Original Research Article

Experimental and Analytical Investigations of Innovative Composite Materials using GFRP and Iron Slag for Railway Sleepers

Abstract

This paper presents further results of experimental testing and analytical investigation on the mechanical properties of fiber composite sleeper in order to evaluate its strength and behavior. Recycled high density polyethylene, iron slag, calcium carbonate, styrene and polyester resin were used with different percentages for manufacturing the proposed composite sleepers. Adding glass fiber ropes and woven laminates as a reinforcement to enhance the flexural capacity of the proposed composite material. Negative bending at center and positive rail seat compression were performed on full scale sleeper. Two full scale sleepers were proof loaded up to 72, 82 KN under negative bending test without any generated cracks. Also, under positive rail seat compression test, first crack occurred at load ranged from 170, 195 KN and failure load happened at load 270, 250 KN. That's mean that the strength of sleeper ranged from 36.39 to 39.30 MPa. This result showed that the proposed composite material of sleeper has sufficient strength to hold mechanical connections. Nonlinear finite element analysis (NLFEA) predicted the behavior up to failure load of the proposed composite sleeper reasonably well. This confirms that the behavior and failure modes of composite sleeper can be well predicted by simplified analysis procedures. Comparison of proposed composite with commercially available composite and timber sleepers' behavior was presented. It is found that proposed composite sleeper performance is near or similar to that of timber and better than that of commercially available composite sleepers. It is concluded that the proposed composite sleeper can be effectively used for timber sleeper replacement.

Keywords: GFRP- Composite material- iron slag-railway sleepers-NLFEA

1. Introduction

Railway sleeper is one of the most essential components of railway system. It is a beam laid under the rails to support the track and keep the required gauge width. It is also responsible for distribution and transfer of load to ballast section, and prevent any lateral and longitudinal movement of rail system [1]. Timber sleeper is used for railway lines in wide range. Timber for

railway sleepers has disadvantages such as exposure to mechanical and biological degradation which leading to failure [2]. Several investigations have been carried out in a try to find the most durable, strong and cost effective material for railway sleepers. Recent developments were head to strengthen or combine the existing material with fiber composite materials [3]. Further researches focused on the replacement of existing sleepers using alternative materials such as polymer concrete [4] rubber [5] and fiber composite material [6].
Bulk recycled plastic which was used as a material for railway sleepers has been studied by (Hoger, 2000).[7]. Railway sleepers prepared from the recycled plastic bottles with glass fiber reinforcements have been investigated in the US over the past ten years [8]. This sleeper is featured with its lightweight. Also, recycled plastic sleeper which has high stiffness comparable to softwood sleepers was presented by the Transport Research Laboratory in the UK [9] . Humpreys and Francey [10] have investigated the performance of timber railway sleepers with fiber-reinforced materials. It was found that the load carrying capacity of timber sleepers externally reinforced with carbon can considerably increase if delamination of the carbon reinforcement did not happen early. Manalo et al., [11] also presented a concept of composite sandwich structure manufactured. The mechanical behavior of these sleeper are better than most of the commercially available composite sleepers.

This paper presents the details of the experimental tests and analytical investigations to evaluate the structural behavior of proposed composite material as alternative of timber material for railway sleepers. Tests results and nonlinear finite element analysis results were compared with the universal standards, timber and other commercially composite sleepers.

2. Full scale sleeper Preparation

Several construction phases were performed to prepare the full scale sleepers for testing, including Mold manufacturing, and composite mixture mixing, casting and curing.

2.1 Mold manufacturing

The mold as shown in Figure 1 was manufactured at Egyptian Company for Resins, Badr city. It was made from glass fiber roving with density 400 gm/m^2 and chopped strand mat with density 300 gm/m^2 in addition to epoxy resin to bear the temperature induced from materials reaction. Before casting, the epoxy mold was painted with grease, to ease the form release after casting of the composite mixture. The mold was demounted after 24 hours.

Fig.1. Mold of proposed composite sleeper

2.2 Composite mixture mixing

Mixing of the composite materials with percentages of mixture M_{16} which was selected as an optimal mixture from several mixtures was performed in a mechanical mixer [12], where mixture M_{16} components are shown in Table 1. High density polyethylene (HDPE), steel slag and calcium carbonate were initially mixed for one minute in a dry condition [13]. Unsaturated polyester resin and styrene were added gradually while the mixer was being operated mechanically for about four minutes to achieve a uniform dispersion of composite components. Then, after that cobalt was mixed with other components for one minute. Finally, Peroxide was added and mixed before casting [13].

Table 1 Components of mixture M_{16} [12]

Mix	RHDPE %	Iron slag %	CaCo3 %	Polyester resin %	Styrene %
M_{16}	20	20	20	35	5

2.3 Composite mixture Casting

Once the mixture had been mixed, the mixture was poured into the mold in layers according to number of used fiber laminates. Seven laminates were used in sleeper reinforcement as shown in Figure 2 in addition to two fiber glass twisted ropes 8mm.where one laminate consists of one layer of mat 300 gm/m^2 and two layers of woven roving 600 gm/m^2 in addition to polyester resin to bond between layers. Shape of fiber glass laminates and ropes are shown in Figure 3. After casting each layer, the mold was vibrated to merge the mixture as well as keeping fiber layer in flat position. After casting specimen, its top surface was given a smooth final finish by hand troweling. Demolding was carried out after 24 hours of room temperature curing.

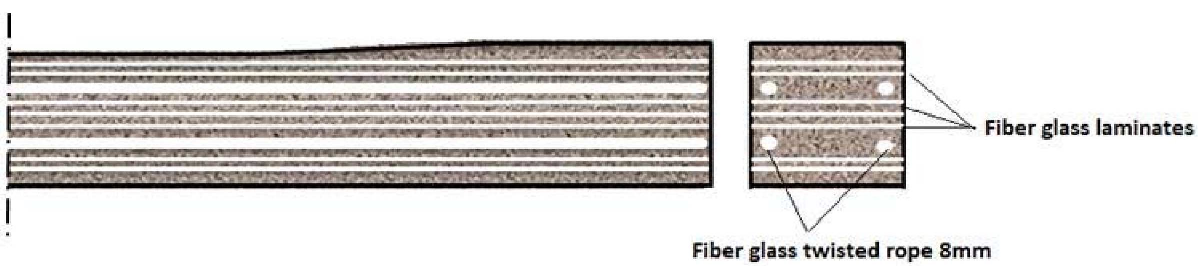


Fig. 2. Reinforcement of full scale proposed composite sleeper

Fig.3. used fiber glass laminate and rope in sleeper reinforcement

3. Tests Procedures

3.1 Static loading test on sleeper center section (negative position)

Negative Bending test at center of sleeper was performed according to AREMA standards [14] at The Egyptian Company for pipes and cement products (Siegwart) at Helwan. The test was carried out on two full scale sleepers. The supports arrangement for static loading test on center of sleeper is shown in Figure 4 where the distance Lc between the centerlines of supports was 152 mm. Loading frame of capacity 500 KN was used as shown in Figure 5. The load was applied with, loading rate 10 KN /minute and stroke loading 2.5 mm/minute. Deflection of the center of sleeper relative to vertical support was measured by data logger connected with strain gauge which was placed at top surface of sleepers. The following formulae are used to determine the negative moment at center of sleeper:

$$M_c = \frac{P}{4}\left(Lc - \frac{0.076}{2}\right) \quad [14]$$

Where M_c = Negative bending moment at center of sleeper (KN.m)

P = Negative bending load at center of sleeper (KN)

Lc = Distance between the centerlines of supports (m)

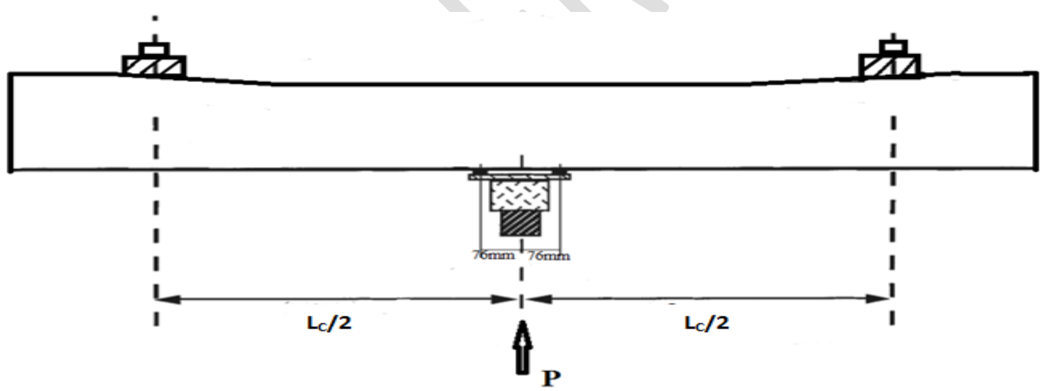


Fig.4. Schematic set up of negative bending test at center of sleeper

Fig.5. Actual set up of negative bending test at center of sleeper

3.2 Static loading test on rail seat sections (Positive position)

Static loading test on rail seat sections was performed according to AREMA standards [14] at The Egyptian Company for pipes and cement products (Siegwart) at Helwan. The test was carried out on two full scale sleepers. The supports arrangement for static loading test on rail seat section is shown in Figure 6 where the distance Lc between the centerlines of supports was 600 mm. Loading frame of capacity 600 KN was used as shown in Figure 7. The load was applied with loading rate 10 KN/minute. The following formulae are used to determine the positive moment and stress at rail seat:

$M_r = \frac{P}{4}\left(Lc - \frac{0.057}{2}\right)$ [14]

Where M_r = positive bending moment at rail seat KN.m

P = positive rail seat load (KN)

Lc = the distance between the centerlines of supports (m)

Stress = $6M_r/bt^2$

Where: b= width of sleeper mm

t = depth of sleeper mm

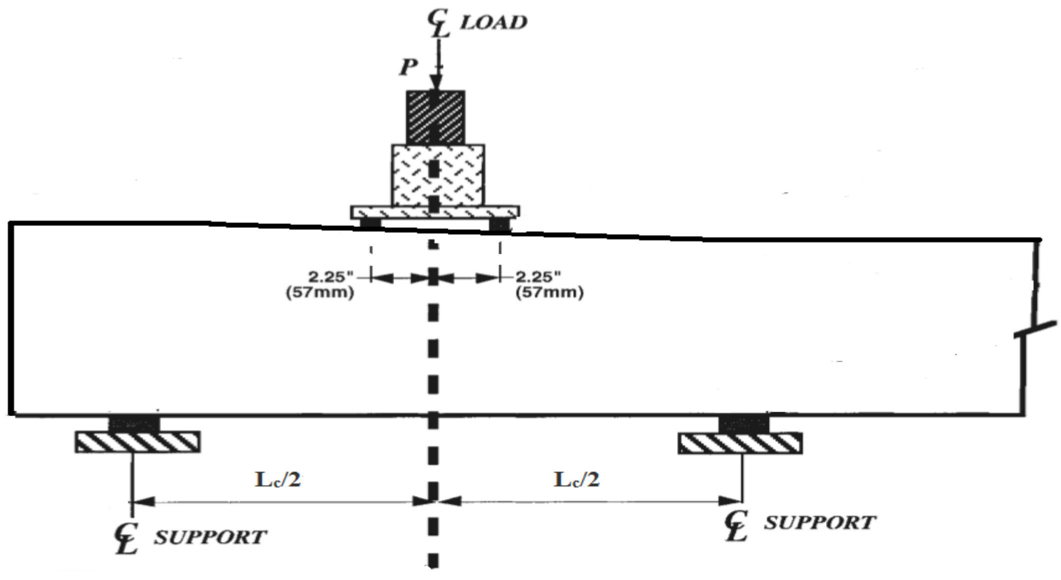


Fig.6. Schematic set up of positive bending test at rail seat position

Fig.7. Actual set up of positive bending test at rail seat position

4. Results and analysis

4.1 Static loading test on sleeper center section (negative position)

Load deflection relationship of negative bending test at center of sleepers **(S_{10})** and **(S_{11})** proof loaded up to 72 KN and 82 KN respectively is shown in Figure 8. Bending moment, modulus of elasticity and stiffness of sleepers were calculated as shown in Table 2.

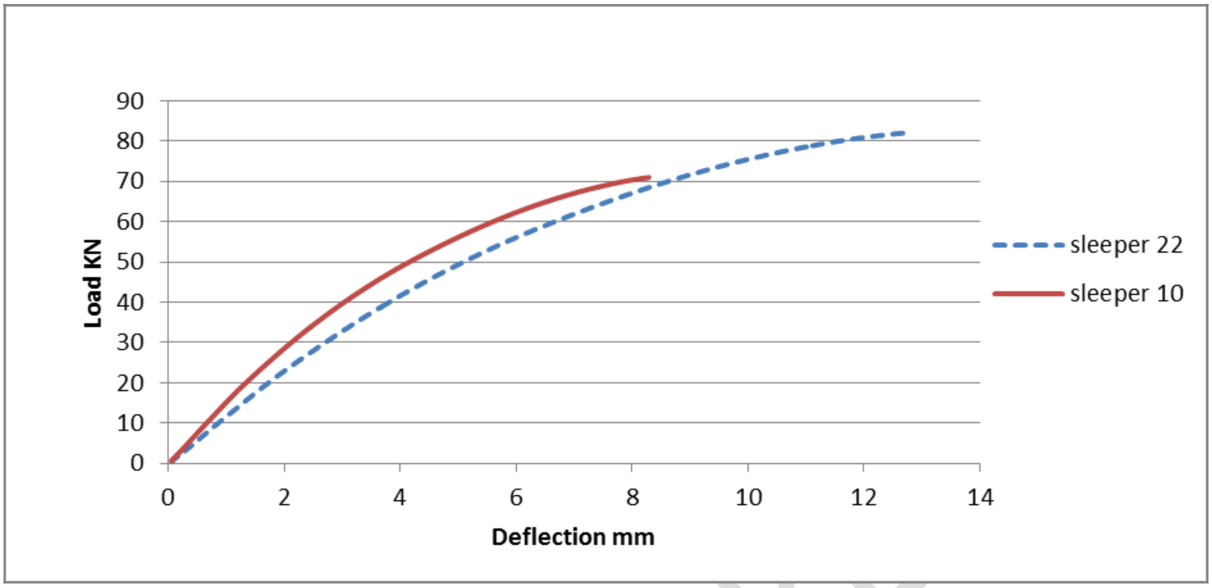


Fig.8. load deflection relationship of negative bending test at center of sleeper

Table 2 Results of negative bending test at center of sleeper

	Load KN	Bending Moment KN.m	Modulus of elasticity MPa	stiffness EI× 10^9 N.mm^2
Sleeper (S_{10})	72	27.3	12962.96	838
Sleeper (S_{11})	82	31.1	11111.11	718

Results analysis

As observed, both of sleepers behaved linear elastic up to the applied proof load (bending moment =27.3 and 31.1 kN-m) without any observed cracks which is due to increasing of fiber reinforcement at bottom of sleepers. Thus, the strength of both sleepers is greater than 35 MPa. The Deflection increased relatively evenly until the loading level of 72 -82 kN to record 8.2 and 12.8 mm respectively. Behavior of full scale sleeper **(S_{10})** under 72 KN static loading is illustrated in Figure 9.

It is concluded that the strength of proposed composite sleeper which is more than 35 MPa is higher than minimum recommended values 17.23 and 13.8 MPa by CTA and AREMA standards [14] respectively.

The modulus of elasticity of flexure (negative bending) for proposed composite sleepers **12962.96** and **11111.11** MPa is higher than the minimum performance requirements for fiber composite sleepers 1172 MPa recommended by the AREMA and CTA standards [14].

Fig.9. Sleeper (S_{10}) under 72 kN static loading of the sleeper center section.

4.2 Static loading test on rail seat section (positive position)

Positive rail seat bending moments corresponding to the formation of the first crack and to failure were shown in the Table 3 in addition to compression strength at rail seat section.

Table 3 Results of static loading test on positive rail seat sections

	First crack		**Failure**		
	Force (KN)	**Moment (KN.m)**	**Force (KN)**	**Moment (KN.m)**	**Rail seat compression strength (MPa)**
Sleeper (S_{10})	170	26	250	35.72	36.39
Sleeper (S_{11})	195	29	270	38.57	39.30

5. Results analysis

It was noticed that the cracks were nearly fully closed. Under loading, the behavior of sleeper (S_{10}) differed from sleeper **(S_{11})**. In the case of sleeper (S_{10}), first crack occurred at force 170 KN and width increased steadily until failure at force 250 kN. The failure mode of the rail seat sections was often bending failure which was represented as a crack at bottom of sleeper with width 2mm. Cracks at failure of rail seat section are shown in Figure 10.

In case of sleeper **(S_{11})**, first crack occurred at force 195 KN and width increased significantly when the load was increased until failure which occurred at force 270 KN. When loading ended, the crack width was about 1.5 mm.

From results, it is concluded that bending strength at rail seat (positive position) of both two proposed composite sleepers is higher than values of AREMA and CTA standards which are 6.2 and 6.8 MPa [14].

Fig.10. Failure mode of sleeper S_{10} under static load on rail seat section

6. Sleeper strength evaluation

After Rail seat load was obtained by using theoretical equations in terms of composite sleeper stiffness, positive bending stress at rail seat position of proposed composite sleeper can be calculated according to Clarke equation [15]:

$M_r = q_r *$ [illegible] ([illegible]) [15]

$\sigma_{ru} = 2.87$ MPa

It is concluded that tensile bending stress of proposed composite sleeper at rail seat is 2.87 MPa which is lower than maximum recommended value (7.6 MPa) of AREA standards [16].

7. Comparison of the performance of proposed composite sleeper with the timber and commercially available composite ones.

Comparison between proposed composite sleeper with the timber and commercially available composite ones is summarized in Table 4. From Table 4, it is concluded that the strength of proposed composite sleeper is within range of different species of existing timber sleepers in railway lines. Also, it is found that behavior of proposed composite sleeper is higher than that of other commercially available composite ones.

Table 4 Comparison of the performance of proposed composite sleeper with other sleepers

	Unit	Proposed composite	TieTek [6]	Polywood [9]	IntegriCo [13]	Axion [18]	Glue laminated [14]	Timber	
								Oak [9]	Azobe [15]
Density	Kg/m^3	1318	1153	—	1121	897	—	1093	1000
Compressive strength	(MPa)	32.08	—	—	15.2	8.27	23.5	—	—
Modulus of elasticity compressive	(MPa)	8581	—	1172	2000	1172	—	—	—
Modulus of rupture	(MPa)	Greater than 35	Greater than 18.6	20.68	18.6	20.6	60	58	87
Modulus of elasticity rupture	(MPa)	12962	Greater than 1724	1516.8	1655	1516	4270	8411	10300-14000
Rail seat compression	(MPa)	39.3	16.5	8.27	15.9	20.6	—	4.6 (Min)	—
Screw spike pullout force	(KN)	52	35.6	66.72	73.4	31.6	62	30 (Min)	—
Thermal expansion	cm/cm/C^0	0.23×10^{-4}	1.35×10^{-4}	0.9×10^{-4}	0.72×10^{-4}	0.74×10^{-4}	—	—	—

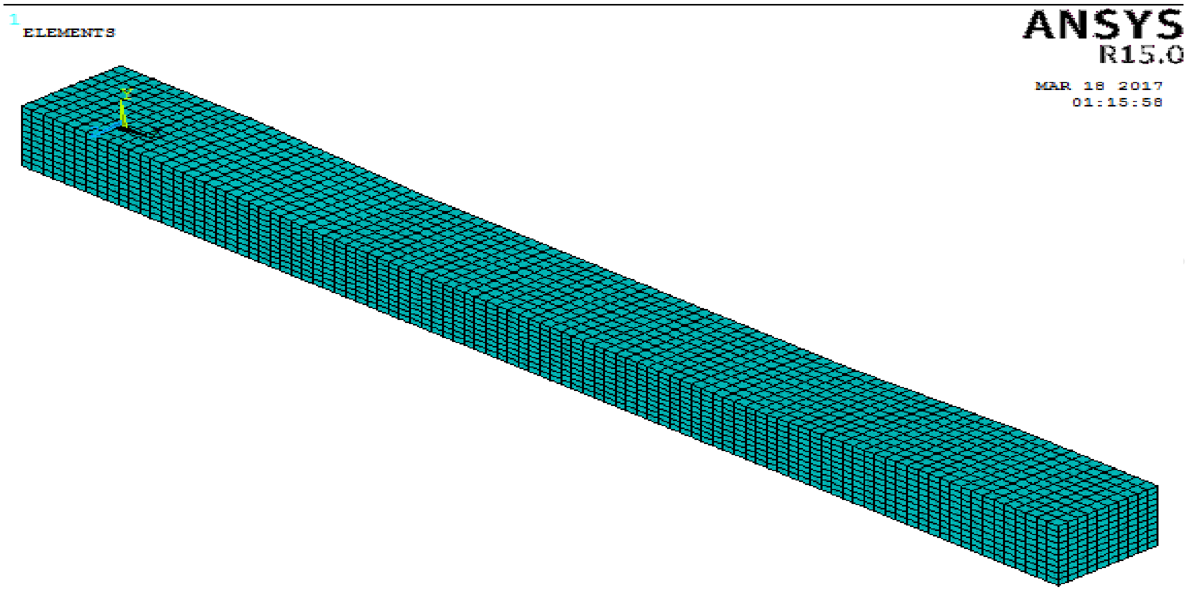
8. Non-Linear Finite Elements Analysis [12]

8.1 Idealization of tested sleeper.

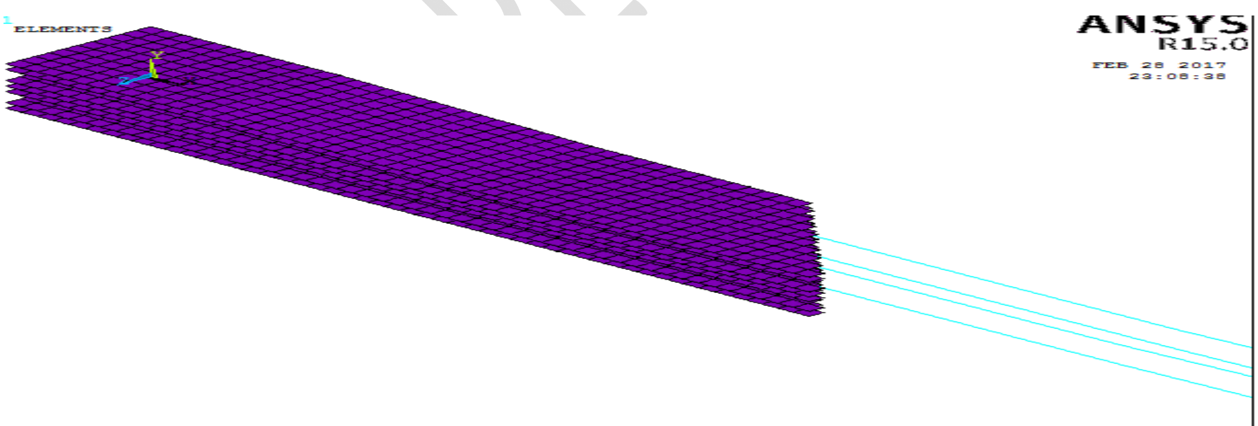
The proposed composite sleeper was modeled with full scale in ANSYS release 15.0.

The composite material was modelled using a 3-D solid element, SOLID65 as shown in Figure 11 a.

The reinforcing fiber laminates and ropes were idealized using 4-Node SHELL 181 and 2-node Link 180 respectively as portrayed in Figure 11 b.



(a) Composite element; Solid65



(b) Reinforcing fiber laminates and ropes element; Shell 181 & Link 180

Fig.11. Typical idealization of tested sleeper

8.2 Model Verification of flexure behavior (positive rail seat test)

The following sections present a brief discussion on the results of NLFEA as compared to the experimental results of the tested sleeper. The discussion includes the cracking and ultimate capacities. Output samples for NLFEA indicating the deformed shape, sleeper stresses and cracks propagation are given in Figure 12 to Figure 15. Comparison of the numerical cracking and failure loads with experimental results is shown in Table 5.

For composite sleeper, the maximum numerical compressive and tensile stress was 20 MPa and 3.5 MPa, respectively. Further, Figures 17, 18 show the predicted stress distribution in sleeper along a section of mid-span of the beam at various stages of loading. The stress distribution in sleeper at the early stages was linear. After cracking load the distribution of stress becomes nonlinear. The maximum mid-span deflection obtained is 3.93 mm.

8.2.1 Cracking Load

For composite sleeper, flexural cracks appeared when the tensile strength and, consequently, the crack moment were reached in the pure bending zone. Cracks were first noticed at the tension region near the constant moment region. Under increasing the load, cracks propagated in a vertical direction and further new cracks appeared through the shear span.

The experimental results indicated formation of flexural cracks in the tested sleeper at loads ranging from 170 to 195 KN While the numerical cracking load for sleeper is about 157.5 kN. Referring to Table 5, the predicted cracking loads; P_{ct-nu} is shown to be in a good agreement with the experimental loads; P_{ct-exp} with P_{ct-nu} / P_{ct-exp} ratio of 0.86.

8.2.2 Ultimate capacity

A comparison of the calculated with experimental ultimate loads of the tested sleeper are given in Table 5. The actual ultimate load based on experimental results ranging from 250 to 270 KN while numerical ultimate load is about 282.2 KN. The ratio of the calculated to experimental ultimate strength (P_{nu} / P_{exp}) for composite sleeper is 1.08. As shown, good coinciding between the experimental results and the analysis was attained.

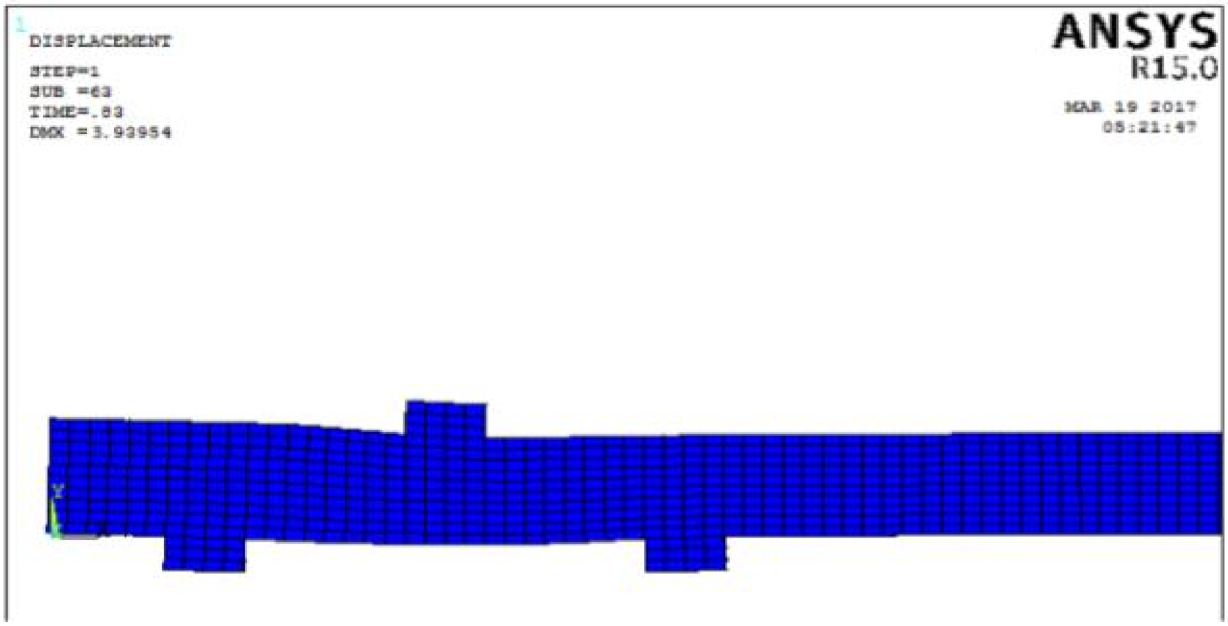


Fig.12. Deformed shape at failure

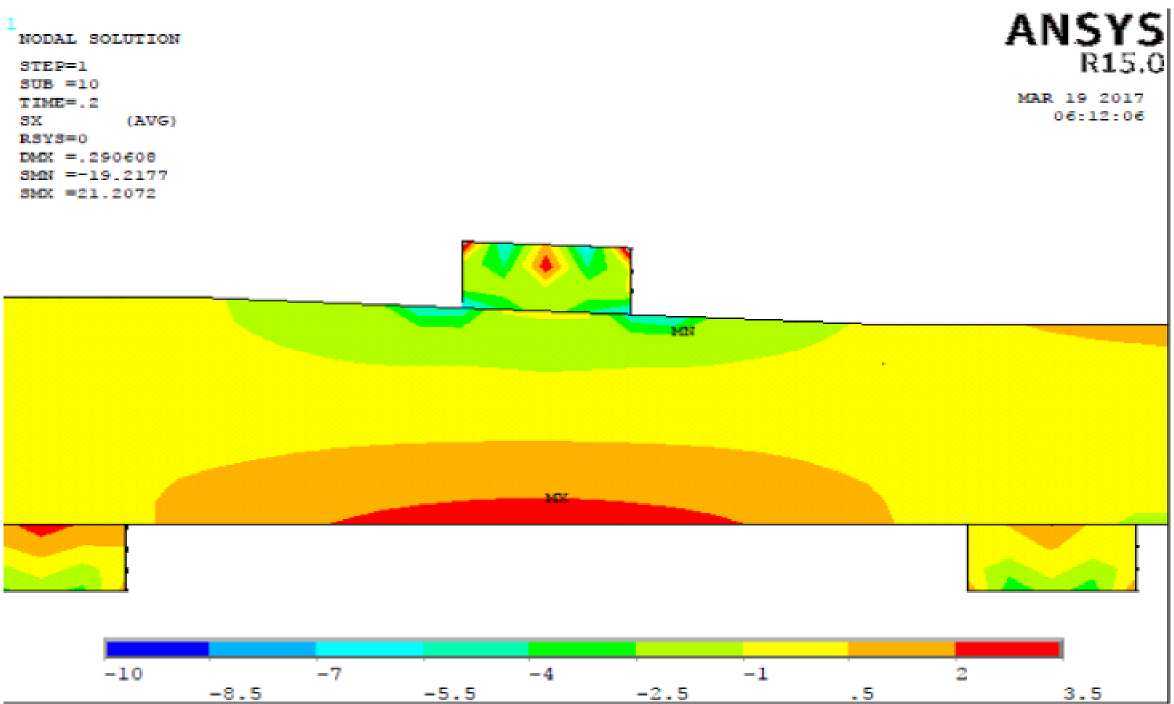


Fig.13. Composite sleeper stresses at cracking load (N/mm^2).

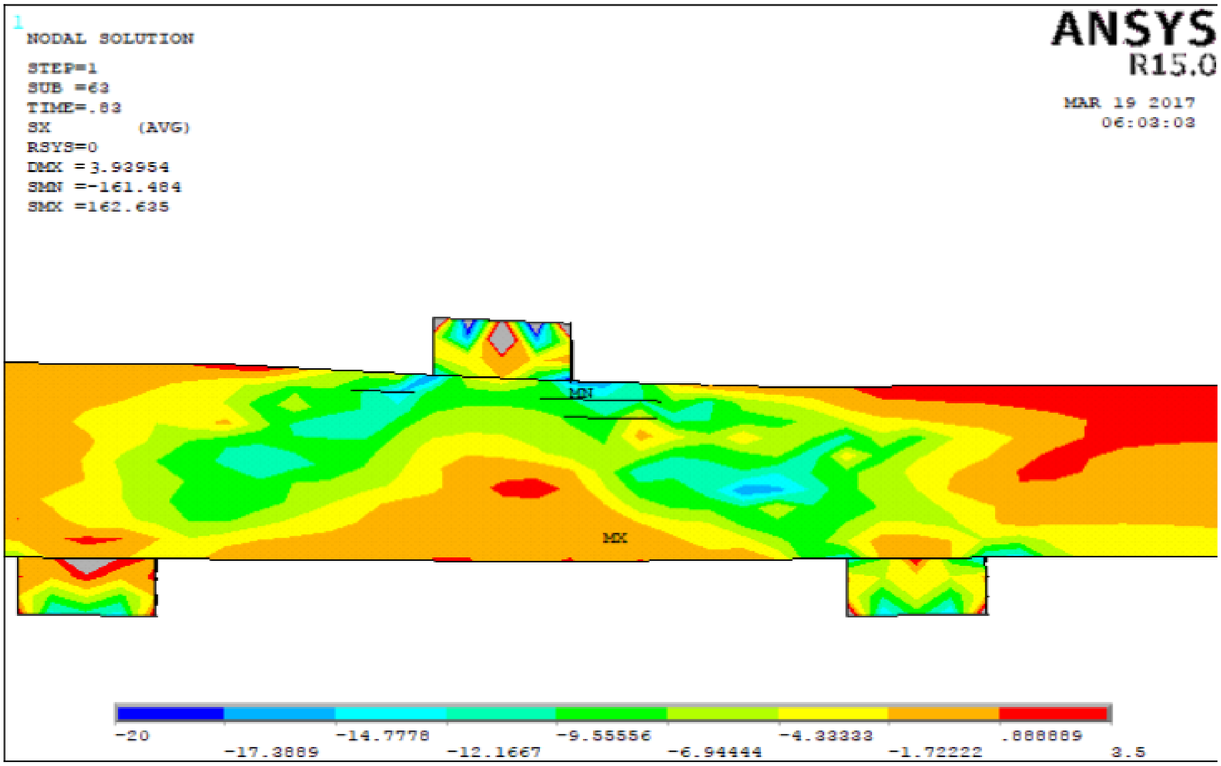


Fig.14. Composite sleeper stresses at failure (N/mm^2).

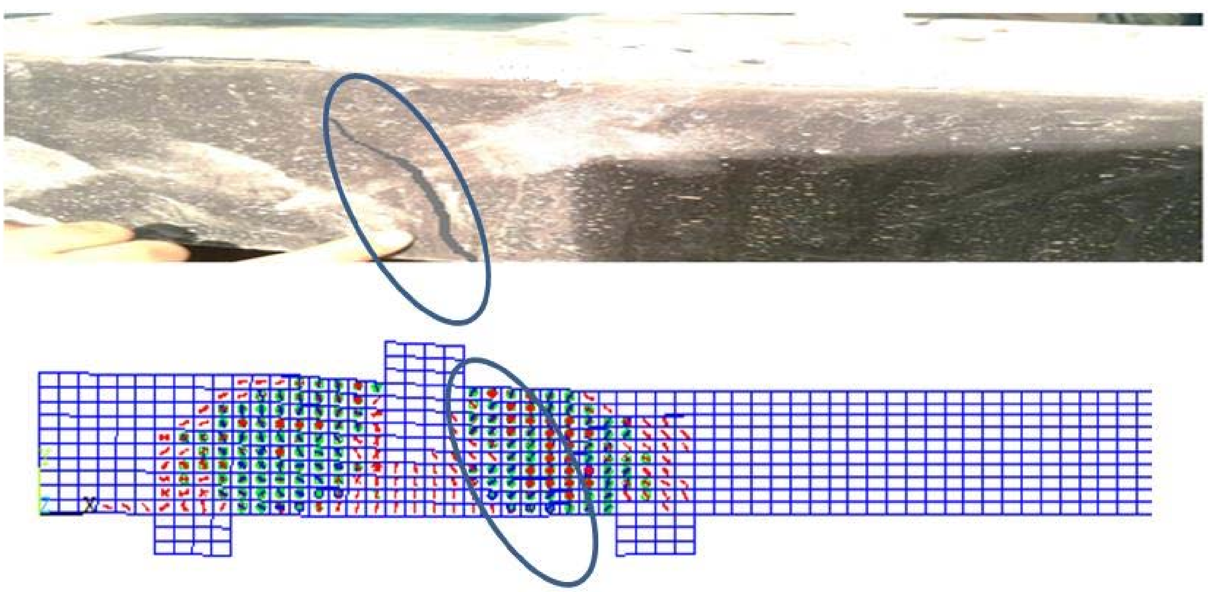


Fig.15. Cracks expansion at failure

Table 5 Comparison of test results with numerical results.

	Experimental results		**Numerical results**		**Numerical / experimental results**	
	cracking load $P_{ct\text{-}exp}$ (KN)	Ultimate load P_{exp} (KN)	Cracking load $P_{ct\text{-}nu}$ (KN)	Ultimate load P_{nu} (KN)	$P_{ct\text{-}nu}$ / $P_{ct\text{-}exp}$	P_{nu} / P_{exp}
Sleeper	170	250	157.5	282.5	0.86	1.086
	195	270				

8.3 Model Verification of flexure behavior (negative bending test)

The following sections present a brief discussion on the results of NLFEA as compared to the experimental results of the tested sleeper. The discussion includes the ultimate capacities and the load-deflection behavior. Output samples for NLFEA indicating the deformed shape and sleeper stresses are given in Fig. 16 to Fig. 18. The load- deflection relationships for test specimen is displayed in Fig. 19.

The maximum numerical compressive and tensile stress for composite was 25MPa and 3.1 MPa, respectively. Further, Figures 18, 19 shows the predicted stress distribution in composite sleeper along a section of mid-span of the beam at various stages of loading. The stress distribution in composite sleeper at the early stages was linear. After cracking load the distribution of composite stress becomes nonlinear. The maximum mid-span deflection obtained is 12 mm at failure load of 124 KN.

8.3.1 Ultimate capacity

The actual composite sleeper was proof loaded up to 82 KN without failure. Ultimate capacity of proposed composite sleeper obtained by using NLFEA reached to 124 KN. This result confirms that the composite sleeper has a high ultimate capacity.

8.3.2 Load-deflection behavior

The load and mid-span displacement relationship of the fiber composite railway sleepers tested up to failure (FL) using finite element analysis and the experimental load deflection behavior of sleeper proof loaded (PL) up to 82 kN as shown in Figure 20. The figure shows that the load-deflection relation based on a FEM simulation is in good coinciding with the experimental result.

The difference in the predicted and experimental results is only 7% for tested sleeper. Manalo, A.C. [2] also concluded the load deflection relationship between numerical and experimental for composite sandwich beam with difference ranged from 4 to 8%. In general, the results showed that a simplified FMA can reasonably predict the load-deflection behavior of composite sleepers.

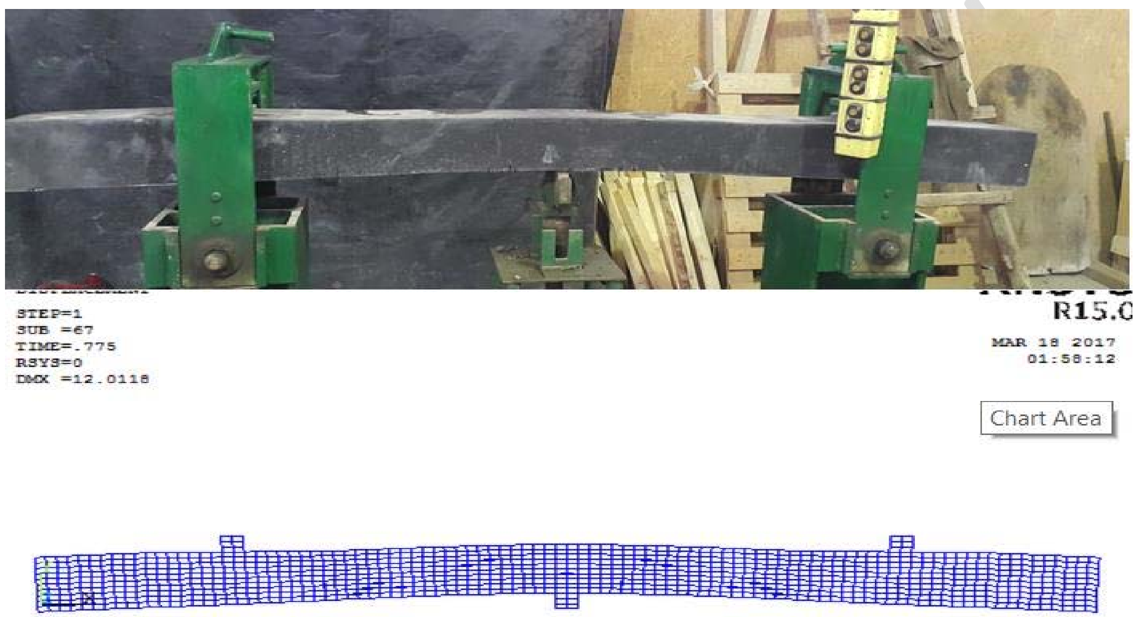


Fig.16. Deformed shape of proposed composite sleeper

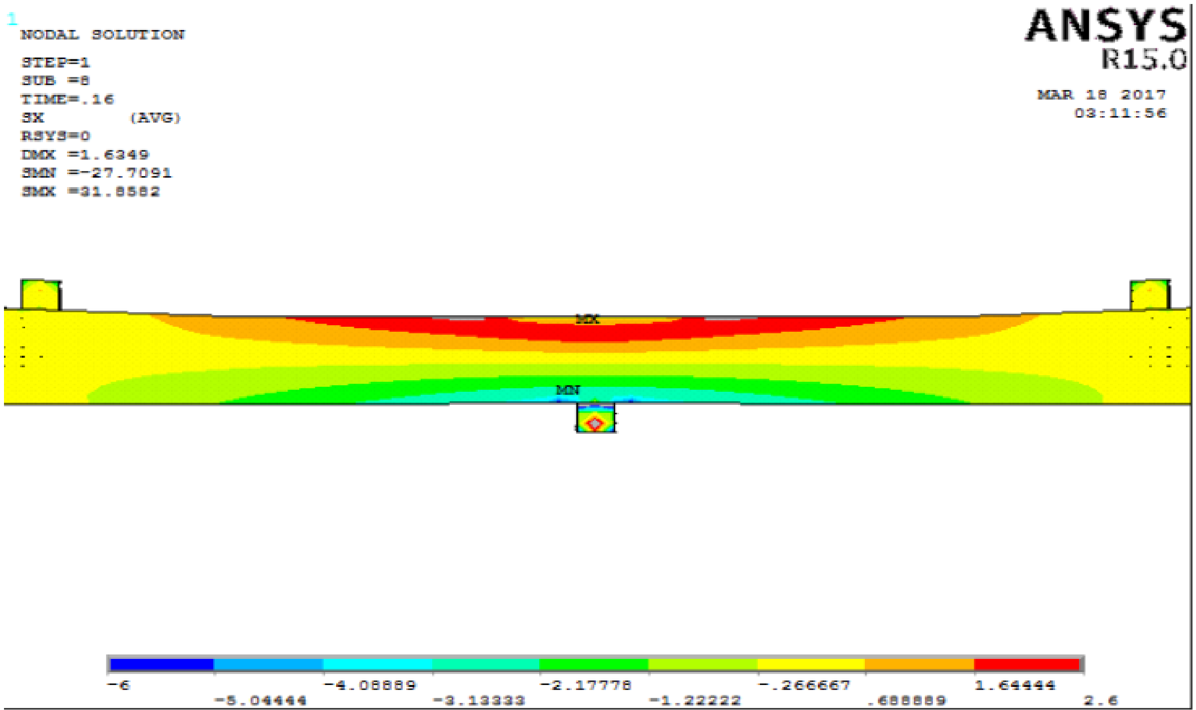


Fig.17. Stress distribution at cracking load

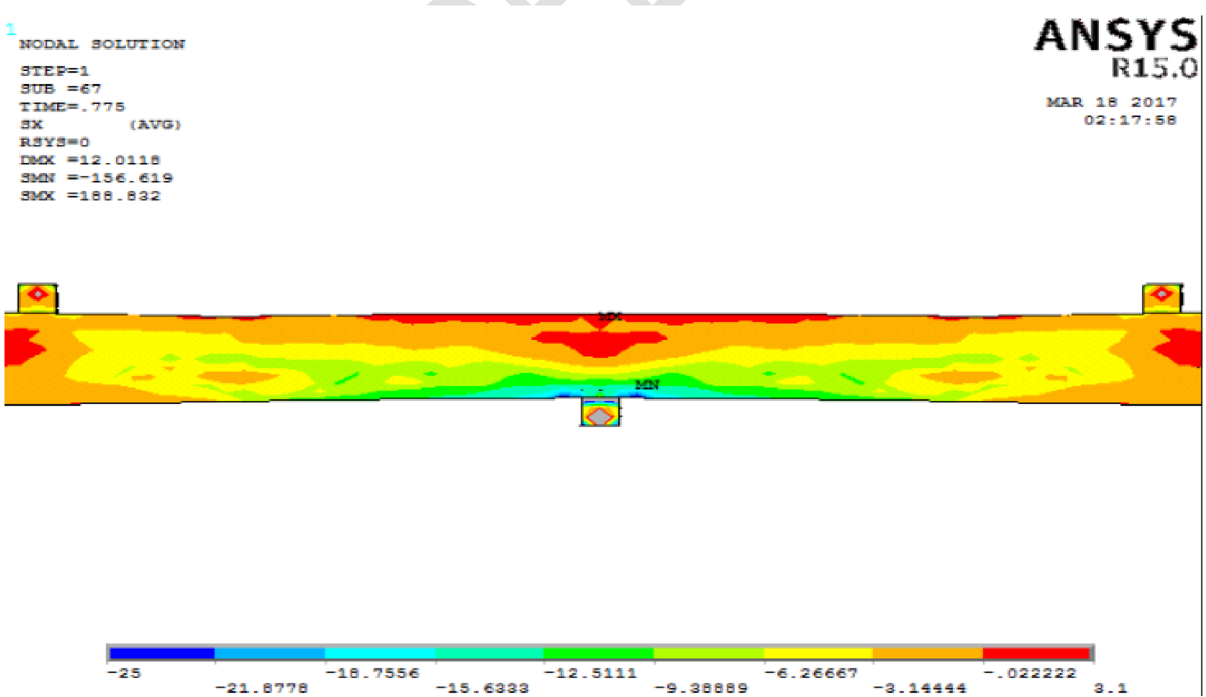


Fig.18. Stress distribution at failure

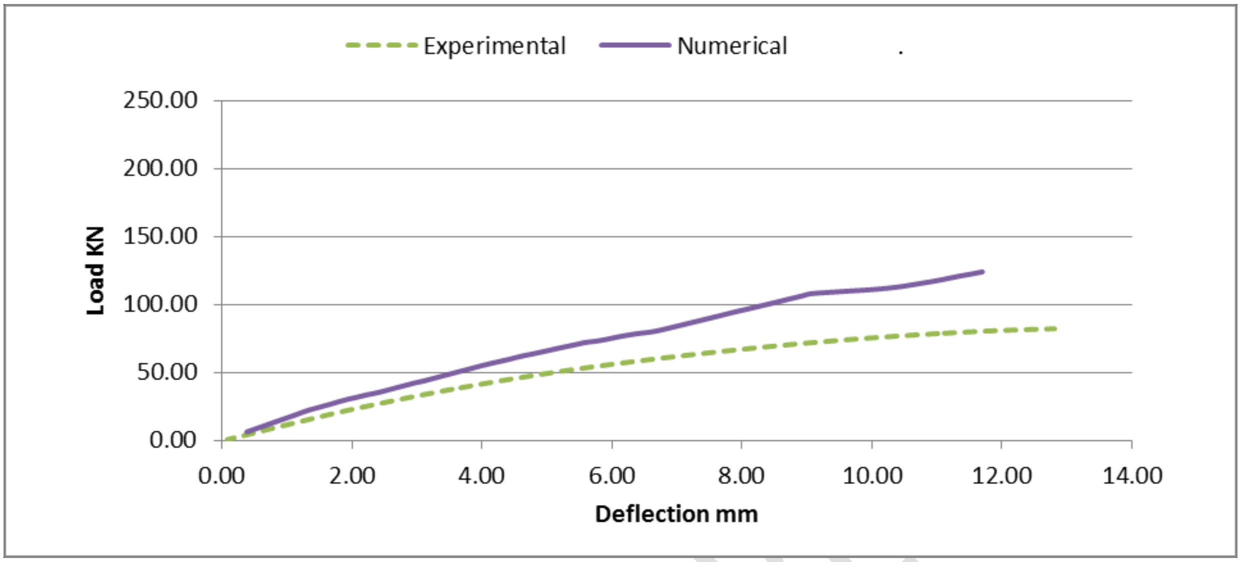


Fig.19. Load deflection behavior of proposed composite sleeper

8.4 Composite sleeper behavior under design rail seat load using NLFEA

The simulation was performed for the sleeper which was loaded with 43.42 KN Rail seat load for speed 100km/hr. Rail seat load is theoretically calculated from equations as mentioned in the previous section. The sleeper is assumed to be supported by ballast layer with 300 mm thickness. To reduce the computational time required, only half the sleeper was modelled as, due to symmetry, the other half would exhibit similar behavior.

The vertical deflection at rail seat in addition to bending stress of sleeper and the sleeper-ballast contact pressure were investigated for the composite sleeper using finite element analysis. The results are then compared with their allowable limits as discussed in the following sections. Comparison of numerical results with theoretical results which is based on equations is also discussed.

8.4.1 Vertical deflection of sleeper

Figure 20 shows the deformed shape of composite sleepers. The maximum vertical deflection which was obtained at rail seat location and at a 43.42 kN rail seat load is 1.5 mm which is within the allowable limit of 6.35 mm [21]. On the other hand, sleeper deflection obtained from theoretical result which based on equations is 2.1 mm. The ratio of numerical to theoretical result is 0.71 which is a good agreement between them.

8.4.2 Bending stress behavior

The maximum tensile bending stress obtained at the bottom side of rail seat location is presented in Figure 21. At a 43.42kN rail seat load, the tensile bending stress of composite sleeper is 2.20 MPa which does not exceed the maximum allowable limit of 7.6 MPa specified in the AREA standard [21]. From other hand, tensile bending stress obtained from theoretical result which based on equations is 2.87 MPa. As shown in Table 6, the ratio of numerical to theoretical result is 0.76 which is a good agreement between them.

8.4.3 Sleeper-ballast contact pressure

The numerical result of sleeper contact pressure between sleeper and ballast as illustrated in Figure 22 showed that the sleeper ballast contact pressure is 0.393 MPa which is within the limit of the maximum allowable contact pressure of 0.59 MPa [22]. From the other hand, the sleeper-ballast contact pressure obtained from theoretical result which based on equations is 0.339 MPa. As shown in Table 6, the ratio of numerical to analytical result is 1.15 which is a good agreement between numerical and theoretical result.

Table 6 Numerical and theoretical results for proposed composite sleeper

	Numerical results	Theoretical results	Numerical/ Theoretical results
Vertical deflection (mm)	1.5	2.1	0.71
Bending stress (MPa)	2.2	2.87	0.76
Sleeper- ballast contact pressure	0.393	0.339	1.15

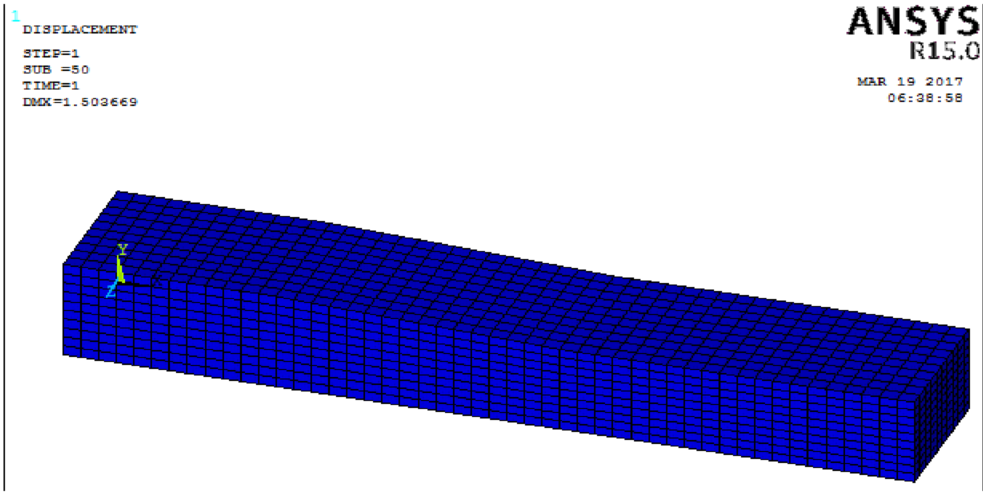


Fig.20. Deformed shape of composite sleeper under 43.42 KN rail seat load

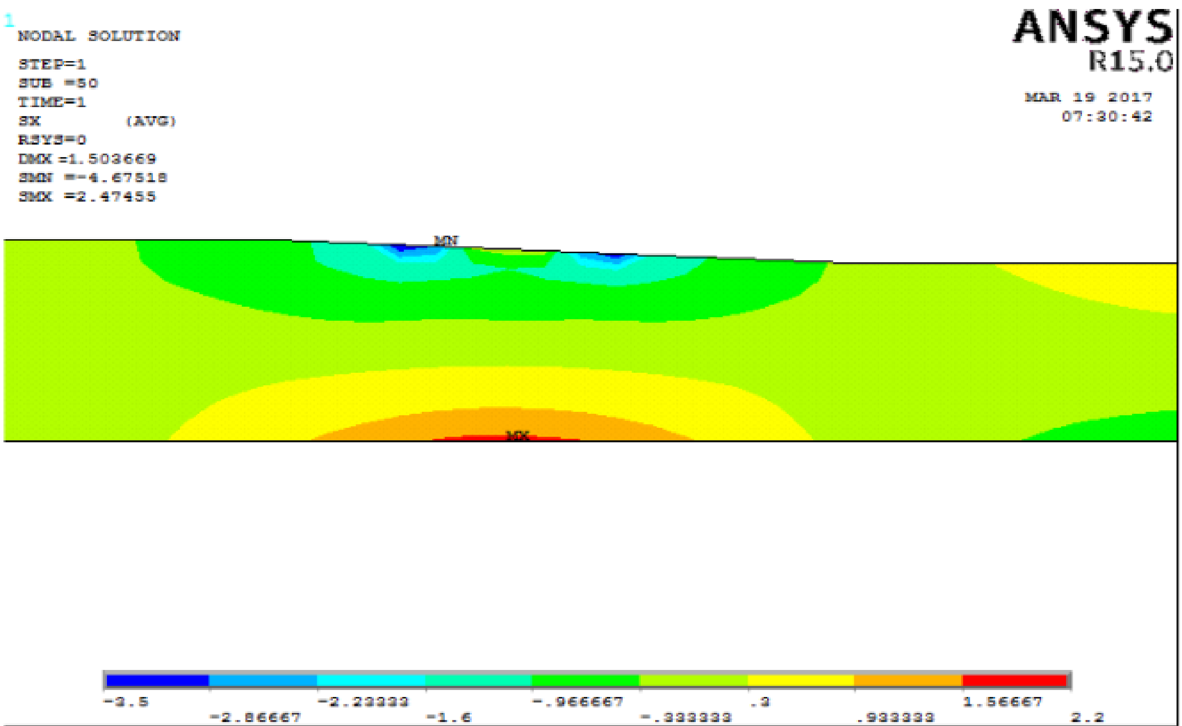


Fig.21. Bending stress of composite sleeper under 43.4 KN rail seat load

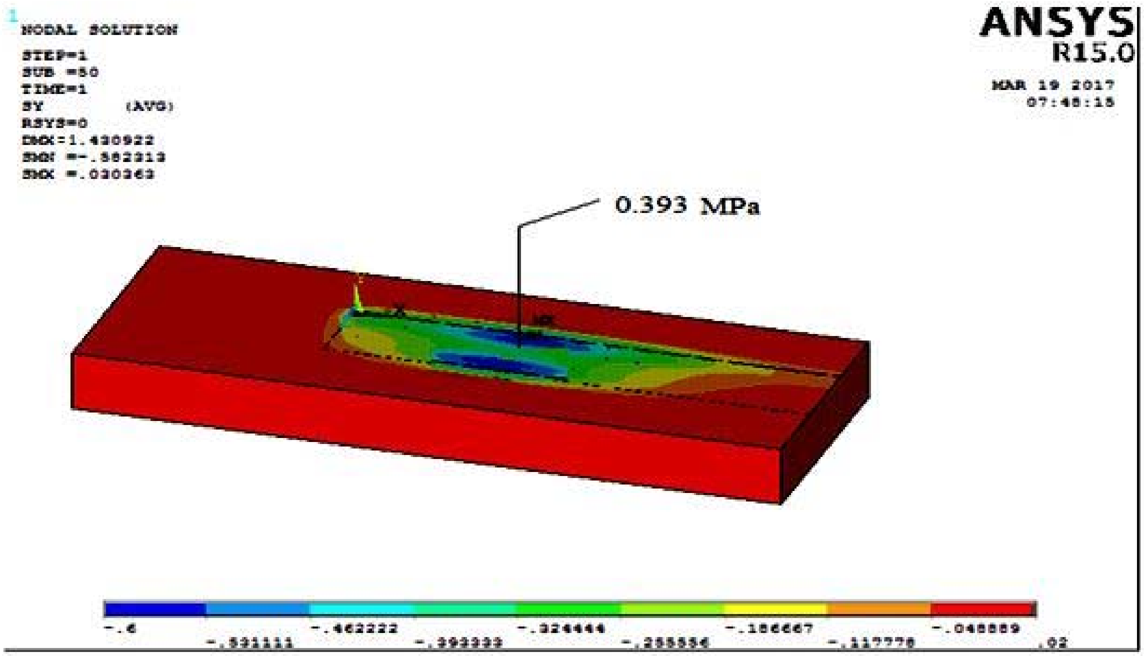


Fig.22. Composite Sleeper- ballast contact pressure under 43.4 KN rail seat load**[12]**

9. Conclusions

Behavior of full scale composite sleeper can be summarized as follows:

a- From negative bending test at center of sleeper, the proposed composite sleeper which was proof loaded to an applied load 82 KN without any cracks has a modulus of rupture (MOR) greater than 35MPa.This value is higher than minimum recommended values 17.23 and 13.8 MPa by CTA and AREMA standards respectively.

b- The bending modulus (negative bending) for proposed composite sleepers is 12962.96 and 11111.11 MPa which is higher than the minimum performance requirements for fiber composite sleepers 1172 MPa recommended by the AREMA standards and CTA specifications.

c- From positive bending test at rail seat position, first crack occurred at force ranged from 170 to 195 KN .Width of cracks increased significantly when the load was increased until failure which occurred at force ranged from 250 to 270 KN. When loading ended, the crack width was about from 1.5 to 2 mm.

d- NLFEA model accurately predicted the response of the proposed composite sleeper at both of negative bending at center and positive rail seat compression test. NLFEA predicted that the proposed composite sleeper has an ultimate capacity reached to 124 KN

e- From calculations of percentage of wheel load transferred to proposed composite sleeper, it is found that track stiffness (K) value is 65 KN/mm .That's mean the calculated track deflection (Y) is 2.11 mm. This value is less than a maximum track deflection value (6.35 mm) recommended by AREMA.

f- By comparing of proposed composite sleeper with other ones, it is concluded that the strength of proposed composite sleeper is within range of different species of timber sleepers used in railway lines. Also, it is found that behavior of proposed composite sleeper is higher than that of other commercially available composite ones.

10. References

1- Ellis Dc, (2001), "Track Terminology" British railway track, the permenant way, Institution, England.

2- Manalo, A.C., Aravinthan.T, Karunasena,W., M.M. Islam, (2011)," Flexural behaviour of structural fibre composite sandwich beams in flatwise and edgewise positions". ASCE journal of composite for construction, 16 (6), pp 724-736.

3- R. M. Bajracharya, W. P. Lokuge, W. Karunasena, K.T. Lau, (2011)," Structural evaluation of Concrete Expanded Polystyrene sandwich panels for slab applications ", Centre of Excellence in Engineered Fiber Composites, Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Queensland 4350, Australia.

4- FCDD (Fibre composite design and development), (2006), Centre of Excellence in Engineered Fibre Composites USQ, viewed: 20 April 2015 Website:http://www.fcdd.com.au/Projects%20&%20or%20Products/Railway%20Sleepers/Railway%20Sleepers.htm .

5- Pattamaprom, C., Dechojarassri, D., Sirisinha, C., and Kanok-Nukulchai, W., (2005)," Natural rubber composites for railway sleepers: A feasibility study", Thammasat University, Thailand.

6- TieTek, "composite crossties technical data". Viewed: 11 December 2015, website: http://www.tietek.com/specsheets.php.
7- Hoger DI (2000) Fiber composite railway sleepers. University of Southern Queensland, Toowoomba.
8- Lampo R, Nosker T, Sullivan H (2003) Development, testing, and applications of recycled plastic composite cross ties. US Army Engineer Research and Development Center, Champaign.
9- Jordan, R. and Morris, G., (2006)," The feasibility of recycled plastic railway sleepers", Project report PPR 094, Testing Research Laboratory, United Kingdom.
10- Humpreys, M.F. and Francey, K.L., (2004)," An investigation into the rehabilitation of timber structures with fiber composite materials", Queensland University of Technology, Australia.
11- Ticoalu, A.N.E., (2008),"Investigation on fibre composite turnout sleepers", Master of Engineering dissertation, University of Southern Queensland, Toowoomba, Queensland, Australia.
12- Heba Mahmoud Bakry, (2017), "Investigation on use polymers and iron slag for manufacturing railway sleepers", Ph.D. thesis, Department of Civil Engineering, Benha university, Cairo.

13- Ahmed A. Khalil, (2017), " Mechanical testing of innovated composite polymer material for using in manufacture of railway sleepers", Journal of polymers and the environment, Springer.

14- AREMA (2010) Manual for Railway Engineering – Chapter 30, American Railway Engineering and Maintenance-of-Way Association, Maryland, USA.
15- Gupta, R., (2003), "Composite Sleepers: an Environment Friendly Alternate Sleeper for Track and bridges", forest products journal, 55(12), pp 29-34.
16- Sadeghi, J. & Barati, P., (2010)," Evaluation of conventional methods in Analysis and Design of Railway Track System", International Journal of Civil Engineering, Vol. 8, No.1.
17- Wahid Ferdous, Manalo, A.C., Aravinthan.T, Gerard Van Erp, (2014)," Structural Optimization of Composite Railway Sleeper", CRC –ACS Conference, Australia.

18- IntegriCo, Integrico composites, Viewed: 02 Aug 2015, Available from: www.integrico.com.
19- Axion-EcoTrax, Axion EcoTrax composite railroad ties, viewed: 02 Aug 2016, Available from www.axionintl.com.

20- Van Belkom, A. (2015)," Recycled Plastic Railway Sleepers", 12th international conference, Scotland. Viewed: 02 November 2016, http://www.lankhorstrail.com/en/railway-sleeper.

21- AREMA (2006) Manual for Railway Engineering – Chapter 16, American Railway Engineering and Maintenance-of-Way Association, Maryland, USA.
22- Doyle, N.F., (1980), "Railway Track Design: A Review of Current Practice", Occasional Paper No. 35, Bureau of Transport Economics, Commonwealth of Australia, Canberra.