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Lightweight Design of Front Axle Structure of A Certain Type of Automobile

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Abstract

In this paper, the front axle of a certain model is taken as the research object, and the stress and deformation of the front axle under three typical working conditions are analyzed by finite element technology.Based on the simulation results, the 3D model of the front axle was optimized, and the finite element analysis of the optimized structure of the front axle under three typical working conditions was carried out to verify the correctness of the model.Finally, the fatigue tool module of ANSYS Workbench was used to analyze the fatigue life of the front axle under the optimized emergency conditions, and the feasibility of the model was verified.The analysis data shows that the design of the front axle components still has a lot of potential for lightweighting, and the weight of the front axle can be reduced by 6.73% through optimization, and the performance of the front axle can also meet the needs of use.The research conclusion has a certain reference value for the lightweight design of automobile front axle.

Keywords: *automobile front axle; structural optimization; Fatigue life*

1 Introduction

As the number of private cars continues to rise, the consumption of gasoline and its dependence on oil is also increasing, which is also leading to the increasing problem of global warming. To alleviate this, governments around the world have introduced a series of policies to limit energy efficiency and pollutant emission standards for vehicles, putting pressure on automakers. The automotive industry must continue to strive to improve its technological capabilities and develop more high-quality and environmentally friendly new automotive products.

The front axle, which is the majority of the weight of the front axle assembly, is mainly loaded at the leaf spring seat and kingpin, while the I-beam in the middle is subjected to relatively little stress. Since these areas do not use the material to its full potential, there is a huge possibility of reducing the mass. As an important part of the vehicle's suspension system, the mass reduction of the front axle can lead to more significant energy savings and emission reductions, as well as improve the operating efficiency of the whole vehicle. It is also a vital safety device in a vehicle, and it has strict requirements for its mechanical properties. In addition, the design and construction of the front axle is quite complex, and it needs to cope with various potential risk driving environments, which makes the structural lightweight not only need to meet the stability requirements under heavy loads, but also adapt to the durability standards under low load conditions. For the front axle, lightweighting is therefore an optimization task with multiple objectives and involves a complex structural design process. Thanks to the development of finite element technology and calculation tools, it has been possible to effectively optimize and interpret structural characteristics, thereby significantly reducing the development time and cost of products.The schematic diagram of the structure of the integral front axle of an automobile is shown in Figure 1.

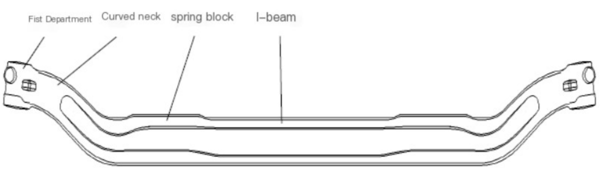

Figure 1 Schematic diagram of the front axle structure of the automoile

Due to its complex front axle construction and operating environment, the front axle of a vehicle must be high strength and durability, which often relies on the expertise of the designers and the results of extensive experimental testing. This traditional way of building is time-consuming and expensive, resulting in slow new product development and weak performance improvements. To address these challenges, a lightweight

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simulation model of the front axle architecture was created using the finite element method, and its physical properties under various operating conditions were explored in depth, and then the architecture was optimized and its fatigue life was verified. Through this study, the problem of lightweight design and reliability evaluation of front axle structure is effectively solved, which provides important value for practice.

2 Finite Element Analysis of a Front Axle in a Car

2.1 Finite element model construction

The front axle model JT-TR01 is studied in this paper, and the 3D model of the front axle is established by Solidworks and imported into ANSYS Workbench software, as shown in Figure 2:

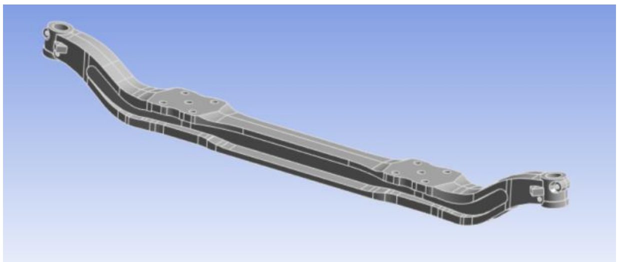


Figure 2 Finite element analysis model of the front axle

The main material of the front axle is 42CrMo, and the main parameters are shown in Table 1:

Table 1 Front axle material properties

Material	42CrM
Density	7900kg/m^3
Elastic modulus	206000MPa
Yield Limit	930MPa
Strength limit	1080MPa
Poisson's ratio	0.3

The front axle was meshed using ANSYS Workbench with a mesh size of 10 mm with a total of 113,190 elements and 175343 nodes, as shown in Figure 3.

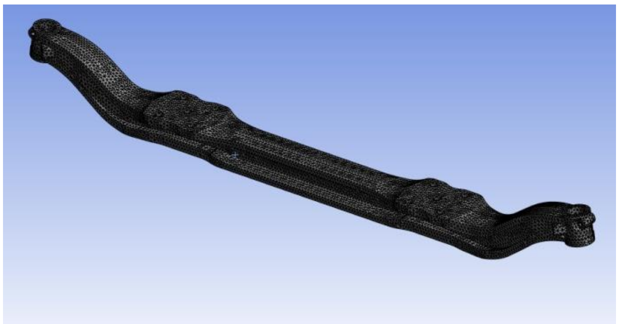


Figure 3 Meshing result graph

2.2 Finite element analysis of the front axle of a car

2.2.1 Finite element analysis under emergency braking conditions

In the event of an emergency braking of the car, the front axle will be subjected to the increased vertical load due to the forward movement of the overall center of mass and the horizontal load caused by the braking forces of the road surface. These vertical loads are applied to the leaf spring face of the front axle, while horizontal loads are applied to the bolt mounting holes of the leaf spring face.

By setting intrinsic constraints within the kingpin bore and implementing vertical loads on the two leaf spring faces, these loads are evenly distributed across the two leaf spring faces of the entire front axle. A lateral load is also set in the ten screw holes on the front axle, which is also evenly distributed to each screw hole. The braking condition of the front axle is shown in Figure 4 as a loading boundary condition.

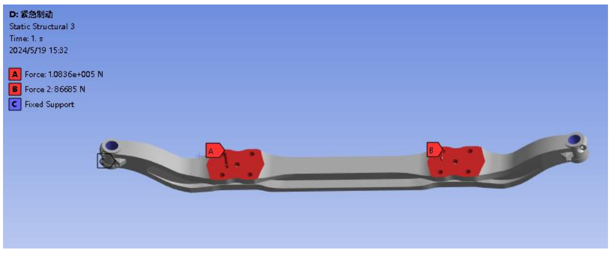


Figure 4 Load boundary conditions for emergency braking conditions

As shown in Fig. 5, when the vehicle is subjected to a sudden braking action, the main deformation of the front axle occurs in the middle part of the vehicle, and the most significant change occurs in the rear side area located at the top of the I-beam. In addition, it is found that the deformation at the top of the front axle is greater than that at the bottom, and the increase in deformation moves from the top to the bottom of the I-beam. Full constraints are set in the kingpin hole of the front axle, so the deformation of this part is relatively small; As you get closer to the kingpin hole, the deformation increases to a maximum of 2.74 mm and is concentrated in the center of the front axle.

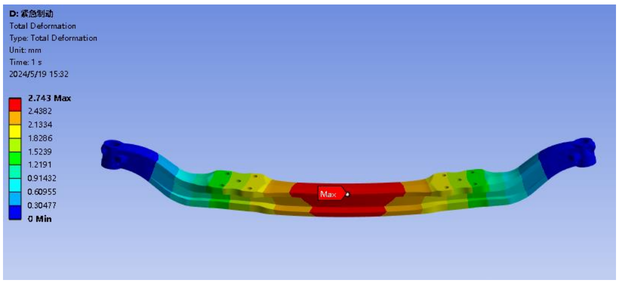


Figure 5 Contour of front axle deformation under emergency braking conditions

As shown in Fig. 6, in the middle of the front axle, the main bending stress of the I-beam is mainly concentrated in the boundary area of the fenders on both sides of it. Because the bolt holes on the leaf spring of the front axle contain the transverse load, the stress of the fender on the front axle is greater than that of the lower fender, and the boundaries of the front and rear sides of the fender on the front axle have significant bending stresses, while the tail end of the lower fender has obvious bending stress, and the bending stress distributed at the web of the I-beam is the smallest. The most serious bending stress on the front axle reaches 355.5 MPa, but this value is far less than the compressive limit of 42CrMo of 930 MPa, so the safety performance of the front axle can be guaranteed in the case of hard braking.

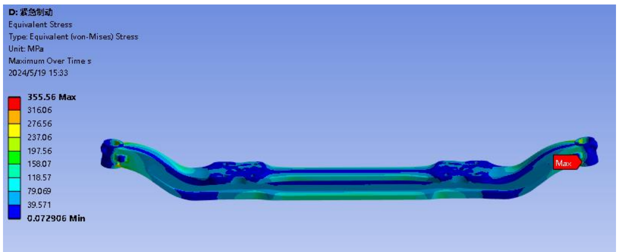


Figure 6 Front axle stress contour under emergency braking conditions

2.2.2 Finite element analysis under uneven pavement conditions

When a car crosses an uneven road, the front axle is mainly subjected to vertical impact loads from road impacts, which act on the leaf spring surface in an evenly distributed manner.As shown in Figure 7, vertical impact loads are applied evenly on the two leaf spring surfaces of the front axle so that these loads are evenly distributed to the two leaf spring faces of the front axle. Full constraints are placed at the kingpin holes of the front axle to prevent its displacement.

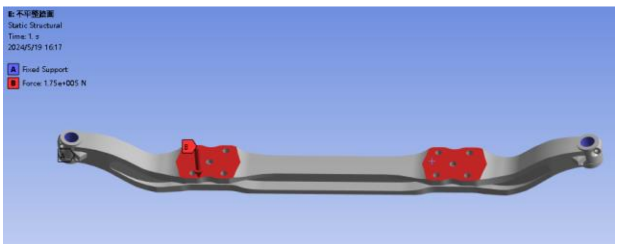


Figure 7 Load boundary conditions for uneven pavement conditions

The stress and deformation of the front axle are obtained through simulation analysis, as shown in Fig. 8 and Fig. 9. Looking at these images, it can be seen that the deformation of the center of the front axle is most pronounced during the bumpy road section, and the degree of deformation exceeds that of the front axle when it is only subjected to the heavy braking load. Compared with the front axle, which independently receives the vertical impact force, this part shows a more balanced deformation state when dealing with the lateral impact force, and on the whole, the deformation of the central area is larger, while the two sides are relatively small, and the most significant deformation occurs in the middle of the front axle, which is about 1.26 mm.When the front axle is subjected to shock loads, the bending stress generated by the upper part of the I-beam in the middle is relatively small, and it is also relatively small on the leaf spring surface of the front axle. The lower wing of the I-beam of the front axle generates large and concentrated bending stresses, especially in the web area, which even exceed the bending stress of the upper wing. The overall bending stress of the front axle reaches a maximum of 201.7 MPa, but this is far less than the stress yield limit of 930 MPa for this material, so the safety performance of the front axle is guaranteed during driving under such non-uniform road conditions.

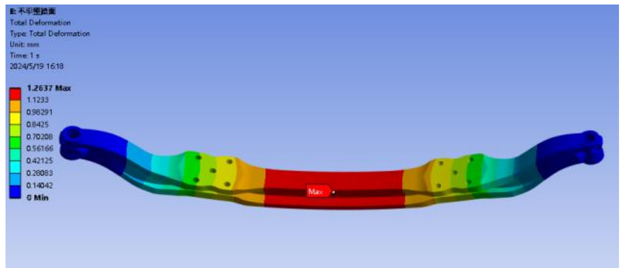


Figure 8 Front axle deformation contour under uneven pavement conditions

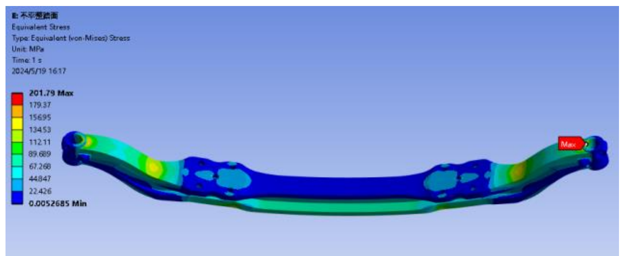


Figure 9 Front axle stress contour under uneven pavement conditions

2.2.3 Finite element analysis in sideslip conditions

When the car slips sideways during rotation, the left and right leaf springs of the front axle produce a change in the vertical load. The lateral forces exerted by the ground on the wheels subject the front bearing to lateral forces, which are stored in the bolt holes of the front axle in an evenly distributed manner.As shown in Figure 10,the vertical load on the front bearing is distributed to the leaf spring surface of the front axle on both sides of it, and the lateral forces due to inertia and acting on the leaf spring surface of the front axle should be taken into account, which should be achieved by distributing it to the bolt holes on the leaf spring surface on both sides of the front axle. Set full constraints in the kingpin hole on the front axle.

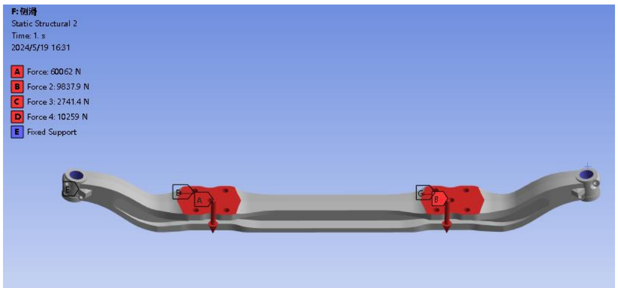


Figure 10 Load boundary conditions for sideslip cases

As shown in Fig. 11, when the vehicle is in a side-slip state, the left and right leaf spring surfaces of the front axle need to bear a new vertical load distribution, which makes the deformation of the front axle show an asymmetrical change, which is more obvious than the equilibrium form in the previous two working conditions. The maximum measure of the bending deformation of the front axle is 0.57 mm, mainly from the leaf spring surface in the left half of the front axle to the middle of the I-beam.

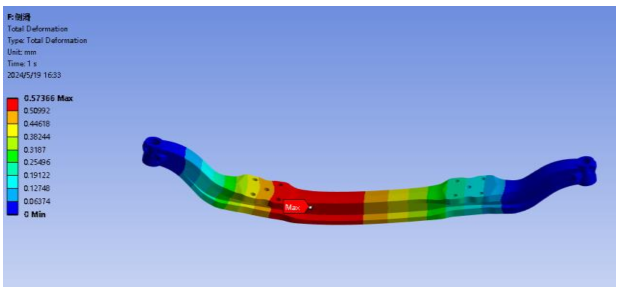


Figure 11 Deformation contour of the front axle under the side-slip condition

As shown in Figure 2, if the vehicle skids, the axle on the left side of the front wheel is subjected to significantly greater bending stress than on the right part of the front axle, and this stress is more concentrated. In this case, the maximum bending stress on the front axle is 199.71 MPa, but this is also much less than the compressive limit of 930 MPa for this material, which occurs in a circular opening area near the bottom of the kingpin hole. Therefore, in the sideslip state, the safety performance of the front wheels is guaranteed.

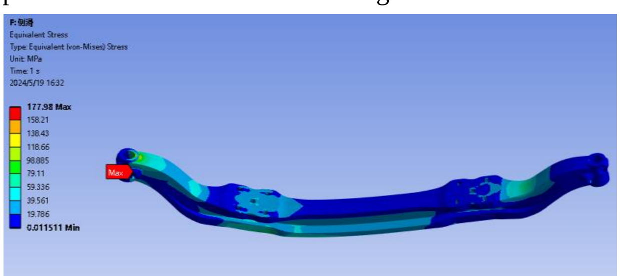


Figure 12 Front axle stress contour under sideslip conditions

Table 2 Maximum stress and maximum deformation for three operating conditions

Operating conditions	Maximum stress/ MPa	Maximum deformation/ mm
Emergency braking	355.5	2.74
Uneven pavement	201.7	1.26
Sideslip	199.71	0.57

As shown in Table 2, the maximum stress and maximum deformation of the three typical working conditions, the maximum stress is less than the compressive limit of 42CrMo material 930MPa, which meets the requirements, and the data in the table can also understand that under the emergency braking condition, the stress and deformation are the largest, so in order to ensure the safety of the structure, the topology can be optimized for the load of the emergency braking condition.

3 Lightweight Design of the Front Axle of The Car

3.1 Lightweight design of the front axle

After completing the stiffness evaluation of the front wheel in three working states, it was found that it bears the maximum stress under emergency braking. Therefore, the simulation results of front axle deformation and stress under emergency braking conditions were input into the ANSYS Workbench structural optimization tool. The optimization goal was set to retain 60% of the front axle mass. The restricted and optimized areas are shown in Figure 13, and the optimization parameter settings are shown in Figure 14.

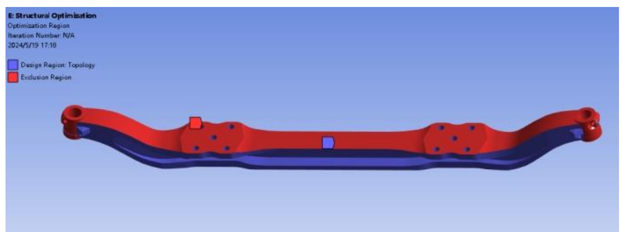


Figure 13 Optimize regional constraints

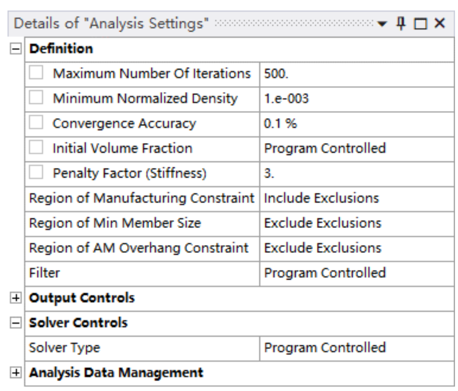


Figure 14 Optimize parameter settings

As shown in Figure 15, when the vehicle is in an emergency braking state, the topology optimization of the front axle focuses on the web plate of the I-shaped crossbeam in its central part, and the optimization adjustment of the front wheel structure is completed by drilling three holes. Based on the strength assessment under emergency braking conditions, the grid constructed is used as the basis. The optimization calculation of ANSYS Workbench produces the results of the front axle, which is an ideal state and can provide guidance for the design and optimization of the front wheel model. However, the specific optimization strategy must take into account the manufacturing costs and costs in reality. Based on the optimization results, the front axle model is modified on SolidWorks, and the optimized model is shown in Figure 16. By comparing the quality of the model before and after optimization, a total weight reduction of 6.73% was achieved in this structural optimization.

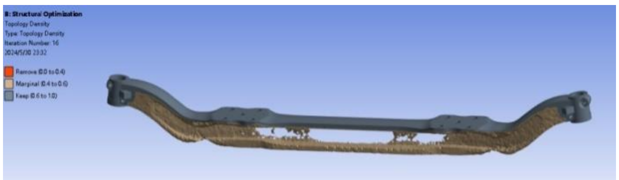


Figure 15 Front axle topology optimization results under emergency braking conditions

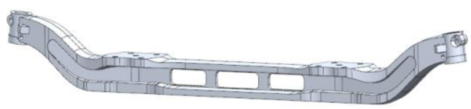


Figure 16 Optimized 3D model

3.2 Static analysis of the optimized front axle

3.2.1 *Finite element analysis under emergency braking conditions*

As shown in Figures 17 and 18, it can be seen that the main bending deformation of the front axle occurs in its middle part, while the part around the main pin hole is relatively stable. As it gets closer to the main pin hole, the degree of deformation gradually increases to a maximum value of 2.76mm, which mainly occurs in the central area of the front axle.In the middle of the front axle, the bending stress borne by the I-beam is mainly distributed at the edges of the upper and lower fenders. The maximum bending stress value reaches 380 8MPa, which is much lower than the yield strength of the material, makes the front axle safe in emergency braking conditions.

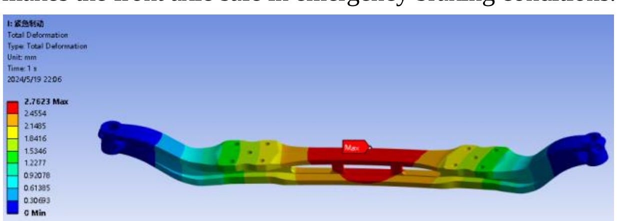


Figure 17 Cloud map of front axle deformation under emergency braking conditions

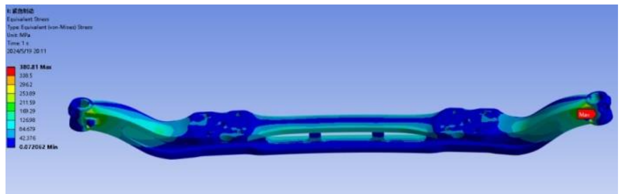


Figure 18 Front axle stress cloud map under emergency braking conditions

3.2.2 Finite element analysis under uneven road conditions

As shown in Figures 19 and 20, it can be observed from the images that during the process of vehicles crossing uneven roads, the deformation degree of the middle part of the front axle is the most significant, with a larger deformation in the central area and smaller deformation on both sides as a whole. The deformation of the upper and lower ends of the front axle is roughly the same, and the deformation of the entire front axle is very regular.

The most obvious deformation is located in the middle of the front axle, with a size of approximately 1.28mm. Under the impact load, the peak bending stress of the front axle reaches 204 1MPa mainly occurs on the cross-section at the connection between the main pin hole and the circular arc segment. This value is much lower than the yield strength of the material of 930MPa. Therefore, even in uneven road conditions, the front axle is still safe.

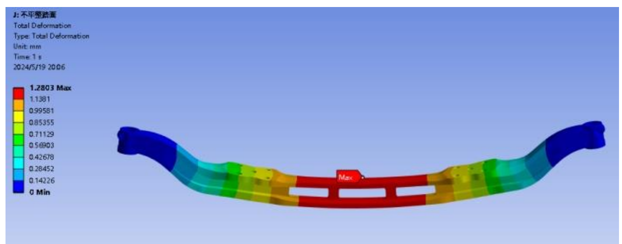


Figure 19 Cloud map of front axle deformation under uneven road conditions

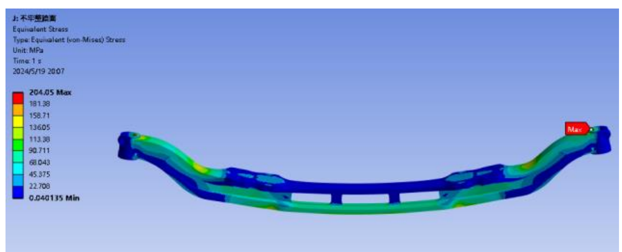


Figure 20 Front axle stress cloud map under uneven road conditions

3.2.3 Finite element analysis under lateral sliding conditions

The simulation analysis shows the stress and deformation status of the front wheel, as shown in Figures 21 and 22. Observing the images, it can be seen that when the vehicle slides to the right during rotation, the maximum bending deformation of the front axle reaches 0.72mm, mainly concentrated in the area from the leaf spring surface on the left side of the front axle to the front crossbeam in the middle.

In the case of a car rotating and experiencing sideslip, the distribution of bending stress on the axle is generally similar to the distribution of bending deformation on the front axle. In this case, the maximum bending stress reached 210.9 MPa, which is much lower than the compressive limit value of 930 MPa for this material. This stress is mainly concentrated in the circular area below the main pin hole and at the edge of the front axle. So, in this situation, the front wheel safety performance is good.

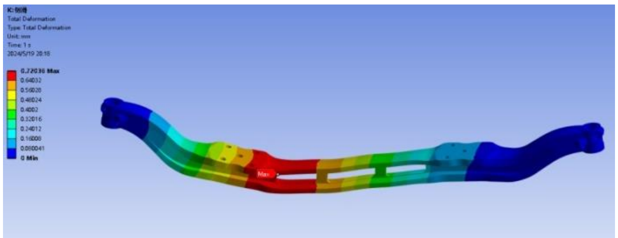


Figure 20 Cloud map of front axle deformation under sideslip condition

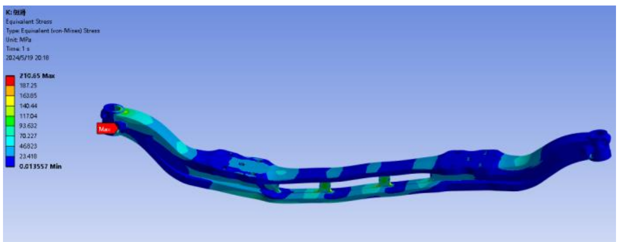


Figure 21 Front axle stress cloud map under sideslip condition

3.2.4 Analysis of stress-strain situations under various working conditions

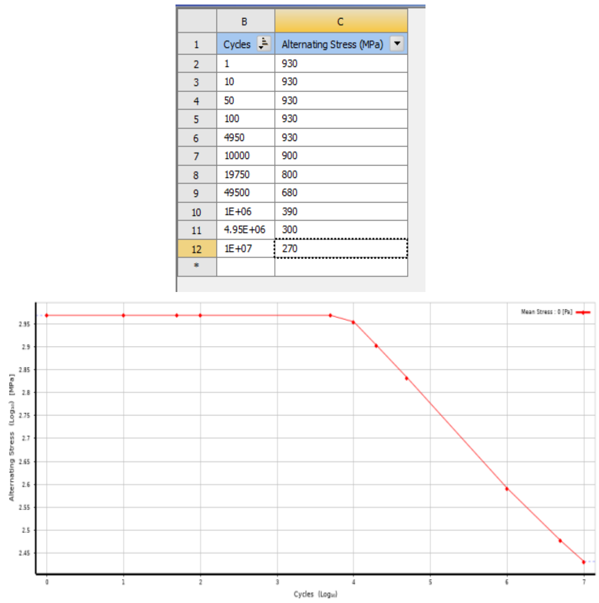
As shown in Table 3, the maximum stress and deformation of the optimized front axle under three typical working conditions are shown. The maximum stress is 380.8 MPa under emergency braking, which is less than the compressive limit of 930 MPa of 42CrMo material. This meets the requirements and verifies the feasibility of the optimized model.

Table 3 Maximum stress and maximum deformation under three working conditions

Operating conditions	Maximum stress/ MPa	Maximum deformation/ mm
Emergency braking	380. 8	2.76
Uneven pavement	204. 1	1.28
Sideslip	210.9	0.72

4 Fatigue Life Analysis of Automotive Front Axles

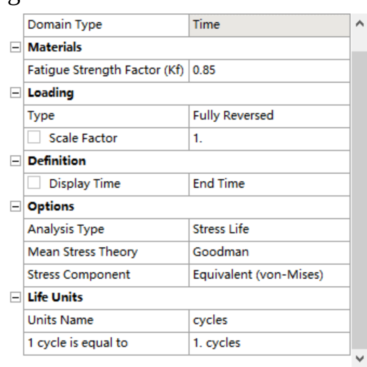
Usually, fatigue life research is based on the results of finite element simulation, extracting stress or deformation stress charts from key parts of the structure, then statistically analyzing these charts, and finally evaluating the life based on the fatigue characteristics and damage principles of the structural material. Figure 22 shows the S-N curve of 42CrMo material in ANSYS.



	B	C
1	Cycles	Alternating Stress (MPa)
2	1	930
3	10	930
4	50	930
5	100	930
6	4950	930
7	10000	900
8	19750	800
9	49500	680
10	1E+06	390
11	4.95E+06	300
12	1E+07	270
*		

Figure 22 S-N curve of 42CrMo material in ANSYS

According to the results of strength finite element analysis under three different working conditions before and after optimizing the weight of the front axle, it was found that the weight optimization of the front axle resulted in the maximum factor under emergency braking conditions. Therefore, the Fatigue Tool module of ANSYS Workbench was used to conduct fatigue analysis on the front axle under emergency braking conditions. The parameter settings of the analysis interface are shown in Figure 23.



Domain Type	Time
Materials	
Fatigue Strength Factor (Kf)	0.85
Loading	
Type	Fully Reversed
Scale Factor	1.
Definition	
Display Time	End Time
Options	
Analysis Type	Stress Life
Mean Stress Theory	Goodman
Stress Component	Equivalent (von-Mises)
Life Units	
Units Name	cycles
1 cycle is equal to	1. cycles

Figure 23 Fatigue Tool Analysis Interface Settings

According to the fatigue life assessment results shown in Figure 5.5, it was found that the maximum stress point corresponds to the lowest fatigue life. The optimized value is approximately 4.72 x 105 cycles, which is greater than low cycle fatigue by 1 x 105 and is within a reasonable range.

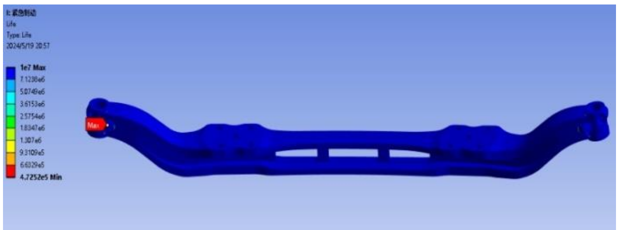


Figure 24 Cloud map of fatigue life analysis after front axle optimization

5 Conclusion

This article takes the TR01 front axle as the main object and creates its finite element model. A thorough exploration and finite element analysis were conducted on the possible loads and their application methods that the front axle may face under three typical working conditions: emergency braking, sideslip, and uneven road conditions, in order to obtain the stress and deformation values generated by the front axle under these conditions. The following conclusions can be drawn:

(1) In emergency braking and vehicle crossing rough roads, the load and direction of force borne by the front wheels are relatively balanced, so the stress and deformation simulation data on both sides also show consistent distribution characteristics. When the vehicle deviates from its trajectory, the main part of the stress and deformation simulation data of the front wheel will appear on the left spring I-beam, and the stress of the front wheel in these three cases is far lower than the yield strength value of the material.

(2) Optimization design of the front axle.Given that the topology optimization of the front axle under emergency braking mainly occurs in the web area of the middle I-beam, in this case, the topology optimization strategy of the front axle is to excavate three holes at the middle web position.

(3) To evaluate whether the minimum fatigue life of the optimized front axle meets the requirements, the finite element modeling of the optimized front axle parts can be re imported into the static analysis module to calculate the stress levels under three working states. It was found that the stress generated by the optimized front axle under these three conditions is significantly lower than the yield stress value of its material; And compared it. After optimizing the fatigue life of the front axle, the simulation results show that the minimum fatigue life of the optimized front axle meets the requirements.

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