© MAR 2019 | IRE Journals | Volume 2 Issue 9 | ISSN: 2456-8880

Design and Analysis of Train Brake Blocks

DR. AUNG KO LATT
Department of Mechanical Engineering, Mandalay Technological University

Abstract* – This paper focus on the design and analysis of locomotive brake blocks. The brake is a critical feature in order to retard and stop the railway vehicle within minimum possible time. It is must for all vehicles to have proper brake system. The purpose of braking action is to perform controlled reduction in velocity of the vehicles, either to reach certain lower speed or to stop a fixed point. In this paper stopping distance, braking time and braking efficiency are calculated for three moving conditions of locomotive (moving on level, moving up and moving down) and braking force and brake blocks length are also calculated for the tread brake. The existing air brake system of railway coach has the following drawbacks due to excessive brake force on the brake blocks – thermal cracks on wheel tread, brake binding and reduced life of brake blocks. The analysis is done by applying three different materials Grey Cast Iron, Low Carbon Steel and High Carbon Steel for Locomotive brake. This paper is to overcome drawbacks by changing the brake blocks length. Structural (von-Mises stress, effective strain) behaviour of brake blocks are computed by theoretical approach. SolidWorks software is used for modelling. Structural (von-Mises stress, effective strain) behaviour are analysed by using ANSYS software.

***Index Terms* – Structural Analysis, Locomotive Brake Blocks, Braking Conditions, ANSYS**

I. INTRODUCTION

Rail or train transportation is one of the important and economical transportation systems available. Different types of braking systems are used in railway vehicles. A brake is a device that decelerates a moving object such as a machine or vehicle by converting its kinetic energy into another form of energy, or a device, which prevents an object from accelerating. Most commonly, brakes use friction convert kinetic energy into heat, but in regenerative breaking much of the energy is converted instead into useful electrical energy or potential energy in a form such as pressurized air, oil, or a rotation flywheel [4]. The disc brake is a device for slowing or stopping the rotation of a wheel. A brake disc (or rotor) usually made of cast iron or ceramic composites (including carbon, Kevlar and silica), is connected to the wheel and /or the axle. To stop the wheel, friction material in the form of brake pads is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop [2]. Axle mounted disc brakes require sufficient space to accommodate therefore used in trailer bogies.

Wheel mounted disc brakes are used on motor bogies because it requires accommodating the traction motor only and having insufficient space for an axle-mounted brake. In both systems, compressed air or oil is applied to a brake cylinder that pushes the brake lining against the disc. Brake discs are dead weight that is useful only during braking; therefore, operators can install lighter discs. Carbon/carbon-composite multi-disc and aluminum composite discs offer lighter weights and are widely used [3]. Tread of block braking is popular and frequently used mechanical braking system in trains.

In tread braking, the braking action is obtained by pressing one, two or four brake block (brake shoes) against the tread of a wheel. There are different kinds of brake blocks materials; cast iron, organic composite materials and sinter materials. During tread braking, kinetic energy of train gets dissipated in the form of heat at wheel – brake block interfaces. Heat generated during tread braking is shared by wheel and brake blocks. The main components of air braking system are shown in Figure 1.

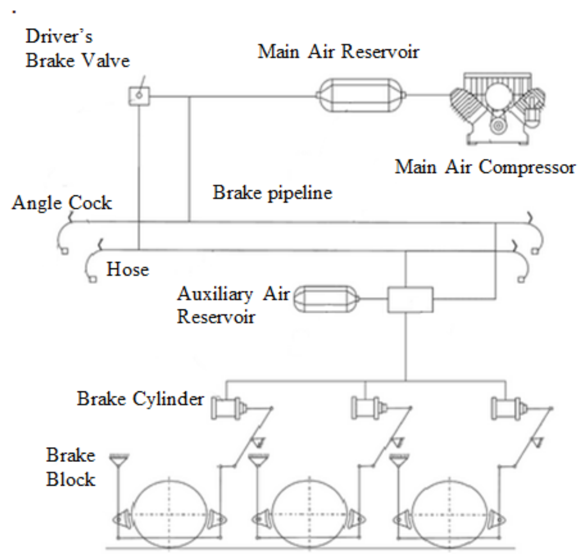

Figure 1. Components of Air Braking System

The main components of air braking system are main air compressor, main air reservoir, driver's brake valve, angle cock, hose, brake pipe, auxiliary air reservoir, brake cylinder and brake. Compressor is the pump which draws air from atmosphere. Main reservoir is a storage tank for compressed air for braking. Driver control the brake. Angle cocks are provided to allow the ends of the brake pipe hoese to be sealed when the vehicle is uncoupled. The pipe running the length of the train, which transmits the variations in pressure required to control the brake on each vehicle. The movement of the piston contained inside thee cylinder operates the brake through links called rigging. The movement of brake cylinder transmits pressure to the brake blocks on each wheels. The brake block are the main source of wear in the brake system [4]. The main components of tread brake as shown in Figure 2.

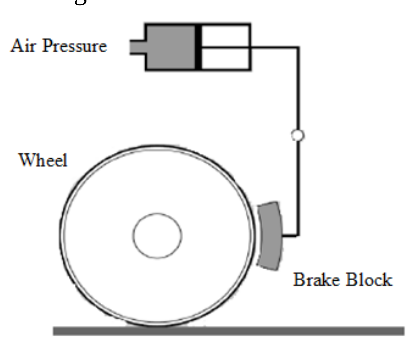

Figure 2. Components of Tread Brake [3]

II. DESIGN OF TREAD BRAKING SYSTEM

Table I illustrates the design data of tread braking system.

Table I. Specification Data of Locomotive

Technical category	Symbos	Value
Total vehicle weight	w	43545 kg
Maximum speed	v	40 km/hr
Angle of inclination	θ	2.29°,1.43°
Overall height of vehicle	H	3500 mm
Overall length of vehicle	L	13103 mm
Overall width of vehicle	W	2813 mm
Height of CG of locomotive	h_{CG}	1829 mm
Total wheel base	b	8020 mm
Wheel diameter with tyre	D_w	990.6 mm
Coefficient of dry friction	μ	0.4

A. Consider for the vehicle moving on linear

Brake applied on all wheel

$$\sum Fy = 0(\uparrow +)$$

$$R_A + R_B + R_C + R_D = W$$

$$\sum Fx = 0(\rightarrow +)$$

$$\mu R_A + \mu R_B + \mu R_C + \mu R_D = W\frac{a}{g}$$

$$\mu = \frac{a}{g} \quad (1)$$

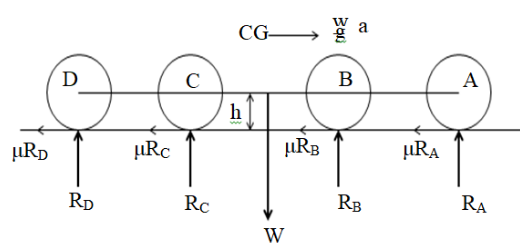

Figure 3. Vehicle Moving Level Condition

Deceleration produced from the brake applied on all conditions. Stopping distance (S), braking time (t) and braking efficiency (η) are calculated based on these deceleration and maximum velocity of 40 km/hr by using the following equations,

$$S = \frac{v^2}{2a} \quad (2)$$

$$t = \frac{v}{a} \quad (3)$$

$$\eta = \frac{a}{g} \times 100\% \quad (4)$$

Table II. Result Table for Vehicle Moving Level

Deceleration(m/s^2)	3.924
Stopping Distance (m)	15.73
Braking Time (sec)	2.832
Efficiency (%)	40

B. Consider for the vehicle moving up

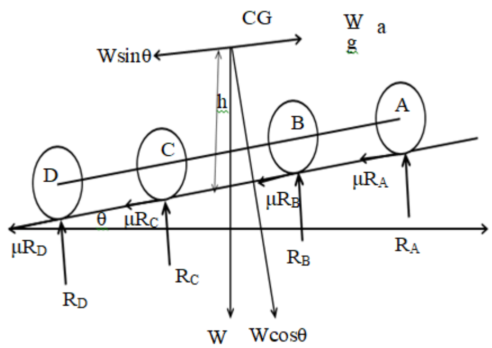

Figure 4. Vehicle Moving up on Inclined

Brake applied on all wheel

$$\sum Fy = 0(\uparrow +)$$

$$R_A + R_B + R_C + R_D = W\cos\theta$$

$$\sum Fx = 0(\rightarrow +)$$

$$\mu R_A + \mu R_B + \mu R_C + \mu R_D + W\sin\theta = W\frac{a}{g}$$

$$\mu W\cos\theta + W\sin\theta = W\frac{a}{g}$$

$$\mu\cos\theta + \sin\theta = \frac{a}{g} \quad (5)$$

Table III. Result Table for Vehicle Moving up

	$\theta = 2.29°$	$\theta = 1.43°$
Deceleration (m/s2)	4.313	4.168
Stopping Distance (m)	14.312	14.81
Braking Time (sec)	2.58	2.67
Efficiency (%)	44	43

C. Consider for the vehicle moving down

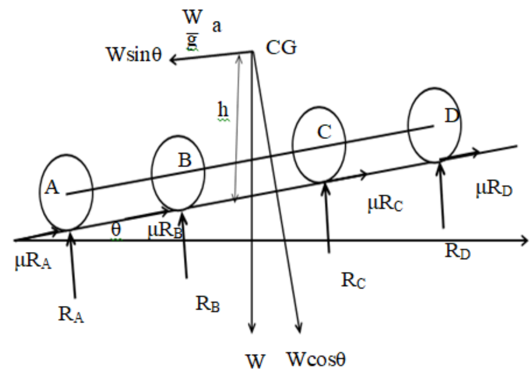

Figure 5. Vehicle Moving Down on Inclined

Brake applied on all wheel

$$\sum Fy = 0(\uparrow +)$$

$$R_A + R_B + R_C + R_D = W\cos\theta$$

$$\sum Fx = 0(\rightarrow +)$$

$$\mu R_A + \mu R_B + \mu R_C + \mu R_D = W\sin\theta + W\frac{a}{g}$$

$$\mu W\cos\theta = W(\sin\theta + \frac{a}{g})$$

$$\mu\cos\theta - \sin\theta = \frac{a}{g} \quad (6)$$

Table IV. Result Table for Vehicle Moving Down

	$\theta = 2.29°$	$\theta = 1.43°$
Deceleration (m/s2)	3.529	3.678
Stopping Distance (m)	17.492	16.783
Braking Time (sec)	3.148	3.021
Efficiency (%)	36	38

According to the design calculation, the optimum stopping distance, braking time and efficiency are found that brake applied on all wheel in vehicle moving up as shown in Table III. This brake applied on all wheel are used in locomotive.

D. Consider calculation of braking force

Table V. Specification Data of Tread Brake

Technical Category	Symb	Value
Brake cylinder diameter	Dc	203 mm
Maximum brake cylinder pressure	P	0.38 N/mm^2
Leverage ratio	r_L	256:134

No of lever per axle	n_L	2
No of brake block	n_b	16
Brake cylinder efficiency	η_c	0.9
Rigging efficiency	η_r	0.83
Coefficient of friction between brake block and wheel	μ_1	0.3
Brake block width	B	79.4 mm

E. Air Brake Details

(1) Area of the piston, A_p

$$A_p = \pi r_c^2 \quad (7)$$

(2) Force available on the piston,

$$F_p = A_p \times P \quad (8)$$

(3) Mechanical advantage /axle,

$$MA = r_L \times n_L \quad (9)$$

(4) Theoretical braking force available on an axle,

$$(F_a)_{theo} = F_p \times MA \quad (10)$$

(5) Theoretical braking force available on a coach,

$$(F_c)_{theo} = (F_a)_{theo} \times 4 \quad (11)$$

(6) Theoretical braking force on each brake block,

$$(F_b)_{theo} = \frac{(F_c)_{theo}}{16} \quad (12)$$

(7) Actual brake force available on each brake block,

$$(F_b)_{actual} = (F_b)_{theo} \times \eta_c \times \eta_r \quad (13)$$

F. Brake Force Calculations

Table VI .Brake Force Calculations

No	Description	Value
1	Brake block curve length, L	317.5 mm
2	Brake block area, A	25210 mm
3	Pressure, P	0.38 N/mm^2
4	Area of the piston, A_p	32365 mm^2
5	Piston force, F_p	12.3 kN
6	Mechanical advantage/axle, MA	3.82
7	Theoretical braking force available on an axle, $(F_a)_{theo}$	46.986 kN
8	Theoretical braking force on a coach, $(F_c)_{theo}$	187.944 kN
9	Theoretical braking force available on each brake block, $(F_b)_{theo}$	11.7465 kN
10	Actual brake force available on each brake block, $(F_b)_{actual}$	9.5147 kN

G. Calculation of von-Mises stress and strain

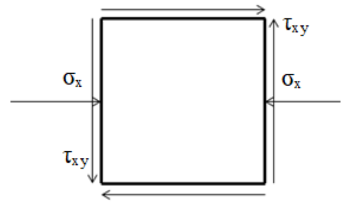

Figure 6. Stress on XY Plane

Compressive stress on the brake block is equal to the actual brake force available on each brake block divided by area of the brake block. Shear stress occur due to friction between the wheel tread and the brake block is 0.3.

$$\tau_{xy} = \mu_1 P \quad (14)$$

The principle stress and effective stress for the brake block can be calculated in von-Mises criteria

$$\sigma_{1,2} = \frac{1}{2}\sigma_x \pm \frac{1}{2}\sqrt{\sigma_x^2 + 4\tau_{xy}^2} \quad (15)$$

The effective stress of brake block is

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]^{\frac{1}{2}} \quad (16)$$

The relation between stress and strain is called constitutive equation. Hook's law would be show that, Principle strains

$$\varepsilon_1 = \frac{1}{E}\left[\sigma_1 - \upsilon(\sigma_2 + \sigma_3)\right] \quad (17)$$

$$\varepsilon_2 = \frac{1}{E}\left[\sigma_2 - \upsilon(\sigma_1 + \sigma_3)\right] \quad (18)$$

$$\varepsilon_3 = \frac{1}{E}\left[\sigma_3 - \upsilon(\sigma_1 + \sigma_2)\right] \quad (19)$$

For the von-Mises criterion the effective strain of brake block,

$$\bar{\varepsilon} = \left[\frac{2}{3}(\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2)\right]^{\frac{1}{2}} \quad (20)$$

Table VII. Comparison of Stress and Strain for Different Materials

Materials	Grey C.I		Low C.S		High C.S	
	L_B	L_{BC}	L_B	L_{BC}	L_B	L_{BC}
σ_x (10^5Pa)	4.65	3.99	4.65	3.99	4.65	3.99
τ_{xy} (10^5Pa)	1.39	1.19	1.39	1.19	1.39	1.19
$\bar{\sigma}$ (10^5Pa)	5.25	4.50	5.25	4.50	5.25	4.50
$\bar{\varepsilon}$ (10^{-6})	4.16	3.57	2.24	1.92	2.20	1.89

H. Structural Analysis

Structural analysis is performed on train brake to find its strength. Von-Mises (Equivalent stress) is very important stress in design safe or not. If von-Mises stress is within the Yield strength of the material then the design is safe [2].

I. Material Properties of Brake Blocks

Table VIII. Material Properties of Brake Block

Materials Properties	C.I	Low C.S	High C.S	Unit
Density	7200	7870	7850	kg/m^3
Modulus of Elasticity	110000	205000	210000	MPa
Poisson Ratio	0.28	0.29	0.3	-
Yield Strength	320	370	490	MPa

III. NUMERICAL SIMULATION OF BRAKE

A. Modelling of brake block

The brake block is modelled SolidWorks software. Figure 7 shows the brake blocks (change curve length) using in locomotive.

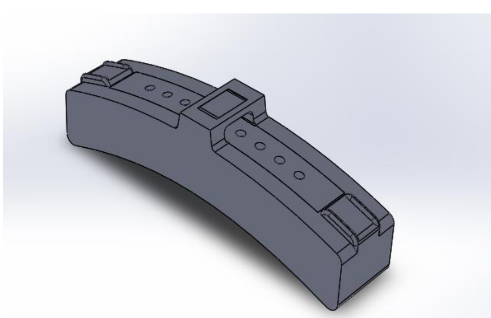

Figure 7. 3D Model of Brake Block

B. Meshing of brake block

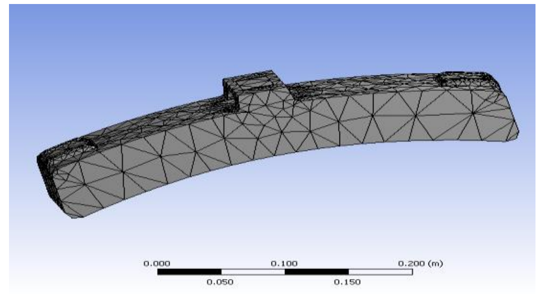

Figure 8. Mesh Model of Brake Block

IV. FEM ANALYSIS

The static structural brake block model was added to the geometry in ANSYS. This model was meshed with linear. This meshed model was imported to static structural for structural analysis of brake block. Then, give the input conditions, which fixed at the brake pad of the brake block. Apply pressure at X-axis. After finishing set up, run the solution and get equivalent (von-Mises) stress and equivalent (von-Mises) strain for static structural analysis of the brake block.

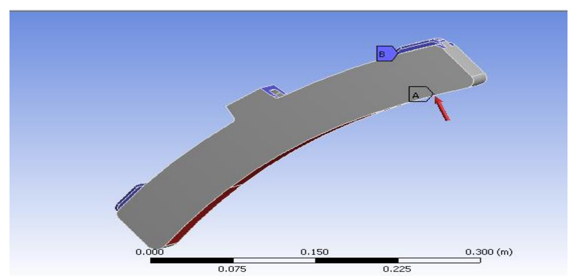

Figure 9. Boundary Condition of Brake Block

The boundary condition and fixed support of brake block is as shown in Figure 8.

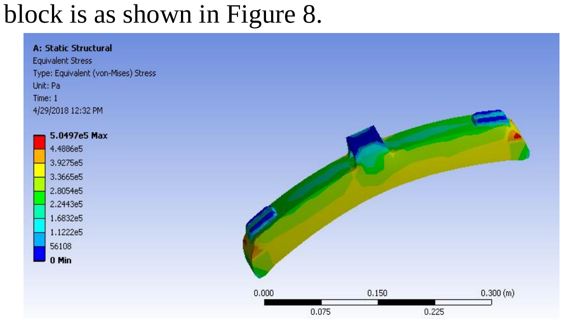

Figure 10. von-Mises Stress on Brake block using Grey Cast Iron

Figure 10 shows the equivalent (von-Mises) stress on brake block using grey cast iron. The maximum simulation result of equivalent (von-Mises) stress on brake block is 5.049×10^5 Pa while the yield strength of the grey cast iron is 320 MPa.

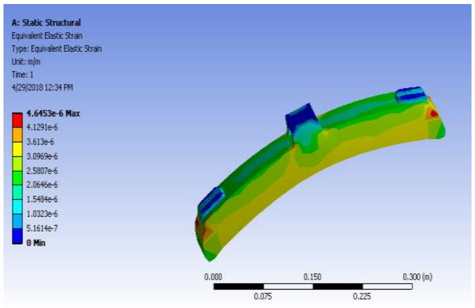

Figure 11. Effective Strain on Brake Block using Grey Cast Iron

Figure 11 shows the effective strain on brake block using grey cast iron. The maximum effective strain of the brake block for grey cast iron is 4.645×10^{-6}.

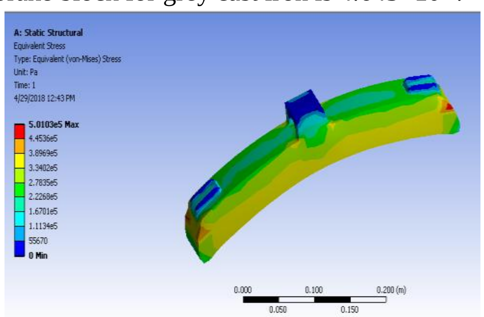

Figure 12. von-Mises Stress on Brake Block using Low Carbon Steel (AISI 1018)

Figure 12 shows the equivalent (von-Mises) stress on brake block using low carbon steel. The maximum simulation result of equivalent (von-Mises) stress on brake block is 5.010×10^5 Pa while the yield strength of the low cast iron is 370 MPa.

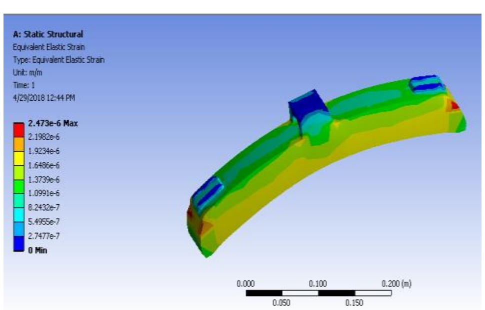

Figure 13. Effective Strain on Brake Block using Low Carbon Steel

Figure 13 shows the effective strain on brake block using low carbon steel. The maximum effective strain of the brake block for low carbon steel is 2.473×10^{-6}.

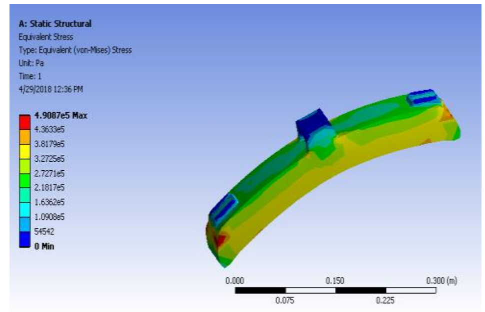

Figure 14. von-Mises Stress on Brake Block using High Carbon Steel (AISI 1065)

Figure 14 shows the equivalent (von-Mises) stress on brake block using high carbon steel. The maximum simulation result of equivalent (von-Mises) stress on brake block is 4.908×10^5 Pa while the yield strength of the high carbon steel is 490 MPa.

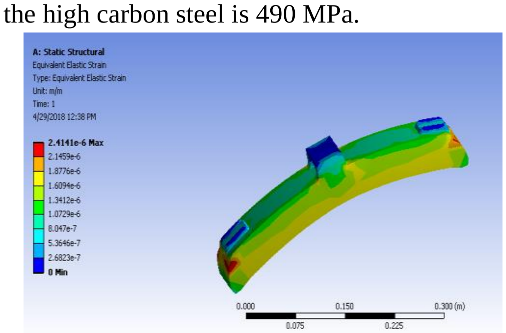

Figure 15. Effective Strain on Brake Block

using High Carbon Steel

Figure 15 shows the effective strain on brake block using high carbon steel. The maximum effective strain of the brake block for high carbon steel is 2.414×10^{-6}.

Table IX. Comparison of Numerical and Theoretical Results of von-Mises Stress and Effective Strain

Materials	von-Mises Stress (10^5Pa)		Equivalent Strain (10^{-6})	
	Theo	Numerical	Theo	Numerical
Grey C.I	4.506	5.049	3..576	4.645
Low C.S	4.506	5.010	1.929	2.473
High C.S	4.506	4.908	1.893	2.414

V. CONCLUSIONS

The existing air brake system of railway coach has the following drawbacks due to excessive brake force on the brake blocks – thermal cracks on wheel tread, brake binding and reduced life of brake blocks. This paper is to overcome drawbacks by changing the brake blocks curve length. Before changing the brake block curve length, equivalent stress applied per one brake block is 5.252×10^5 Pa. After changing, equivalent stress applied per brake blocks is 4.506×10^5 Pa. In this study, locomotive brake block was analysed by using SolidWorks software with three different materials. From the results, High carbon steel have low stress when compared with low carbon steel and grey cast iron (4.908<5.010<5.049) and also less equivalent strain than grey cast iron and low carbon steel. Hence High carbon steel is better than grey cast iron and low carbon steel materials the design is safe and von-Mises are within the yield strength of the materials. So, High carbon steel is best suited material for locomotive brake as it increases the life period. The maximum speed of 40 km/hr has the best stopping distance 14.312 m for the brake applied on all wheel.

REFERENCES

[1] G.Sudheer, "Static and Thermal Analysis of Train Brake Pad and By Using Fem", International Journal & Magazine of Engineering, Technology, Management and Research, ISSN No: 2348-4845, 2016.

[2] Chintha Sreedhar, "FEM Analysis on Locomotive Train Brake for Improved Efficiency by Using CATIA and ANSYS-Workbench", International Research Journal of Engineering and Technology, IRJET, vol.2, Issue 8, Nov 2015.

[3] Rakesh Chandmal Sharma, "Braking Systems in Railway Vehicles", International Journal of Engineering Research & Technology, IJERT, ISSN: 2278-0181, vol.4, Issue 1, January 2015.

[4] A Ramana Chary - M.Tech Pursuing, "Design and Analysis of Train Braking System", International Journal of Advanced Research and Innovation, ISSN: 2319-9253, vol.7, Issue 3, Oct 2014.

[5] Abdulmenan Sulti, "Thermal and stress analysis of AALRT Wheel when braking with Block Brake", Dec 2014.

[6] Dr. D.S. Deshmukh, "Design Evaluation and Material Optimization of a train", Internarional Journal of Research Studies in Science, Engineering and Technology[IJRSSET], Volume 1, Issue 2, May 2014.

[7] James M. Gere, Barry J. Goodno. "Mechanics of Materials, Eighth Edition", 2012.