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Light Weighting of Buses using Aluminium with Safety and Durability Considerations

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ABSTRACT

Automobiles, while making living easy and convenient, have also made human life more complex and vulnerable to toxic emissions. Transport sector is huge contributor in polluting air in the entire world in the tune of around 23%.Mass transport uses buses as the medium for generalized and convenient means for commutation from one place to other. Similar pattern is observed in India for mass transportation mainly in the cities. However, commuting through buses comes with penalty of environmental pollution. City buses are large contributor in GHG emission and can be considered as prime candidates for making any kind of changes which will help in reducing environmental pollution. Immense potential lies in existing bus designs for weight optimization which has direct impact in improving fuel economy and hence will have sustainable impact in reducing carbon emissions.

This paper outlines systematic approach used for development of lightweight buses using Aluminium addressing safety, durability and necessary regulatory requirements. Effective use of aluminium in development of lightweight bus structure is demonstrated in this project. While designing lightweight structure for weight optimization due care is taken for addressing prevailing regulatory norms related to AIS:052 bus body code, AIS:153 outlining safety requirements and Urban Bus Specification issued by Ministry of Road Transport and Highways specifying strength and safety requirements of bus structure.

Aluminium bus designs developed shows more than 30% weight reduction compared to steel structured buses of similar class. Fuel efficiency improvement in the tune of minimum 8% and maximum 10% are observed during field level trials.

KEYWORDS: Aluminium; Lightweighting; Fuel Economy; Public Transport; Safety and durability.

Introduction

Indian automotive sector have been recording impressive growth figures; India is the second fastest growing auto market. Thus transport sector contributes to a large extent in country's gross domestic product (GDP). With greater urbanization in India, Indian cities are getting crowded resulting in dense population pockets at the same time showing higher economic growth. These factors are triggering demand for quick, affordable means of transport. Government focuses on providing better infrastructure with the emphasis on public transport enrichment. Metros in various cities with efficiently connected last mile public transport by means of buses throughout India has risen demand of mass transit buses[1].

There is growing interest in providing good mass transit system (shift from private to public transport) due to variety of reasons, including rising fuel costs, road congestion in urban areas, environmental concerns, and greater mobility needs. Led by the legislation norms, automotive Industry is working towards sustainable mobility options by exploring lightweight vehicles, electrical vehicles operated on REESS, Hybrid vehicles alongwith plugin hybrid variants and Hydrogen fuel cell vehicles etc.

Fuel economy of any vehicle has inverse relation with its mass. This factor becomes more prominent in deciding fuel efficiency of the vehicle when it plies at relatively lower speed as in case of a passenger bus. Buses has to make stops at short distances resulting in constant acceleration and deceleration which plays the most significant role in the fuel consumption and power requirement. Lowering the mass of the vehicle lowers the amount of energy required for acceleration and declaration cycle. Vehicle mass has inverse functional relationship with fuel efficiency and emissions, with the assumption that the powertrain efficiency remains constant throughout bus life. Marginal improvement in fuel economy results in lower GHG emissions for given distance travelled and this has phenomenal impact on air quality. It is therefore imperative to strive for weight optimization of public transport buses to achieve better fuel efficiency enablingpositive impact on environmental.

ABBREVIATIONS: REESS – Rechargeable Electrical Energy Storage System; GHG – Green House Gas; AIS – Automotive Indian Standard; IRC – International Road Congress; UBS – Urban Bus Specification.

Fuel economy improvement is feasible by two ways. One way is by adopting fuel efficient powertrain, which has been researched over the years and poses certain limitations to achieve any further improvement in that aspect. Other way is to lower the vehicle mass, which will lead to lesser requirement of energy to propel the same vehicle and thus achieving higher fuel efficiency for given distance travelled.

Lightweghting of the vehicle by means of design optimization in the existing designs has its own limitation due to various manufacturing constraints. Other promising area for weight optimization is the use of lightweight material and designing the vehicle structure taking into account necessary physical properties of the lightweight material. Study shows that significant improvementin fuel economy can be achieved with the use of lightweight materials especially for heavy duty applications like buses and trucks[2].

While selecting lightweight material, total life cycle analysis i.e. cradle to grave analysis of material is very important.Study of cost involved during different material manufacturing stages viz. pre-manufacturing, manufacturing, use and post-use throws light on superiority of Aluminium as a material over other materials. During the use stage, savings provided by aluminium in terms of fuel consumption and consequentGHG reductions outperforms any other metal. Aluminium scores high on recyclability and re-usability in the post-use stage in comparison with any other metal used in the automobile[1,3].

This paper presents describesapproach and methodology adopted for aluminium lightweight bus design with due regulatory compliance and due considerations of very important aspects like safety and durability of the bus structure.

Bus Light Weighting Methodology

There are typically three stages of bus development process viz. Design, Manufacturing and Testing.

Design process started with product benchmarking, deriving concepts, simulation driven engineering detailing followed by design freeze and release of manufacturing drawing. Manufacturing stage involves building of physical bus prototype as per bus structure drawing. Assessment of bus performance against regulatory norms was carried out during testing phase. Conformance of bus structure was checked against standards viz. AIS: 052 for bus body critical dimensions and strength compliance, AIS:153 for noise and vibration compliance and structural durability under road loads.

Benchmarking

Weight distribution of current Indian buses is shown in Fig. 1.

From above chart it can be observed that superstructure shows higher contribution around 22% among all other subassemblies in the entire bus followed by axles and chassis frame. Superstructure is made fromsteel tubes welded togetherto form stiff lattice structure. These steel tubes can be conveniently replaced by equivalent aluminium tubes for achieving weight reduction. Aluminium can tubes can be made in any form due to its excellent extrudability property, this makes aluminium right candidate for replacement of heavy steel sections with lightweight extruded sections imparting equal strength that of steel.

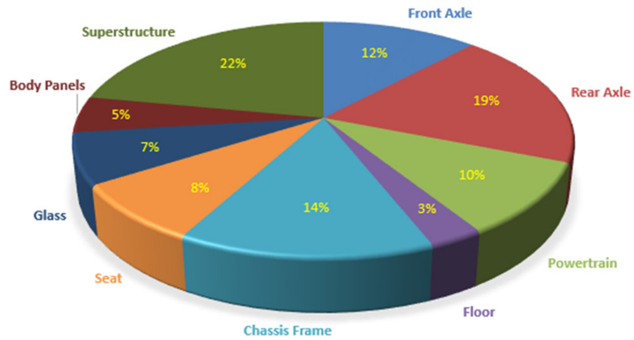

Fig. 1. Weight Chart of Indian Bus.

In the passenger car industry, usage of aluminium has increased especially for sub-systems like engines, transmissions, heat exchangers and wheels. Use of aluminium for BIW, closures, bumpers and fenders is also increasing with the passage of time. However, for heavy commercial vehicle both passengers and goods usage of aluminium is limited.

Aluminium is commercially available in 8 different alloy grades which are designated by 4 digits. 1XXX, 3XXX and 5XXX series wrought alloys are work hardened alloys while remaining wrought alloys can be hardened by solution heat treatment. Various work hardening processes are designated by H series and solution heat treatment processes are designated by T series. T4 and T6 are widely used temper grades of aluminium alloys. Table 1 gives the list of aluminium alloy grades used by various bus designs available globally. Depending upon the alloy content, extrudability of aluminium changes.

TABLE 1

Aluminium Alloy Grades used in Bus Body Design

Aluminium Grade	Component	Remarks
6061-T6	members of superstructure	various rectangular tubes and extrusion are used
6082-T6	vertical pillars	grades selected based on strength requirement
6005A-T6	other structural members	
6005A-T6	various structural members	detailed extrusion profile catalogue is available
6106-T6		
6060-T6		
6351-T6 (64430-WP)	structural members, rivets	information collected from visits to STUs
6063-T6 (63400-WP)	body panels, cant-rail	

Typical Steel Bus Body comprises of various elements viz. superstructure i.e. lattice structure, floor, glass, body panels and air conditioning system. Weight matrix of these sub-systems is provided in Table 2.

TABLE 2
Bus Body Weight Detailing.

Bus Body Systems	Weight (kg)
Superstructure (lattice structure)	2200
Floor	540
Glass	300
Body Panels	350
Aircon	240

It can be observed that major weight contributor is lattice structure and hence this element in the entire bus was targeted for more than 30% weight reduction using lightweight material like aluminium.

Setting Strength Target through Joint Testing

In order to design steel equivalent aluminium sections it was important to know physical behavior of different bus body joints in real load scenario. Strength of steel bus body joints in terms of load carrying capacity was checked at lab level for various events like rollover,braking, cornering etc. Fatigue behavior of welded steel joints was also checked against dynamic road load data. These tests were conducted at laboratory level in controlled environment as shown in Fig. 2 to develop repeatable and reliable test data which can be used further while designing equivalent strength aluminium joints.

Fig. 2. Experimental Strength Assessment of Bus Body Joint.

Bus Superstructure Design

Aluminium is three times lighter than steel and hence it is prominent candidate to be used in place of steel for light weighting. However, aluminium is less strong compared to steel and hence this imposes challenge to designer for making it steel equivalent. Aluminium can be made as strong or better than steel in strength by improving its section modulus. Extrudability of aluminium allows designer to try different sections for strength modulus improvement which otherwise are not feasible in steel. Various design concepts were evaluated based on parameters like mass, modal frequency, torsional stiffness, and bending stiffness andidentified design concept was engineered further using simulation driven design approach.

Detailing of concept was carried out by assigning various aluminium extruded sections tobus lattice structure as shown in Fig. 3.

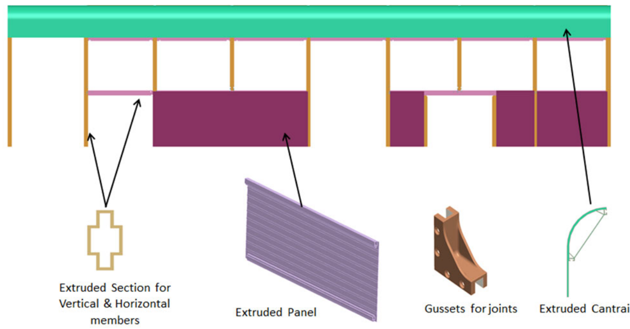

Fig. 3. Detailed Design of Bus Superstructure.

Use of single extruded section for part commonality was considered while designing bus superstructure. Concept of self-aligning gussets and interlocking was explored. Gussets were used for joining horizontal rail and vertical pillars. One piece extruded Cantrail for joining sidewall and roof was designed. Use of single Cantrail showed remarkable improvement in assembly time with improved rigidity for improving torsional and bending behavior of bus lattice structure

Steel structure is made of fusion welding. While designing aluminium structure both welding and mechanical joining technique were studied. Fig. 4 shows one of the concept evolved for aluminium bus superstructure with welding as a joining technique. Extrusion profile concepts suitable for welding were developed and lab scale models of profiles were also developed for understanding weldability of astructure and it's behavior under physical loading.

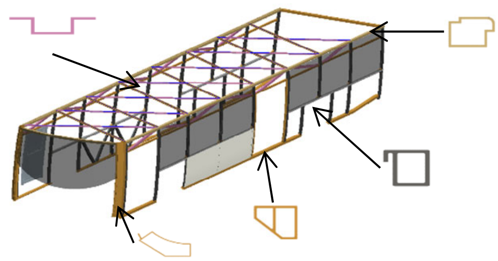

Fig. 4. Aluminium Welded Superstructure.

Experimental study showed that welded joints prepared with aluminium sections which were steel equivalent are susceptible to premature failure in fatigue. This is mainly because of reduction in material strength in Heat affected Zone (HAZ) near aluminium weld. For Aluminium fusion welding MIG and TIG welding were used and it was observed that aluminium material is very sensitive to heat. In the absence of controlled heat input in HAZ near weld joint load carrying capacity of aluminium joint is reducing.

As the weld quality is depending on controlled heat input provided during welding operation which is manual in nature in bus body building industry, with the variation in the skill, joint strength of aluminium is getting affected. This imposed main restriction in exploring welding as a joining technique for aluminium bus body development. Lab level durability tests conducted on welded aluminium joint and joint with mechanical fastening substantiated decision of usingmechanical joining technique only for further bus design exploration.

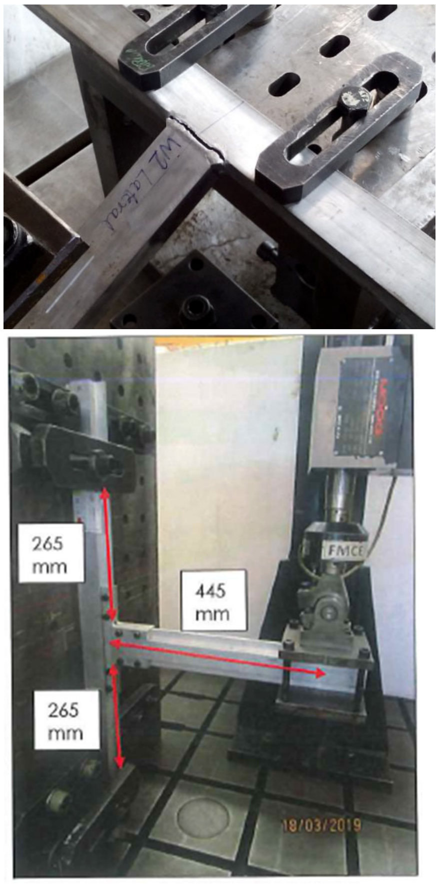

Fig. 5. Lab Testing of Aluminium Joints.

Based on selected chassis configuration and bus body code requirements of clear vision and door positioning, various pillars and doors openings were marked and concept skeleton was designed as shown in Fig. 6. Bus superstructure design was carried out in agreement withbus body code AIS:052 dimensional requirements, Urban Bus Specification strength and safety requirements. Additionally, design was also modified to meet durability aspects under measured Indian road load data.

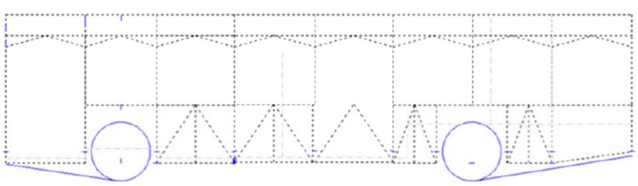

Fig. 6. Skeleton of Bus Superstructure.

Following structural changes were carried out at chassis level (Refer Fig. 7):

- Chassis outrigger positioning
- Modulation in rear side floor area
- Wheel arch
- Seat mounting positions
- Door location
- Handicap platformstructure

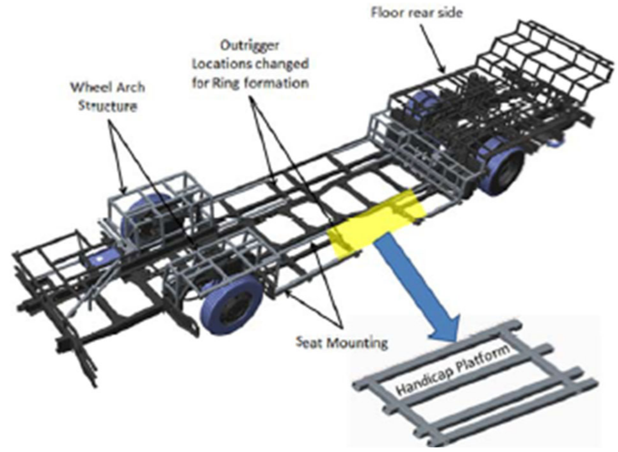

Fig. 7. Design Modifications at Chassis Level.

Better load distribution at chassis & superstructure was achieved by adopting load ring formation concept between chassis cross member, outriggers aluminium vertical pillars and roof structure as shown in Fig. 8. This has resulted in improved torsional and bending strength of bus structure.

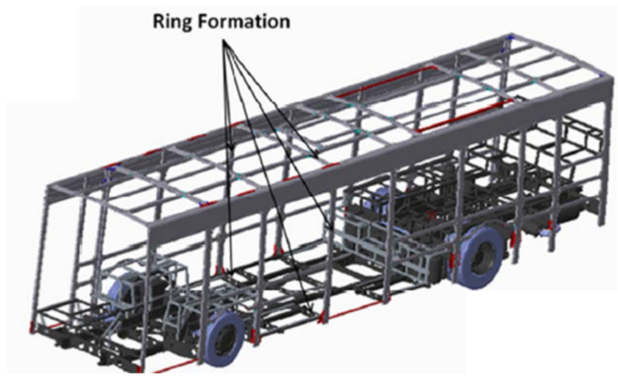

Fig. 8. Load Ring Formation for Bus.

Virtual Assessment of Bus Interior layout

Interior layout of the bus was designed in accordance with bus body code requirements. Its compliance to the dimensional requirements viz. Gangway area, seat pitch, interior height, door and window openings etc. was carried out using virtual templates as shown in Fig. 9. This helped in providing right at first time design.

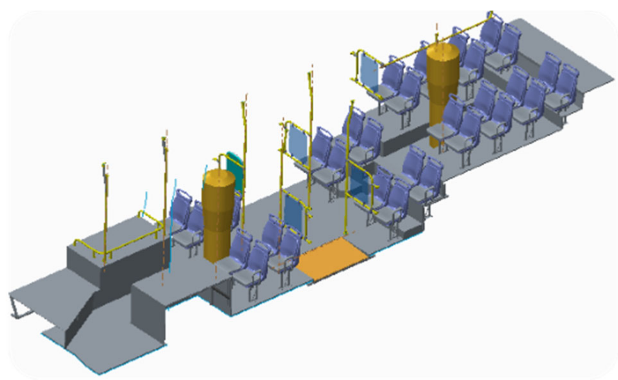

Fig. 9. Bus Interior layout as per regulatory requirements.

Necessary provisions were made in the bus superstructure design for integration of air conditioning system, escape hatch, door assembly, stanchion pipes etc. These sub-systems were virtually integrated as shown in Fig. 10 to check fouling or interference and necessary corrective design measures were carried out in the aluminium bus superstructure. This ensured easy integration of all the sub-systems to bus superstructure during prototype building stage.

Fig. 10. Subsystem Integration with Bus Superstructure.

Assessment of Safety and Durability of Structure

Strength assessment of aluminium bus structure was carried out to check its compliance against static, bump, durability, buckling, rollover and vibration criteria mentioned in Urban Bus Specification, a recommendary standard by Ministry of Urban Development. Additionally, dimensional verification for bus exterior and interior was carried out in accordance with AIS:052 bus body code.

Bus Structure Assessment for Static Loads

Bus structure was subjected to following static loading condition to check its strength worthiness under real life loading conditions.

- Gravity loads - 1.0 ‘g’ with full GVW
- Static durability Bump loads i.e. displacement at tyre patch considered is 150mm and IRC gudelines.
  - Single wheel on bump
  - Twisting - Diagonally opposite wheels on bump
  - Both wheels front wheels on bump/pot hole
- Braking conditions – 0.6 ‘g’ longitudinal and 1.0 ‘g’ vertical applied simultaneously
- Cornering loads – 0.4 ‘g’ lateral, 0.6 ‘g’ longitudinal and 1.0 ‘g’ vertical applied simultaneously
- Vibration analysis under laden condition as per AIS:153 to check modal natural frequencies greater than 3Hz for 1st torsional mode and greater than 5Hz for vertical or lateral bending mode

Maximum stresses were observed under diagonally opposite wheels on bump load cases depicting torsional loading condition. However, stresses generated were lesser than yield limit as shown in Fig. 11. Stress generated under various loading conditions are summarized in Table 3.

As the stress levels are well below material yield, structure meets static strength requirements.

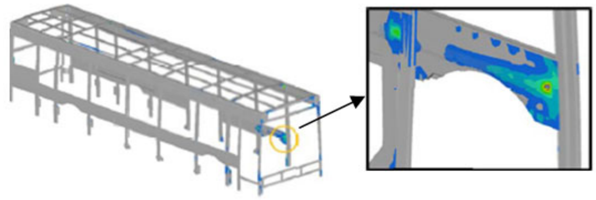

Fig. 11. Stresses induced under Torsion Loading.

TABLE 3

Stress Levels under Static Loading

Load Cases		Results
Static		Stress levels for all well below material yield of 310 MPa
Single Wheel on Bump	Front LH	
	Front RH	
	Rear LH	
	Rear RH	
Twisting - Diagonally opposite wheels on bump		
Both wheels on bump	Front	
	Rear	

Bus Stability Determination

Stability angle determination by virtual validation method as defined in AIS:052 Bus body Code is very important compliance parameter from bus rollover perspective. As per mandatory requirement, surface on which the overturning occurs should be greater than 28 degrees from the horizontal for a fully laden bus. CG of the vehicle in laden condition is recorded and stability of the bus is checked on driverand passenger side as depicted in Figure 12.

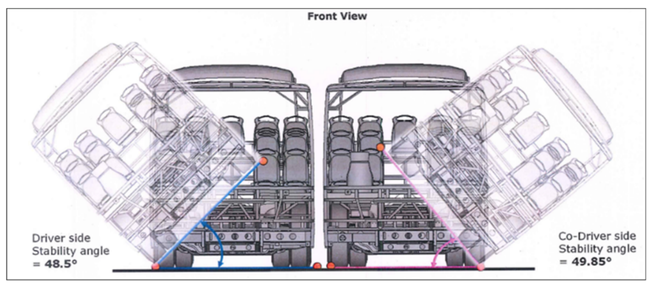

Fig. 12. Stability Angle Determination.

Due to lightweight bus structure stability requirement was comfortably met by Aluminium bus.

Assessment of Bus Safety under Rollover Condition

Structural strength worthiness of bus structure during impact events are very vital from passenger safety view point. The assessment of such an impact event was checked by carrying out virtual validation of rollover of bus as per UBS standard.

GVW conditions i.e. bus with fully laden weight is considered for rollover simulation. Passenger mass of 75 kg was considered and the same was application at appropriate location as per passenger seating and standee location. Modeling of Survival space was carried out as per guidelines mentioned in the standard for bus passenger compartment. Rollover compliance of the structure was checked by amount of side structure intrusion in passenger survival space during rolling over condition and after impact condition. This intrusion check for rollover event was carried out on driver and passenger side. Side structure does not intrude in survival space when bus was rolled over on driver side and passenger side. In order to capture worst loading conditions i.e. higher CG from ground was depicted by putting CNG weight on bus roof top as shown in Fig. 13.

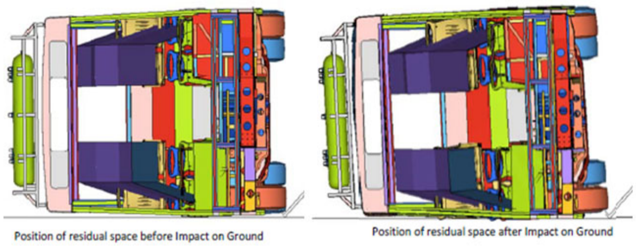

Fig.13. Bus Rollover Simulation.

Evaluation of Lateral Protection Device

Lateral underrun protection devices safeguards small vehicle from going under the bus structure from sideways. In Trucks this lateral device is externally installed, however for buses side structure itself act as lateral protection device. Strength of lateral structural is evaluated by applying perpendicular load at rear most point, center of maximum span and foremost point on Lateral protection device. Virtual validation setup is shown in Figure 14.

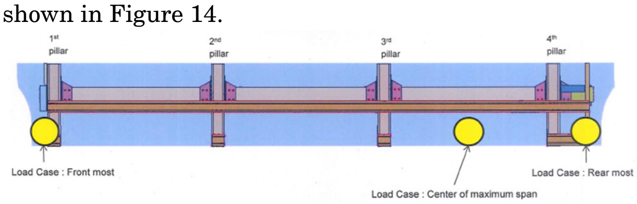

Fig. 14. Test Set-up for Lateral Protection Device.

Test set-up as per standard IS:14682 was carried out and load of 1KN was applied at three locations. Deflection of Lateral protection device was lesser than maximum allowable deflection at all the three loading locations. Aluminium lateral protection device of bus thus met safety aspects as per IS:14682 standards.

Assessment of Modal Vibration Behaviour

AIS:153 regulation mandated for bus application requires compliance of bus structure for modal behavior to safeguard structure and occupant from vibration perspective. Modal natural frequency of the bus structure need to be determined under GVW condition. AIS:153 regulation specifies targets for 1sttorsion and 1st vertical/lateral bending modes. Both these vibration modes should be more than 3Hz and 5Hz respectively.FE model of bus structure was modelled considering weight parameters of engine, transmission, drive train, front and rear axle and suspension. Roof sheets, window glasses, front and rear windshield, handle bars and interior and exterior panels were modelled to capture bus structure mass elastic matrix. Unconstrained modal simulation was carried out and 1st torsion and 1stbending mode frequencywas studied.1sttorsion mode of a bus structure was observed at 5.6 Hz meeting stipulated requirement as shown in Fig. 15.

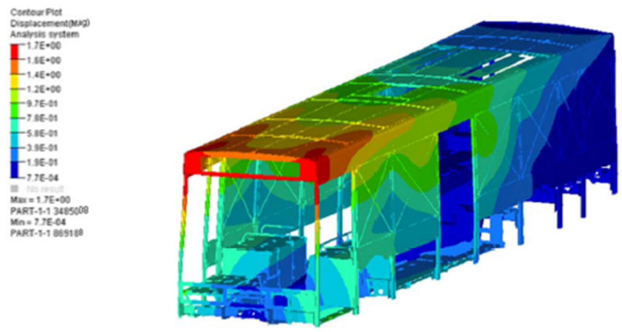

Fig. 15. 1st Torsion Mode of Bus Structure.

1st lateral bending was observed at 7.6 Hz which is well above requirement of 5Hz hence structure meets torsion and bending frequency targets mentioned in AIS:153.

Durability Assessment for Real World Condition

Availability of real world road load data forstrength simulation is vital for strength assessment of any vehicle structure. This time domain data is especially useful for durability assessment of the vehicle, as it captures frequency dependent loading which is more damaging and responsible for fatigue failure of the vehicle structure. In order to have real time load recipe, RLDA was carried out on similar class of bus for different city driving conditions. Typical load events during panic breaking, acceleration/deceleration, cornering, negotiating speed breakers, humps and pot holes were captured using accelerometer sensorsat identified locations. Structural response of bus structure for corresponding road load events was captured using strain gauges at specified locations. Synchronous data measurement was carried out for laden and un-laden condition. Dynamic 'g' values were captured above air suspension, which is the primary load path for bus superstructure. Refer Fig. 16 for vehicle level instrumentation.

Fig. 16. Capturing input 'g' loads above suspension.

Rosette type of stain gauge were pasted on bus structure at identified critical joints of bus structure viz. Cantrail, Waist rail and skirt rail to capture structural response to road load events in terms of dynamic strain data, as shown in Fig. 17.

Fig. 17. Measuring structural strain on bus.

RLDA was carried out with the aim to capture loads from various road types and events. City road, Highway patch, Rough road with uneven undulations, roads with constant gradient, corrugated road patch were part of the road mix during RLDA exercise. Data was captured in real time using accelerometers and then by using FFT algorithm acceleration data was converted to frequency domain. As the nature of load is random in nature, Power Spectral Density (PSD) was used for capturing energy content of loading signal. Fig 18 shows converted PSD for front air suspension in vertical direction.

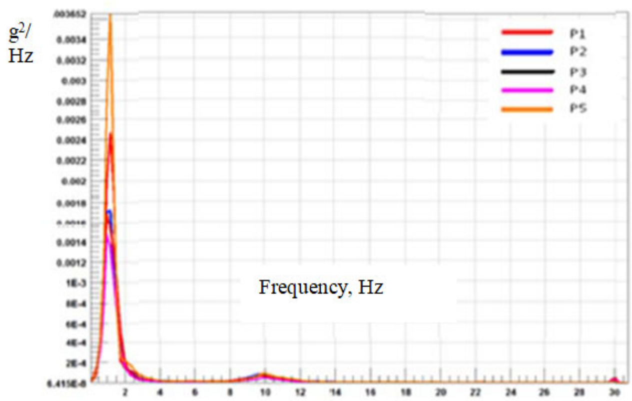

Fig. 18. Load in PSD format for Front Air Suspension.

PSD curve of loading input above suspension shows frequency content of loading excitation for various road types. As the data is measured above sir below, suspension filters out most of the disturbing frequencies however passes very low order excitation. For all type of road types, suspension plays its role by filtering loads with frequencies above 5Hz. Overlay plot of PSD for different road patches shows that loading with only 1Hz excitation are getting transferred through suspension. Similar phenomenon was observed for Rear suspension as shown in Fig. 19.

As the superstructure torsional and bending frequencies are more than 5Hz, the loading excitations has no damaging effect on superstructure strength as modal frequency of bus structure was well above excitation frequency avoiding damage due to resonance condition.

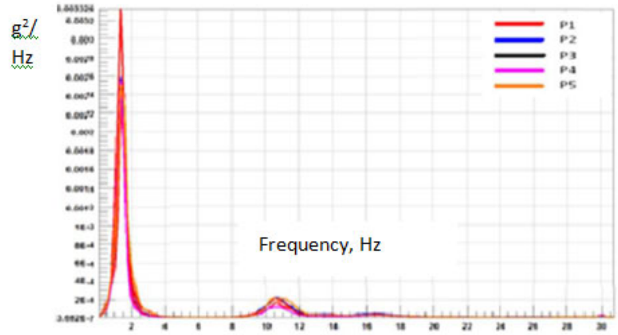

Fig. 19. Load in PSD format for Rear Air Suspension.

Measured accelerations above front and rear suspension alongwith front and rear axle acceleration data is tabulated in Table 4 & 5. Effectiveness of air suspension in reducing acceleration magnitude can be seen from tabulated data for both front and rear side.

TABLE 4

Axle and Suspension Acceleration at Front side.

Front Acceleration (g) --> (Input)									
Chanel Detail	Track	Unladen				Laden			
		Absolute		Range		Absolute		Range	
		Max	Min	Max	Min	Max	Min	Max	Min
FR_AXL_Z	City	9.2	-9.9	18.1	5.8	11.2	-12.5	23.7	5.6
	Rough	20.8	-6.1	21.8	16.4	9.0	-5.8	14.6	12.5
	Track	6.6	-9.9	16.4	11.9	7.2	-9.5	16.4	14.3
FR_AIRB_X	City	0.8	-0.9	1.6	0.5	0.8	-1.0	1.6	0.4
	Rough	1.2	-0.8	2.0	1.2	0.4	-0.4	0.9	0.8
	Track	0.7	-0.9	1.6	1.0	0.6	-0.8	1.5	0.9
FR_AIRB_Y	City	1.4	-1.8	2.8	0.8	2.1	-2.6	4.7	0.5
	Rough	2.2	-1.8	4.0	3.2	0.4	-0.6	1.0	0.8
	Track	0.8	-1.1	1.9	1.8	0.7	-1.3	2.0	0.9
FR_AIRB_Z	City	0.8	-1.8	2.3	1.0	1.4	-1.8	3.2	0.9
	Rough	1.8	-1.8	3.7	1.9	0.6	-0.5	1.1	0.9
	Track	1.2	-0.9	2.0	1.4	0.9	-1.5	2.2	1.3

TABLE 5

Axle and Suspension Acceleration at Rear side.

Rear Acceleration (g) --> (Input)									
Chanel Detail	Track	Unladen				Laden			
		Absolute		Range		Absolute		Range	
		Max	Min	Max	Min	Max	Min	Max	Min
RL_AXL_Z	City	10.2	-10.2	19.0	9.1	12.3	-12.3	24.6	9.7
	Rough	-	-	-	-	6.7	-7.3	14.0	12.9
	Track	10.4	-10.2	20.5	14.6	9.7	-10.8	20.4	9.6
RLF_AIRB_X	City	1.1	-1.2	2.3	0.6	1.3	-1.7	2.7	0.8
	Rough	1.3	-1.1	2.0	2.0	0.8	-0.6	1.4	0.9
	Track	0.9	-1.2	2.1	1.3	1.1	-1.7	2.7	1.7
RLF_AIRB_Y	City	0.9	-1.6	2.1	0.9	1.7	-0.9	2.6	0.6
	Rough	1.6	-1.6	3.2	2.8	0.4	-0.4	0.8	0.7
	Track	0.9	-1.0	1.9	1.0	0.5	-0.5	1.0	0.9
RLF_AIRB_Z	City	2.6	-3.0	5.6	1.4	1.4	-3.2	4.4	1.1
	Rough	2.0	-2.2	4.2	3.0	0.9	-0.8	1.6	1.5
	Track	1.3	-1.2	2.3	1.6	1.4	-1.6	2.7	2.0

Measured RLDA database was useful for future reference and to understand transferred vibration from axle to structure not only in pure magnitude terms but also its frequency content.

Aluminium Bus Prototype Building

Fig. 20 and Fig. 21 shows final prototype images of aluminium super strutured buses.

Fig. 20. Aluminium superstrutured bus prototype - AC.

Aluminium structure with 30% weight reduction compared to steel structure has also shown structural strength worthiness in terms of static, bump loads, rollover, safety, vibration etc. in virtual assessment using FEA technique. With assurance on structural strength, design was freezed and further porotype building activity was carried out.

Fig. 21. Aluminium superstrutured bus prototype - Non-AC.

Bus Proto Validation for NVH & Durability

NVH performance of bus was assessed by subjecting bus porotype for AIS:153 compliance check. Measurements related to noise and vibrations inside passenger compartmentwas carried out as per procedure mentioned in regulatory standard.

- Noise measurement was carried out at below mentioned locations using microphone
  - Driver ear level
  - Middle Passenger ear level
  - Rear Passenger ear level
- Vibration in terms of 'g' were measured at following locations using seat pads
  - Driver seat
  - Middle passenger seat
  - Rear passenger seat
  - Bus floor locations
  - Gangway location
- Operating Condition for measurements were described below:
  - Stationary Vehicle –Engine Idling and speed rev-up
  - Running Vehicle -'D' mode, maximum speed and speed in steps

Acceptance criteria for Noise in the standard is 80 dB(A) and acceptance criteria for vibration is $3 m/s^2$. Aluminium bus prototypes meets regulatory requirements mentioned in AIS:153 standard. Measured values for noise and vibration for bus protos are tabulated in Table 6.

Fig. 22. AIS:153 measurement set-up.

TABLE 6

Measured Noise & Vibration for Aluminium Buses.

	Max Noise, dB(A)		Max Vibration, m/s^2	
	Low entry (rear seat)	SLF (DEL)	Low entry	SLF
Stationary run-up	75.4	76	-	-
Max Speed	68.4	70.4	1.04	1.8
Drive mode	76.7	-	0.82	1.0

For durability assessment of aluminium bus RLDA activity was carried out with the aim of measuring accelerations, strain and additionally dynamic fuel consumption. RLDA was carried out on instrumented bus as shown in Fig. 23.

Fig. 23. RLDA Set-up.

RLDA was performed on City road, Highway patch, Rough road with uneven undulations, roads with constant gradient, corrugated road patch as used for reference bus. Reduced weight of aluminium bus showed marked improvement in fuel economy in both laden and unladen condition as seen from Table 7. Comparison of fuel consumption readings for conventional steel bus and lightweight aluminium bus for same driving cycle shows fuel economy improvement of 8-10% in routine laden condition.

TABLE 7

Fuel Efficiency Improvement Matrix.

Driving Cycle	Fuelconsumption, km/ltr		Fuel economy Improvement
	12m Steel Bus	12m Aluminium Bus	
D-1	1.79	1.97	10%
D-2	1.68	1.82	8%

In fuel saving terms for 1 bus in 1 year, it can be calculated that 3000 liters of fuel saving due to lightweight aluminium structure can be expected with daily running of vehicle between 200- 220 km.

RLDA carried out on aluminium bus was used as reference input for generating loading cycle for accelerated durability load cycle for assessment of bus life at lab level. Fig 24 shows accelerated durability test set-up carried out for single bus section. Multi axis shaker table was used for applying synchronous load data in all the three translational directions and all three rotational directions.

Aluminium Bus Section was subjected to accelerated durability cycle derived from RLDA on MAST. Test was continued for 150 accelerated hours which is equivalent to 1 lakh kilometer of public road as per damage correlation study. Bus section withstands accelerated load without any damage substantiating virtual strength assessment inferences.

Fig. 24. Accelerated Durability Testing.

Conclusion

Aluminium can be effectively used for building light weight buses for typical Indian road application meeting necessary Indian regulatory requirements and providing considerable fuel economy improvement. Aluminium can impart necessary strength to the bus structure addressing necessary strength, safety, noise& durability requirements.

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