Lightweight Design of the Vehicle Suspension Control Arm

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Keywords: Control Arm, Lightweight, Structural optimization.

Abstract: The restraint relationship of the lower control arm of McPherson suspension under extreme conditions is studied. The strength, stiffness and free mode of the control arm are analysed by using the finite element software ANSYS. The structure optimization of the control arm is carried out. The results show that the lightweight reduces by 0.5KG. Finally, the comprehensive effect of the lower control arm using advanced high strength steel is better than that of aluminium alloy.

1 INTRODUCTION

Automobile lightweight is the design of reducing structure quality based on guaranteeing strength and stiffness. At the same time, economy should be considered comprehensively. Lightweight design includes structural design and selection of lightweight materials. Lightweight can not only improve the power performance of automobiles, but also improve fuel economy, control stability and collision safety. The data show that if the vehicle weight is reduced by 10%, the fuel efficiency can be increased by 6%-8% (Mitchell, Erik T, 2018). For every 100 kg reduction in vehicle quality, the fuel consumption of 100 km can be reduced by 0.3-0.6 liters. At present, due to the need of environmental protection and energy saving, lightweight automobile has become the trend of world automobile development.

The lower control arm of McPherson suspension is one of the most important parts of the whole suspension system. It is mainly composed of spherical hinges, bushing and control arm, which transmits the force and moment acting on the wheel to the body (Zhang Z, Chen R, Zhongming X U, et al, 2017). In the process of vehicle movement, especially in the complex and harsh road conditions, the impact of road surface irregularity is transmitted to the body through wheels and lower control arms. It not only bears all kinds of forces and moments, but also requires the strength, rigidity and fatigue life of the control arm. At the same time, the lower control arm has a direct impact on the vehicle's maneuverability and comfort (Ragab K A, Bouaicha, A, Bouazara, M, 2017).

2 ANALYSIS OF LOWER CONTROL ARM

2.1 Static Load Acquisition under Limit Conditions

The three supporting points of the lower control arm are referred to as A, B and C respectively. As shown in Figure1.

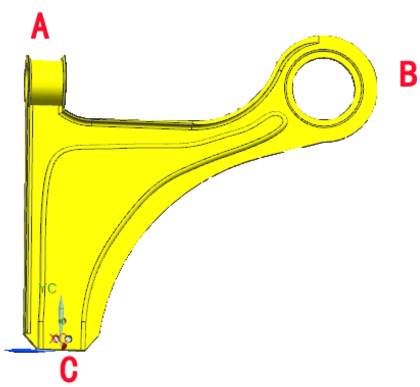

Figure 1. Three Connection Points of Lower Control Arm.

Zhao, H., Chen, Y. and Liu, X.
Lightweight Design of the Vehicle Suspension Control Arm.
DOI: 10.5220/0008849300210025
In *Proceedings of 5th International Conference on Vehicle, Mechanical and Electrical Engineering (ICVMEE 2019)*, pages 21-25
ISBN: 978-989-758-412-1

Table 1. This caption has one line so it is centered.

Connection point	Load(N)	Accelerated forward	Forward braking	Steady left turn	Steady right turn
A	*Fx*	1035	-1745	-37	410
	Fy	-6365	12798	1763	-9833
	Fz	568	-1061	-132	818
B	*Fx*	3777	-8405	-243	2708
	Fy	5823	-12306	-347	3785
	Fz	-279	477	23	-159
C	*Fx*	-4814	10167	280	-3121
	Fy	541	-474	-1414	6045
	Fz	-261	612	137	-631

Among them, A and B are connected to the sub-frame with rubber bushing, and C is connected to the steering knuckle with spherical hinges (Heo S J, D. O. Kang, J. H. Lee, et al, 2013).

In this paper, the whole vehicle dynamics model built by ADAMS of an enterprise is used for reference. According to the design criterion of the enterprise, the strength analysis basis of four representative connection points to the lower control arm is calculated based on the given height and quality of the center of mass, classical formula of automobile theory and dynamic equation of automobile suspension. The linear mechanical parameters of four typical working conditions are simulated. As shown in Table 1:

2.2 Strength and Stiffness Analysis

Because the force on the lower control arm of the suspension is complex in the actual movement of the vehicle. Often multiple forces and moments coexist at the same time. Among the four commonly used strength theories in material mechanics, the third and fourth strength theories of classical material mechanics are closest to the lower control arm. The steel of the original lower control arm is QSTE450, which belongs to plastic yield material and has medium performance index in high strength steel. Yield failure is one of the most important failure failures of the lower control arm of McPherson suspension, because it does not refer to the effect of the second principal stress. So the fourth strength theory is more theoretical basis for composite calculation. Therefore, the fourth strength theory is used to evaluate the mechanical properties of the original control arm.

Stress nephograms under four extreme conditions are shown in Figure 2-5.

According to the finite element analysis of four kinds of simulation under extreme conditions, the worst condition is forward braking, and its maximum stress value reaches 420 MPa. The maximum stress is mainly concentrated in the first rivet-Y direction. Understanding the stress distribution of the control arm under extreme conditions can provide a reference for lightweight drilling and weight reduction.

3 LIGHTWEIGHT DESIGN OF LOWER CONTROL ARM

3.1 Structure-based Lightweight

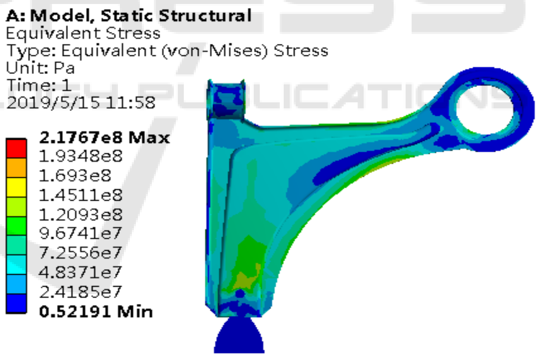

Figure 2. Accelerated Forward.

In the light-weight design, this paper mainly adopts the way of drilling and lightweight. According to the results of stress analysis of four representative working conditions mentioned above, it can be concluded that the working condition of forward braking is the worst. Therefore, structural optimization and lightweight are also optimized based on the stress analysis results of forward braking. In most areas where the stress value is small, we can drill lightweight holes. The regions with large stress values can be strengthened to reduce the regions with large local stress values. At the same time, the minimum safety factor is minimized as much as possible. In the original and optimized strength and stiffness analysis results, the optimized performance can not be much worse than the original. Before and after structural optimization, as shown in Figure 6-7.

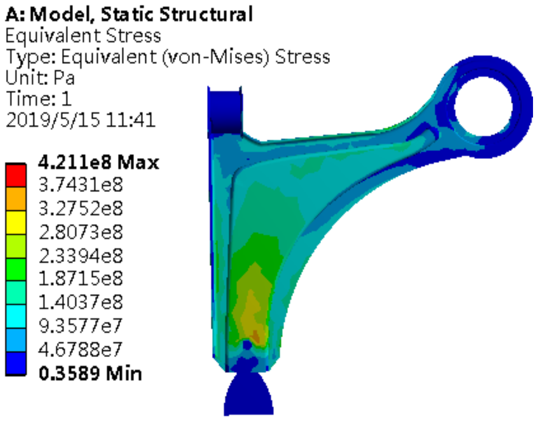

Figure 3. Forward Braking.

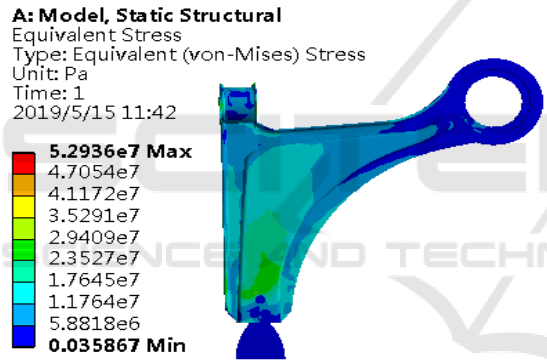

Figure 4. Steady Left Turn.

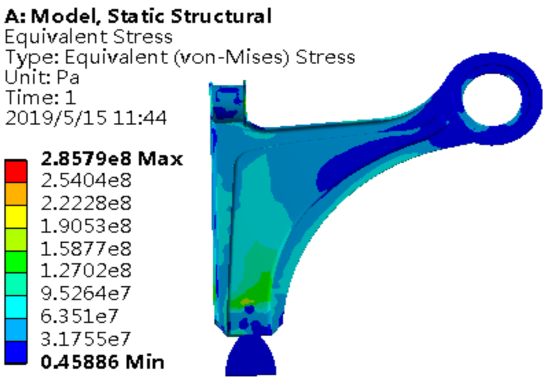

Figure 5. Steady right turn.

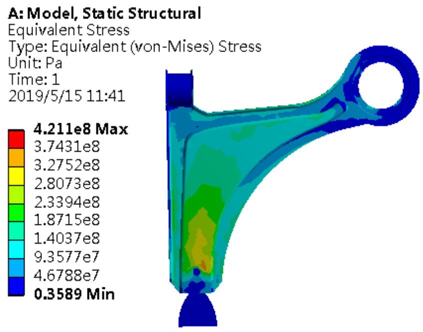

Figure 6. Stress nephogram before structural optimization.

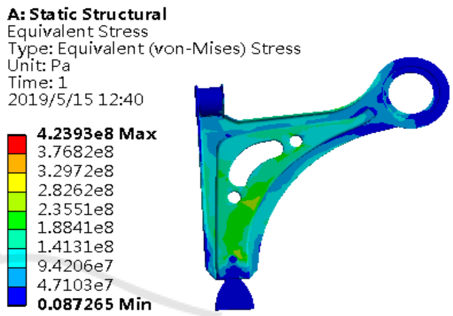

Figure 7. Stress nephogram after structural optimization.

Through comparison, it can be seen that under the same forward braking condition, the optimized structure has little change in the maximum stress value, and can still meet the yield conditions of raw materials. At the same time, the lightweight drilling arm is 0.5 kg lighter than the original control arm. As shown in Table 2 and Figure 8-11.

Table 2. Quality comparison.

	Quality(Kg)
original control arm	5
carbon fibre	4.1

	Mode	Frequency [Hz]
1	1.	0.
2	2.	0.
3	3.	0.
4	4.	5.0567e-003
5	5.	7.1355e-003
6	6.	1.0322e-002
7	7.	691.76
8	8.	945.43
9	9.	1468.1
10	10.	1615.
11	11.	2286.
12	12.	2360.6

Figure 8. Modal Analysis of Original Control Arm.

	Mode	Frequency [Hz]
1	1.	0.
2	2.	2.7271e-003
3	3.	5.87e-003
4	4.	2.8436
5	5.	3.0921
6	6.	5.3301
7	7.	660.55
8	8.	914.17
9	9.	1186.5
10	10.	1447.7
11	11.	2044.8
12	12.	2119.6

Figure 9. Optimized Modal Analysis.

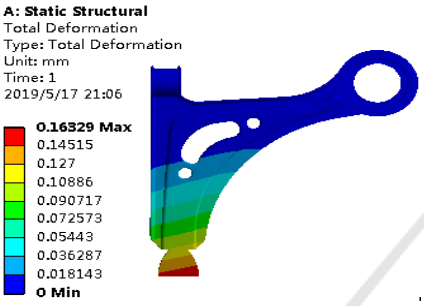

Figure 10. Stiffness analysis of optimized Y-direction.

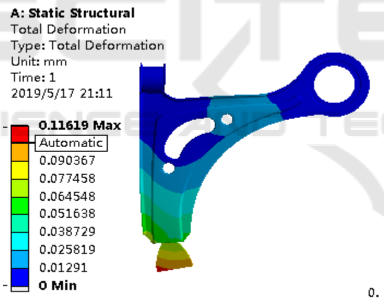

Figure 11. Stiffness analysis of optimized X-direction.

3.2 Material-based Lightweight

For cost research, cost models are usually established. For a complete manufacturing industry chain, the cost calculation begins with the raw materials entering the factory, and then the direct or indirect manufacturing cost generated during the process of vehicle leaving the factory. According to the material cost in NHTSA/EDAG LWV research: HSLA350/450:$1.05/kgor$0.48/lb.DP350/600:$1.19 /kg or $0.54/lb. HF1050/1500 (aluminized): $1.6/kg or $0.75/lb. Austenitic stainless steel: $4.65/kg or $2.10/lb.Average cost of aluminium sheets: $4.71/kg or $2.14/lb. The price of CHSS (HSLA350/450) is about 13% higher than that of low carbon steel. The increase from HSLA350/450 to AHSS DP350600 leads to the price of CHSS (HSI A350/450) higher than that of low carbon steel by about 13%. Hot-Formed (HF) aluminized steel prices have risen sharply on the basis of dual-phase steel, but non-aluminized HF is more within the price range of dual-phase steel. The price of austenitic stainless steel is very high, which is why it has not entered the automotive structure market in large quantities. Austenitic stainless steel can be regarded as the second alternative to AHSS with very high strength and elongation, but the problem with austenitic stainless steel is that its cost is almost equal to that of aluminium.

In this paper, the advanced high strength steel is proposed to replace the high strength steel of the lower control arm in the study of material lightweight. The strength analysis is used to verify whether the advanced high strength steel can meet the requirements. As shown in Figure12-13.

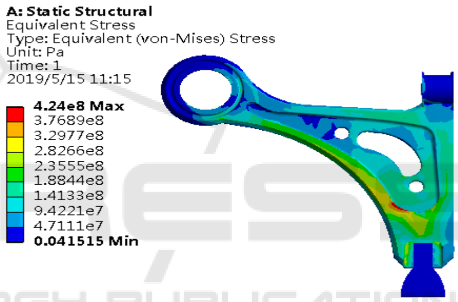

Figure 12. Stress nephogram of high strength steel.

Two better materials 30CrMo and 7075 aluminium alloy were selected. The results of strength analysis show that the yield strength of 7075 aluminium alloy does not meet the strength requirements of the worst working conditions, and 30CrMo is selected as lightweight material for lightweight selection. As shown in Table 3.

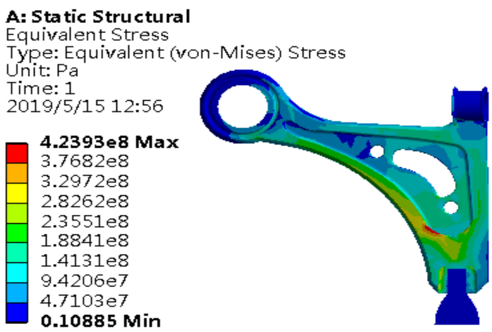

Figure 13. Stress nephogram of 7075 aluminium alloy.

Table 3. This caption has one line so it is centered.

Contrast before and after optimizing structure	Quality (Kg)	Volume ($10^3 mm^3$)	Yield strength(MPa)	Elongation (%)
QSTE450	5	60	460	20
Advanced High Strength Steel	4.1	57	780	13
7075	3.2	57	72	10

The optimized structure in the figure above uses 30CrMo to reduce the quality of lower control arm by reducing the thickness of the structure while meeting the strength requirements. It can be seen that through structural optimization and the use of advanced high strength steel lower control arm quality reduction effect is good. Reducing the thickness of the structure but still meeting the strength requirements, the volume is reduced by $3000mm^3$.

4 CONCLUSIONS

In this paper, four limit conditions of the lower control arm of a vehicle suspension are analyzed by finite element method, and the worst condition of forward braking is obtained. In the lightweight optimization, the stress and deformation of the control arm under forward braking are mainly considered. In the structural optimization, the lower control arm with small stress is lightweight by drilling. The results show that it meets the use requirements. In the analysis of the upper part of C joint, the stress is relatively large, reaching 420 MPa, which is strengthened by strengthening the closed plate. In the aspect of material lightweight, advanced high-strength steel is replaced by raw material high-strength steel by studying its properties. Although the density of advanced high-strength steel is larger than that of raw material, lightweight treatment of structure and thickness is carried out, and the final result is reduced by 0.9 kg.

REFERENCES

Heo S J, D. O. Kang, J. H. Lee, et al. *Shape optimization of lower control arm considering multi-disciplinary constraint condition by using progress meta-model method* [J]. International Journal of Automotive Technology, 2013, 14(3):499-505.

Mitchell, Erik T. *Lightweight Tools and Dashboards for Program Management in Libraries* [J]. Technical Services Quarterly, 2018, 35(1):68-82.

Ragab K A, Bouaicha, A, Bouazara, M. *Optimization of Casting Design Parameters on Fabrication of Reliable Semi-Solid Aluminum Suspension Control Arm* [J]. Journal of Materials Engineering & Performance, 2017, 26(9):4450-4461.

Zhang Z, Chen R, Zhongming X U, et al. *Research on Multi-objective Topology Optimization of Vehicle Suspension Control Arm* [J]. Journal of Mechanical Engineering, 2017, 53(4):114.