

Reducing weight of non structural components using SWCNT Bucky Paper

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ABSTRACT

The efficiency of today's gasoline engines is about 30% and the heavy-duty diesel vehicles is about 42%, whereas maximum theoretical efficiency is about 62%. Achieving theoretical maximum engine efficiency would represent a two time improvement in light-duty vehicles and a 50% improvement in heavy-duty vehicles. This can be achieved by using different materials as these have a significant impact on vehicle efficiency. This can be done in two ways: 1) Using lighter materials to reduce the weight of the vehicle and 2) Using materials that enable higher efficiency engines and power trains. Here, the first option to improve the vehicle efficiency is considered i.e. to use Bucky paper and its corresponding fusion compounds to build the non-structural components such as cabin and body of the heavy-duty truck. Here in this paper we concentrate on a part of the Tata truck that is the foot rest.

Keywords

Bucky paper, CNT(carbon- nano tubes), Bucky tubes, Buckminsterfullerene, Material, weight reduction, FEA

1. INTRODUCTION

Bucky paper is a thin fibre like anisotropic material comprising of carbon nano tubes. These are approximately 50,000 times thinner than a human hair. Originally, it was fabricated as a way to handle carbon nano tubes, but it is also being studied and developed into applications by several research groups, showing great promise as armours etc. Bucky paper is made from these carbon nano tubes. It gets the name from Buckminsterfullerene (Carbon 60) an allotrope of carbon. A sheet of buck paper is much stronger than an equivalent mass of steel. Sheets of buck paper are stacked together and compressed under high pressure to generate a material 500 times harder than steel, at one-tenth of the weight.

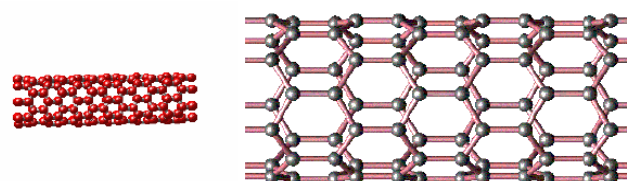


Fig 1: Structure of Carbon Nano Tubes



Fig 2: Showing Samples of Bucky Papers



Fig 3: Bucky paper developed by the High-Performance Materials Institute at Florida State University

2. MANUFACTURING

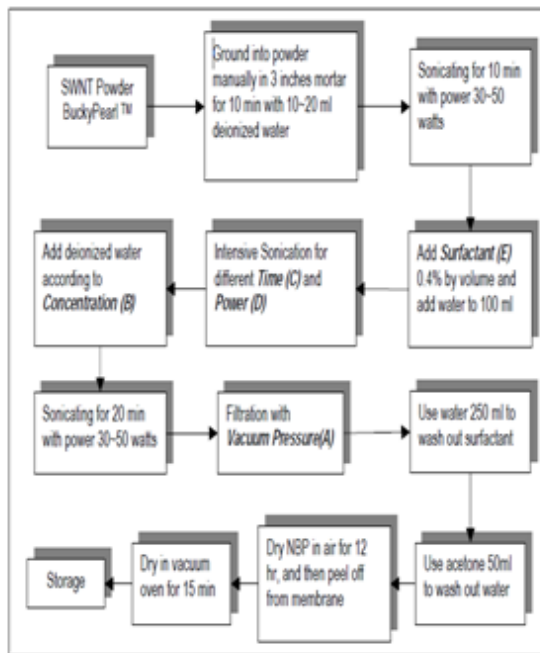


Fig 4: Manufacturing

3. BUCKY PAPER PROPERTIES

1) Ultimate Tensile Stress^[5]

It is said to be 500 times stronger than steel i.e. 62,500 N/mm².

2) Density^[4]

It is said to be 10 times lighter than steel, thus having an areal density approximately 0.5g/cm³.

3) Thickness^[5]

It is extremely thin having a thickness of approximately 25 microns.

4) Conductivity^[5]

It is a good thermal and electrical conductor with a resistivity of 0.1 ohm-cm.

5) Young's Modulus^[5]

Young's modulus of Bucky Paper is experimentally calculated as 12.2 GPA

6) Poisson's Ratio^[5]

Taking the experimental values from the same source as for the young's modulus i.e. = 0.3

4. CAD MODELING

The part that is the foot rest is measured by calipers and a CAD replica is made in CATIA V5.

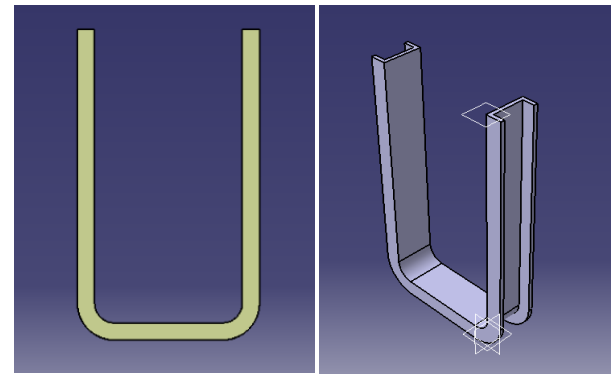


Fig 5: Front and Isometric View

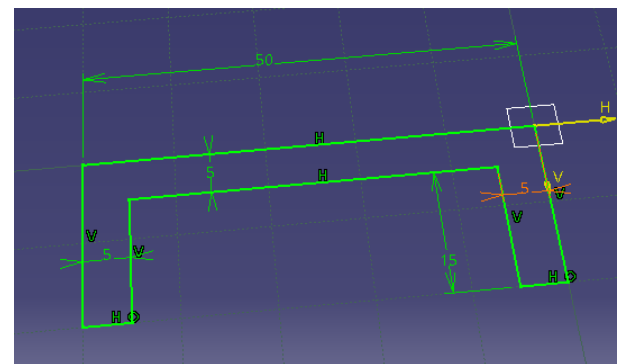


Fig 6: Cross Section

5. STRESS AND DEFLECTION CALCULATIONS

STRESS CALCULATIONS

a) Lower Portion

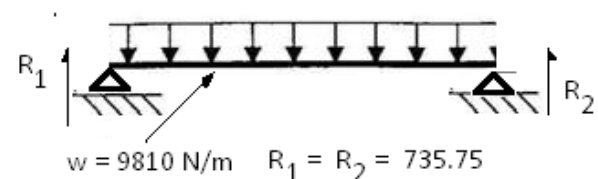


Fig 7: FBD of lower portion

Considering a uniformly distributed load of 150 kg on the lower portion which is here taken like a simply supported beam for stress calculation
load /length (w) = 1471.5/150 = 9.8 N/mm

Now, during equilibrium: summation of forces in vertical direction = 0

$$\sum F_y = 0; R=R_1 = R_2 = 1471.5/2 = 735.75 \text{ N}$$

$$\text{Now, } M_{\max} = wl^2/8 = 9810 \times 150^2 / 8 \text{ N-m}$$

$$= 27590.625 \text{ N-mm}$$

Calculating Inertia

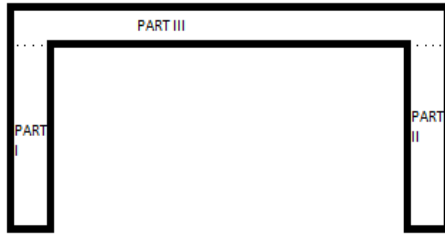


Fig 8: Different parts (cross section)

Table 1. Inertia Calculation

	b	H	Y	Area (a)	aY	aY ²
I	5	15	7.5	75	562.5	4218.75
II	5	15	7.5	75	562.5	4218.75
III	50	5	17.5	250	4375	76562.5

All above values in mm

Calculation of distance of centroid from reference axis

$$\text{Formula} = \frac{\sum aY}{\sum a}$$

$$Y_{cg} = 13.75 \text{ mm}$$

Calculating inertia for the three parts i.e. I_0

$$\text{Part I} = (b \cdot h^3)/12 = 1406.25$$

$$\text{Part II} = (b \cdot h^3)/12 = 1406.25$$

$$\text{Part III} = (b \cdot h^3)/12 = 520.83333$$

$$\text{Formula for } I_{cg} = \frac{\sum I + \sum aY^2 - Y_{cg}(\sum aY)}{12708.33}$$

$$\text{From equation } M/I = \sigma/Y$$

$$\sigma = (27590.625 \cdot 13.75) / (12708.33) = 29.85215 \text{ MPa}$$

$$\tau_{max} = (R \cdot Q) / (I \cdot b)$$

$$[\text{Since } Q = \sum AY = 5500]$$

$$= (735.75 \cdot 5500) / (12708.33 \cdot 50) = 6.3684 \text{ MPa}$$

Equivalent Stress, according to von mises stress theory,

$$\sigma_{resultant} = \sqrt{\sigma^2 + 3\tau^2}$$

$$= \sqrt{(29.85215)^2 + 3 \times (6.3684)^2} = 31.82422 \text{ MPa}$$

b) Upper Portion

Stress = Force/Area under tensile force

Here, Area is cross sectional area = 400 mm² and Force is equal to reaction on lower portion i.e. = 735.75

$$\text{Stress} = 735.75 / 400 = 1.839375 \text{ MPa}$$

DEFLECTION CALCULATION

Formula: Deflection = $(5wL^4)/(384EI)$

w, here is weight per mm i.e. $150 \cdot 9.8 / 150 = 9.8 \text{ N/mm}$

L is length of beam i.e. 150 mm

E is young's modulus

I is inertia i.e. 12708.33 N/mm⁴

Table 2. Displacement Comparison

Steel	0.025416246	mm
Aluminum	0.072617847	mm
Bucky	0.416659777	mm

6. FEM RESULTS

Steel

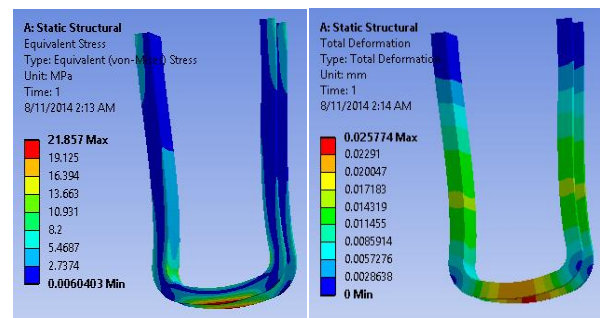


Fig 9: Stress and Deflection

Aluminum

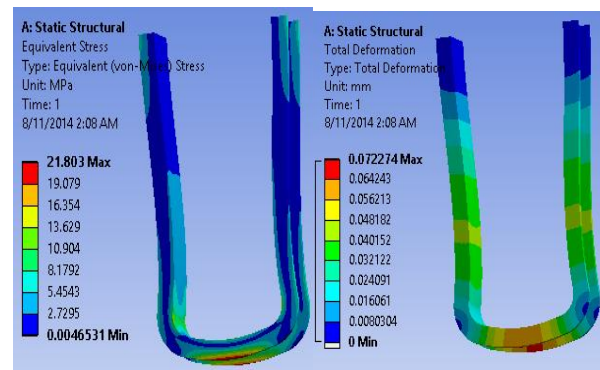


Fig 10: Stress and Deflection

Bucky Paper

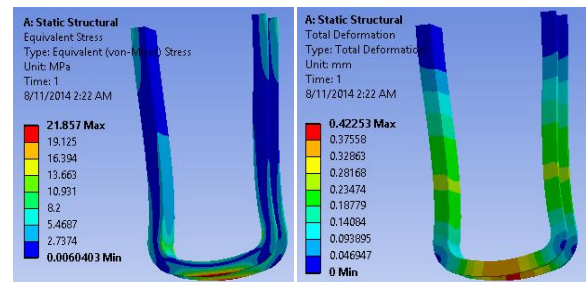


Fig 11: Stress and Deflection

$$= 9.8 \text{ N/mm}$$

7. COMPARISON

Keeping the thickness constant for all materials, We compare their deflections and factor of safety.

Table 3. Comparison Table

Material	Yield Stress	FOS	Deflection
Steel	250 MPa	7.8557	0.025416246
Aluminum	280 MPa	8.7984	0.072617847
Bucky	62500 MPa (Ultimate)	1963.9	0.416659777

8. NEW CROSS SECTION

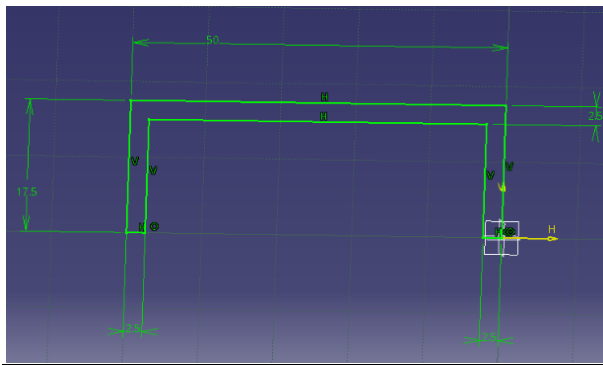


Fig 12: Reduced Thickness from 5mm to 2.5mm

9. NEW STRESS AND DEFLECTION CALCULATIONS

STRESS CALCULATIONS

a) Lower portion

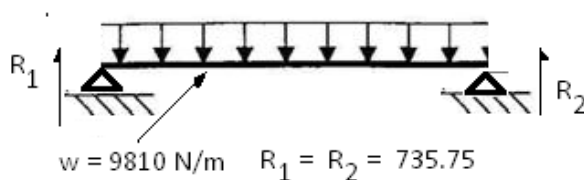


Fig 13: FBD of lower portion

We consider a uniformly distributed load of 9.8 N/mm on the lower portion which is here taken like a simply supported beam for stress calculation.

$$\begin{aligned} \text{Load /length (w)} \\ = 1471.5/0.15 \end{aligned}$$

Now, during equilibrium: summation of forces in vertical direction = 0

$$\sum F_y = 0; R = R_1 = R_2 = 1471.5/2 = 735.75 \text{ N}$$

Now,

$$\begin{aligned} M_{\max} &= wl^2/8 = 9810 \times 0.15^2 / 8 \text{ N-m} \\ &= 27590.625 \text{ N-mm} \end{aligned}$$

Calculating Inertia

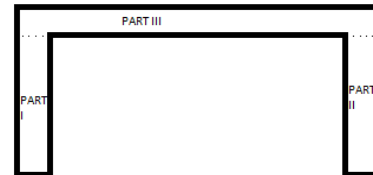


Fig 14: Different parts (cross section)

Table 4. Inertia Calculation

Calculation Of Inertia for given C Section						
	b	h	Y	Area (a)	aY	aY ²
I	2.5	15	7.5	37.5	281.25	2109.375
II	2.5	15	7.5	37.5	281.25	2109.375
III	50	2.5	16.25	125	2031.25	33007.8125

All above values in mm

Calculation of distance of centroid from reference axis

$$\text{Formula} = \frac{\sum aY}{\sum a}$$

$$Y_{cg} = 12.96875 \text{ mm}$$

Calculating inertia for the three parts i.e. I_o

$$\text{Part I} = (b \cdot h^3)/12 = 703.125$$

$$\text{Part II} = (b \cdot h^3)/12 = 703.125$$

$$\text{Part III} = (b \cdot h^3)/12 = 65.10417$$

$$\begin{aligned} \text{Formula for } I_{cg} &= \frac{\sum I + \sum aY^2 - Y_{cg}(\sum aY)}{5060.221} \text{ mm}^4 \end{aligned}$$

From equation

$$M/I = \sigma/Y$$

$$\begin{aligned} \sigma &= (27590.625)(12.96875)/(5060.221) \\ &= 70.711 \text{ MPa} \end{aligned}$$

$$\begin{aligned} \tau_{\max} &= (R \cdot Q)/(I \cdot b) \\ [Q &= \sum AY = 2593.75] \\ &= (735.75 \times 2593.75)/(5060.221354 \times 50) \\ &= 7.542 \text{ N-mm} \end{aligned}$$

Equivalent Stress

$$\sigma_{\text{resultant}} = \sqrt{\sigma^2 + 3\tau^2}$$

$$= \sqrt{(70.711^2 + 3 \times 7.542^2)}$$

$$= 71.908 \text{ MPa}$$

b) Upper Portion

Stress = Force/Area under tensile force

Here, Area is cross sectional area = 200 mm² and Force is equal to reaction on lower portion i.e. = 735.75

Stress = 735.75/200

$$= 3.67875 \text{ MPa}$$

DEFLECTION CALCULATION

Formula: Deflection = $(5wL^4)/(384EI)$

W, here is weight per mm i.e. $150 \times 9.8/150 = 9.8 \text{ N/mm}$

L is length of beam i.e. 150 mm

E is young's modulus of Bucky Paper

I is inertia i.e. 5060.221 N/mm⁴

Deflection for Bucky Paper is 1.046407 mm

10. FEM RESULTS

Bucky Paper

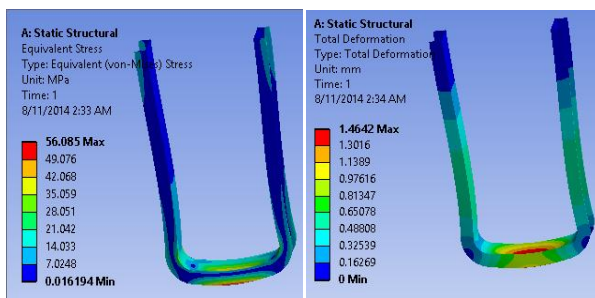


Fig 15: Stress and Deflection

11. DEVIATION IN RESULTS

Due to assumptions considered while doing the hand calculation, the results are bit deviating from FEM results. But they are well under the allowed deviation.

12. WEIGHT REDUCTION

Unmodified Part Volume = 0.00032 m³

Density of Steel = 7750 kg/m³

Mass = 2.48 kg

Modified Part Volume = 0.00016 m³

Density of Bucky Paper = 500 kg/m³

Mass = 0.3 kg

Weight reduced = 2.18 kg

Percentage weight reduced = $(2.18/2.48) \times 100$
= 87.90322581 %

13. CONCLUSION

We achieved a weight reduction of 87.90322581 %. Similarly replacing more of such non structural components on a

vehicle will lead to significant reduction in its weight and hence will increase the power to weight ratio and also the fuel economy as now the self load is less.

14. ACKNOWLEDGEMENTS

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