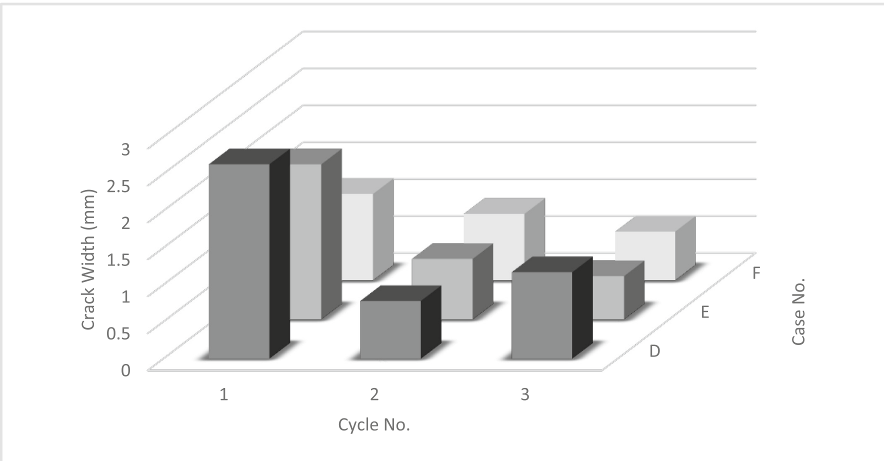

Fig. 12. Crack width results for impact load test on roller compacted concrete beam specimens at failure.

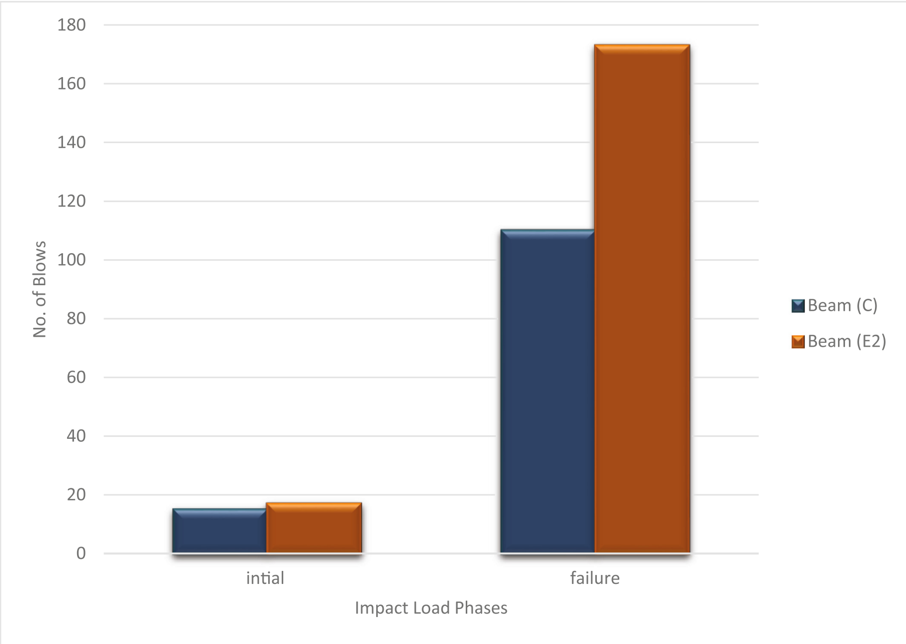

Fig. 13. Comparison between Beam specimens (C) and (E2) at Impact Load Test Results.

Crack width at failure also have no significant difference although maximum crack width can be seen in first cycle (D1, E1, F1) due to low applied loading which is about 10 kg as compared to the other specimens regardless of number of passes.

Comparison has been carried out for impact load test results between SFRC beam specimens with 0.8% V_f of steel fiber that have been compacted using two different compaction techniques; vibrator; (beam specimen C) and roller compacter (beam specimen E2). Impact load test is carried out for both beam specimens although the test for beam specimen (C) is carried out after 150 days and for (E2) beam specimen after 30 days, beam specimen (E2) gives higher values for number of blows for first crack and failure as shown in Fig. 13.

Impact energy required to introduce first crack and failure for beam specimens (C) and (E2) are shown in Table 18 and since impact energy is directly proportional to number of blows, it's greater for beam specimen (E2).

Table 18. Impact Energy Results for (C) and (E2) Beam specimens.

Beam	No. of blows		Impact energy (kN. mm)	
	First crack	Failure	First crack	Failure
C	15	110	435.45	3193.3
E2	17	173	493.51	5022.19

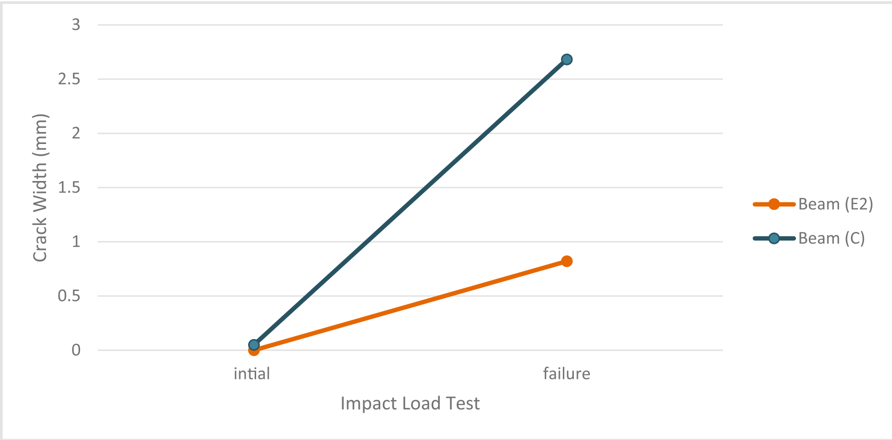

Fig. 14. Comparison between crack width at impact load test for beam specimens (C) and (E2).

As for crack width it can be seen in Fig. 14 that although beam specimen (E2) has more number of blows but its crack width is smaller than beam specimen (C) due to high bonding strength in beam specimen (E2) when using roller compactor.

6 Conclusions

1. Roller compacted steel fiber reinforced concrete beam specimen (E2) which has been compacted in two layers (first layer with 10 kg and 8 passes, second layer with 25 kg and 8 passes) and with 0.8% V_f of steel fiber has the maximum number of blows at impact load test; 173 blows at failure due to its high strength related to the existing of steel fiber; this indicated that compaction in two layers with different incremental loading value is more efficient and enhance high strength and performance with long life by increasing load magnitude at failure, reduce first crack appearance and hence minimal maintenance.
2. The modulus of elasticity for roller compacted specimens is measured using equation method and ultrasonic device and from the obtained results beam specimen (E2) has the maximum value of modulus of elasticity; according to compaction technique of applying different incremental loads at two stages (first layer with 10 kg and 8 passes) and (second layer with 25 kg and 8 passes) enhance the ability of SFRC pavement to deformed elasticity and increased it's stiffness.
3. Comparison between SFRC beam specimens with 0.8 % V_f of steel fiber that have been compacted using two different compaction techniques; vibrator; (beam specimen C) and roller compacter (beam specimen E2) at impact load test show that beam specimen (E2) gives higher values for number of blows for first and failure crack with 15, 17 blows for beams specimen (C, E2) respectively at first crack and 110, 173 blows for beams specimen (C, E2) respectively at failure.

4. Comparison shows that density of specimens (C) and (E2) is increased by about 0.82%, 4.98% and 3.27% for beam, cube and cylinder specimens respectively, which confirm the conclusion that compaction of SFRC using roller compactor is more efficient and give higher strength to SFRC pavement rather than using conventional vibratory compaction technique.
5. Comparison between modulus of rupture and pavement thickness for both beam specimens (C) and (E2) show that SFRC pavement thickness would be decreased with 4.09%; when using roller compactor is used instead of conventional compaction technique.

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