Using of Composite Materials for the Rear Axle Housing

Nguyen Thanh Quang, Nguyen Quang Thai, Pham Viet Thanh, and Le Dinh Manh

Abstract The rear axle housing of the truck receives the load directly from the weight of the cargo and the vehicle's mass and causes an indirect load of torque, bending leading to deformation, cracking, and possibly breakage. Truck's rear axle housing are usually made from main materials such as cast steel, welded steel or cast iron. In the general case, stress and strain analysis when is subjected to bending will predict the failure modes for design and manufacturing. Finite element method (FEM) and simulation in Ansys Workbench 2022R1 software were used in this study. Some composite materials are selected to replace the original material to casting and welding technology replace and reduce the overall mass of trucks. The results of stress and strain analysis on 3 types of materials (steel, cast iron, composite) shown that the maximum value of equivalent stress (von-misses), maximum principal stress, and the maximum shear stress. The crack analysis results shown that the maximum value of J-Integral. When replacing composite material compared with the original material, the mass of the rear axle housing was reduced by 54%, and reliability and durability were also improved.

Keywords Steel carbon · Cast iron · Composite · Stress and strain · Mass reduce

1 Introduction

Truck's rear axle is one of the main components bearing weight of cargo and of itself, torques, bending moments and dynamic loads during movement on bumpy roads. The rear axle housing of axle (hereinafter called the rear axle housing) is used

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to support the vehicle's body and to protect components inside such as differential assembly, half shafts, at the same time, to transmit forces and moments from vehicle's wheels to body. The rear axle housing's common damage is warp due to breaking or cracking. Truck's rear axle housing is usually made of steel or cast iron. It is an independent component with big dimensions and mass. Its manufacturing technology continuously combines main casting fabrication and mechanical manufacturing in working machines. The current trend is to reduce mass and manufacturing cost of car's components.

There are different design solutions to reduce mass. The main solution is to reduce the rear axle housing's thickness, but it raises the cost of main casting fabrication and manufacturing. Another solution is lightweight material instead of traditional steel or cast iron. Composite is a popular lightweight material.

The advantage of lightweight material is low cost and less weight [1, 2]. Composite, plastic and polyme are good alternatives for reducing vehicle's weight thanks to high durability, easy to improve aesthetics [3]. An experiment shows that if the vehicle's weight reduces by 10%, then duel consumption decreases by 5–7%, and greenhouse gas (GHG) emissions decreases [4]. In 1970 the average share of composite was 6% of vehicle's weight. The share increased to 16% in 2010. It is forcasted to 18% in 2020, [5]. The use of composite should meet following environmental and safety requirements: Light weight to reduce fuel consumption, increase environmental friendliness; Increasing vehicle's safety by absorbing energy from impacts outside; Reducing manufacturing and running cost to increase economic efficiency; Posibility of reusing, recycling, prolonging working time of components. Therefore, in designing the rear axle housing, it is necessary to calculate suitable technical criteria, such as stress and deformation due to bending or torsion. Since the rear axle housing has complex structure, the common tools can hardly help to calculate. Modern calculating methods can give accurate results and save time. Finite Element Analysis (FE) is a popular method today to calculate 2 states of strength: fatigue strength and breaking strength by static load multiplied by dynamic load coefficient. There are typical works of FE analyzing stress values and equivalent deformation which help determine static strength parameters of rear axle housing [6]. The local stress—deformation analyzing method is a good tool to forecast parts' fatigue life. In a study of fatigue strength, the rear axle housing, made of high resistance alloy, is cyclically bent at 4 points. The simulation uses Smith—Watson—Topper and Fatemi—Socie parameters to investigate fatigue cycle and starting point of fatigue cracks [8].

2 Simulating Rear Axle Housing of Trucks

This study uses Ansys Workbench 2022R1 to analyze the rear axle housing's strength under bending by static load.

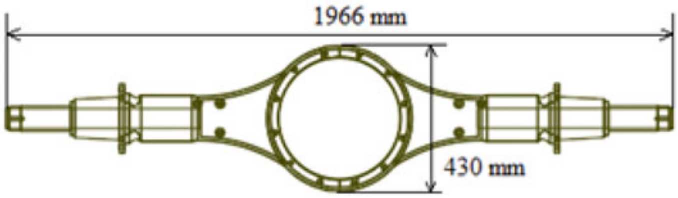

Fig. 1 A truck rear axle housing

2.1 Modeling the Rear Axle Housing

The rear axle housing has complex box shape with average thickness of 10 mm. A 3-D model has been designed according to actual dimensions of a rear axle housing. The dimensions are given in Fig. 1.

2.2 The Rear Axle Housing's Material

The rear axle housing materials are cast steel or cast iron. Some alternatives are composites. The main material parameters are: strength criteria σ, elasticity modulus E and specific mass ρ. The main specifications and strength limits of materials according to SI unit system are given in Table 1, [3, 9].

Table 1 Material properties

Properties	Carbon steel, cast	Cast iron (BS grade Si 10)	Composite PA6/glass fiber
Density (kg/m^3)	7825	7000	1800
Young modulus (Gpa)	203.4	123.9	21.95
Tensile U, Strength (Mpa)	447.9	164.3	396.9
Tensile Y, strength (Mpa)	234.3	164.3	396.9
E/ρ (GPa—m^3/kg), shear stiffness	0.02652	–	0.034
E1/2/ρ (Pa1/2—m^3/kg)—buckling stiffness	58.3	–	116.6
E1/3/ρ (Pa1/3–m^3/kg)—bending stiffness	0.7582	–	1.759

Fig. 2 Rear axle housing's meshing model

2.3 3-D Meshing

The finite meshing model uses quadratic 4-node elements. Finer meshing needed in bending corners, where would be more stress. The element's size is 6 mm. Free meshing method assures meshing flexibility in bending areas or complex shapes. The degrees of freedom are determined by the nodes. There are 3 degrees of freedom per node, i.e. there could be movement to x, y, z direction. Use quality checking function to optimize the mesh. There are 139,122 elements and 245,084 nodes. The meshing model is shown in Fig. 2.

2.4 Load Conditions and Boundary

The load impacts to rear axle housing at 4 points A, B, C, D. Load from cargo and vehicle's body impacts to 2 points C and D and at dampers. Reaction forces impact to wheels and axle at 2 point A and B, Fig. 3.

Forces acting to the rear axle housing at any area are determined by formula (1)

$$P_{cr} = \frac{\pi^2 EI}{L^2} \tag{1}$$

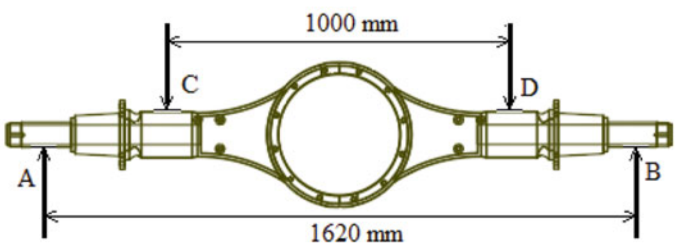

Fig. 3 Drawing of forces placed to rear axle housing

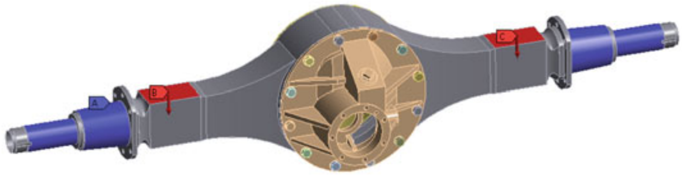

Fig. 4 Model of load placing and boundary conditions

Here: Pcr is the force acting to vertical direction (kG). E is elastic modulus (Young's modulus—GPa). I is the 2nd moment of inertia at area of force placing (m4). L is the length of the rear axle housing—distance of force placing (m).

The rear axle housing's mass according to load Pcr is calculated by formula (2)

$$M = \frac{2L^2\sqrt{P_{cr}}}{\sqrt{\pi}} = \frac{1}{\sqrt{E/\rho}} \tag{2}$$

M is the rear axle housing's mass (kg). ρ is the specific mass (density) of the rear axle housing's material (kg/m^3).

Parameter E/ρ is a strength criteria shown in Table 1. In designing, criterias should be checked in following order: (1) E/ρ; (2) (R0.2)1/2/ρ; (3) (E)1/3/ρ; (4) R0.2/ρ; (5) E1/2/ρ; (6) R0.21/3/ ρ.

Parameter R0.2 is the minimum yield strength [10].

Considering the symmetrical full load of 7200 kg evenly distributed on positions C and D. Positions A and B are boundary surfaces of the model. Force placing and boundary are shown in Fig. 4.

3 Simulating and Analyzing Results

3.1 In Case of Static Load

Under static load, the 2 reducing positions, connected with hubs, are subjected to the greatest stress. Here, the dangerous cross section has maximum stress of 21.81 Mpa. Figure 5 illustrates simulating the rear axle housing's stress in case of symmetrical static load. Figure 5a–c illustrate maximum stress in dangerous cross sections.

Results of simulating stress on the rear axle housing according to different materials are shown in Table 2.

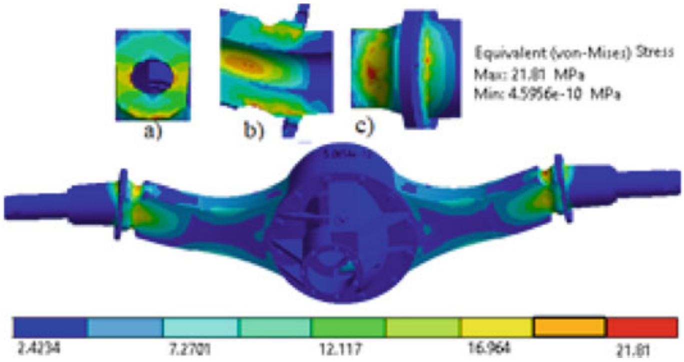

Fig. 5 Distribution of maximum stress in dangerous cross sections

Table 2 Results of simulating maximum stress on the rear axle housing

No.	Parameters	Carbon steel	Cast iron	Composite PA6	Difference (%)
1	Max. stress (MPa)	21.81	22.319	25.602	(+) ~ 15
2	Mass (kg)	144.16	133.54	66.813	(−) ~ 54

3.2 In Case of Load Changes

During running, load acting to the rear axle housing can change according to bumpy level of road surface. We consider sinusoidal road surface. Acting force frequency of 130 Hz is divided into 10 survey intervals. Dephasing between left and right load causes rear axle housing's bending and torsion. Load magnitudes and phase angle are shown in Fig. 6.

The simulation gives equivalent stress values in the rear axle housing using cast steel and composite materials. Stress values according to different frequencies of acting loads are shown in Table 3 and Fig. 7. In cast steel rear axle housing, the

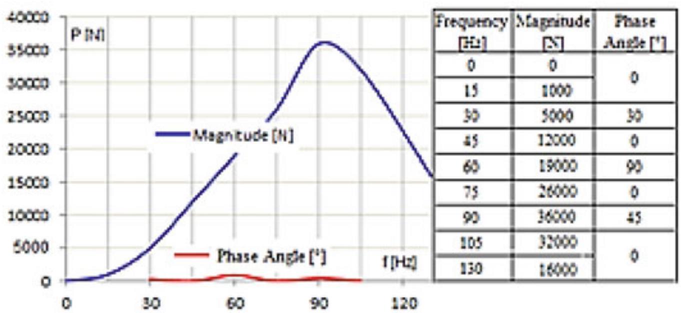

Fig. 6 Load acting to the rear axle housing

maximum stress is 169 Mpa. In composite rear axle housing, the maximum stress is 292.34 Mpa. As the results, the composite rear axle housing has greater maximum stress than that in cast steel rear axle housing.

Figure 9 shows the distribution of rear axle housing's stress in case of load changes.

Table 4 compares maximum stress in case of load changes and that of static load. During running in bumpy road with asymmetrical load, the maximum stress is many times bigger.

Table 3 Stress in the rear axle housing according to acting load frequencies

f (Hz)	26	39	52	65	78
Steel carbon	1.10E+01	2.12E+01	3.77E+01	6.28E+01	9.95E+01
Cast iron	1.3857	3.4605	4.2666	6.0981	11.318
Composite	0.53902	1.3696	1.7292	2.8286	6.4627

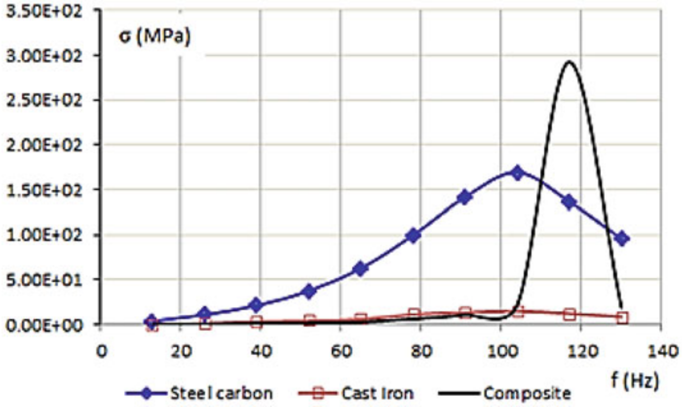

Fig. 7 Rear axle housing's stress

Table 4 Comparing maximum stress in 2 cases

		Carbon cast steel	Cast iron	Composite PA6/Glass fiber
1	Static load	21.81	22.319	25.602
2	Changing load	169	14.96	292
	Difference	129%	67%	**87**

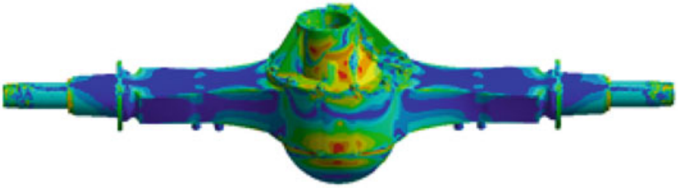

Fig. 8 Model of rear axle housing's fatigue analysis

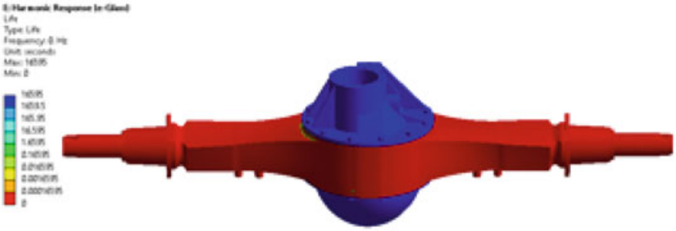

Fig. 9 Distribution of fatigue cycles in the rear axle housing

4 Analyzing Fatigue Cycle

Fatigue analysis uses fatigue tool in the software. Marginal and load conditions are used in case of load changes. Goodman theory, which analyzes equivalent stress, is used to determine cycle life. Figure 8 shows image of simulating fatigue analysis.

The number of fatigue cycles in maximum stress areas is different in rear axle housings using the 2 materials. In steel rear axle housing, there are 7692 cycles. In cast iron rear axle housing, there are 7898 cycles. In composite rear axle housing, there are 16,595 cycles. Green area shows infinite number of cycles.

5 Conclusion

The research analyzes the use of composite material, instead of cast steel and cast iron, for rear axle housing. In the results, the mass can reduce by 54% (144.16/133.54/66.813 kg). The rear axle housing's maximum stress increases by 15% (21.81/22.319/25.602 MPa). Using composite, the rear axle housing's hardness reduces but the number of fatigue cycles increases: 7692 cycles in cast steel rear axle housing, 7898 cycles in cast iron rear axle housing, 16,595 cycles in composite rear axle housing. Therefore, composite material creates double strength, compared with cast steel and cast iron.

Finite element method (FEM) and simulating in Ansys Workbench 2022R1 help to analyze equivalent stress (von-Mises) and determine the rear axle housing's flexural rigidity. Using composite, it is necessary to improve both axle's side, where is concentrated stress, to increase the rear axle housing's reliability and durability.

Material with core of Epoxy E-Glass, which is used popularly thanks to its simple technology, is suitable for experiments and low cost manufacturing.

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