Static strength analysis of hot press forming fuel tank bracket based on equivalent design

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This article uses high-strength steel plates to replace ordinary steel plates in terms of the general relationship between plate thickness reduction and strength, and designs a commercial vehicle hot press forming ultra-high strength lightweight fuel tank bracket. Based on the simulation analysis results of the hot forming process, the structure of the fuel tank bracket is optimized using Siemens NX software, and static strength analysis is carried out using Abaqus software for three working conditions of impact, turning, and braking, meeting the requirements of structural design and forming process.

Keywords: Hot press forming; Lightweight; Fuel tank bracket; Finite element analysis.

1. Introduction

Against the backdrop of rapid development in the automotive industry, reducing body weight, reducing fuel consumption (economy), and reducing exhaust emissions (environmental protection) are receiving increasing attention. At the same time, people's requirements for the safety and comfort of cars are gradually increasing. To adapt to this development trend, various new technologies such as high-strength steel materials and hot forming are constantly emerging. Hot forming technology can greatly improve the stiffness and strength of the overall structure of the vehicle, significantly improve the collision safety and NVH performance of the vehicle. The extensive use of this technology can effectively reduce the weight of the vehicle and improve its economic performance. As a means of production, commercial vehicles are receiving increasing attention for their energy consumption and economic performance. Therefore, the demand for high-strength and lightweight components of commercial vehicles from major manufacturers is also constantly increasing.

As a fixed supporting component of a car's fuel tank, the fuel tank bracket can withstand the weight of the tank and fuel, as well as the impact and vibration caused by turning, impact, braking, and other situations during operation. It can ensure the stability and safety of the fuel tank system during vehicle operation. Therefore, the fuel tank bracket plays an important role in the entire body structure. Due to the unique structure of the fuel tank bracket, there is significant deformation during forming. While using hot press forming ultra-high strength steel to achieve lightweight, it is also necessary to conduct a

Y. Zhang and M. Ma (eds.), *Proceedings of the 7th International Conference on Advanced High Strength Steel and Press Hardening (ICHSU 2024)*, Atlantis Highlights in Materials Science and Technology 3,
https://doi.org/10.2991/978-94-6463-581-2_25

comprehensive analysis of the structure and forming process of the fuel tank bracket in combination with raw materials to ensure safety and usability while achieving lightweight.

This article is based on the existing 600L fuel tank and a commercial vehicle high-strength steel fuel tank bracket with an overall weight of about 700kg at full load. The thickness of the hot press forming lightweight fuel tank bracket is determined based on the general relationship between the reduction of plate thickness and strength when replacing ordinary steel plates with high-strength steel plates. Combined with the analysis results of the hot stamping process, Siemens NX software is used for mathematical and analog optimization design. Abaqus software is used to perform static strength finite element analysis on the braking, steering, and impact three typical working conditions of the existing fuel tank bracket and the hot press forming lightweight fuel tank bracket, providing reference for the structural design of the lightweight fuel tank bracket.

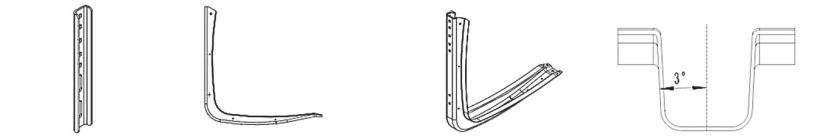
2. Design of hot press forming lightweight fuel tank bracket

2.1. *Strutural design of hot press forming lightweight fuel tank bracket*

The fuel tank bracket consists of two parts: an L-shaped bracket and a reinforcing plate. After assembly and welding, it becomes a finished fuel tank bracket. The parts and assembly diagram are shown in Fig. 1. The existing material is a 510L fuel tank bracket, with an L-shaped bracket thickness of 5m and a weight of 11.22Kg. The reinforcement plate thickness is 5mm and 1.41kg, and the assembly is 12.63kg. According to Pro. Ma's research, using high-strength steel plates instead of ordinary steel plates under various deformation forms results in a reduction in plate thickness that conforms to the following general relationship [1].

$$1 - t_2/t_1 = 1 - (\sigma_1/\sigma_2)^n \tag{1}$$

Among them, t_1 and t_2 represent the plate thickness before and after replacement, σ_1 and σ_2 correspond to the strength of the material, and n is a constant determined by the deformation form. When the deformation generated by the part approaches pure bending, n is taken as 1/2. According to the material parameters listed in Table 2, using formula (1) for equivalent design calculation, the calculated thickness of the hot press forming steel bracket is 2.72mm, taken as 2.8mm, with a weight of 6.27Kg, a strengthening plate thickness of 2.8mm, 0.82Kg, and a total weight of 7.09kg. According to the analysis results of the forming process of the commercial vehicle hot press forming fuel tank bracket [2], optimizing the draft angle of the bracket side wall from 1° to 3° can solve the problem of thinner cracking and facilitate product forming and demolding. The final design scheme is shown in Fig. 1.



(a) Strengthening plate (b) L-shaped fuel tank bracket (c)Fuel tank bracket assembly (d) Fuel tank bracket draft angle

Fig. 1. Schematic diagram of fuel tank bracket product.

2.2. *Material selection for hot press forming lightweight fuel tank bracket*

The original design of the L-shaped bracket and reinforcement plate used 510L, and the hot forming scheme used AC1500HS hot formed steel. The strap was Q235, and the fuel tank was DC01. The various material properties parameters are shown in Table 1.

Table 1. Material properties.

Name	Material	Density (t/mm^3)	Elastic modulus (MPa)	Poisson's ratio	Yield strength (MPa)	Tensile strength (MPa)
Original bracket and reinforcement plate	510L	7.85e-9	210000	0.3	355	510
Hot press forming bracket, reinforcement plate	AC1500HS	7.85e-9	210000	0.3	Before quenching≥300 After quenching≥1200	Before quenching≥600 After quenching≥1500
Strap	Q235	7.85e-9	210000	0.3	235	370
Tank	DC01	7.85e-9	210000	0.3	130～260	270～410

3. Finite element analysis of static strength of hot press forming lightweight fuel tank bracket

3.1. *Finite element model*

Use Siemens NX software for digital and analog design and processing, and use Abaqus software for finite element analysis. The sheet metal parts use shell elements [3], with element type S4R. The bolts use a simplified model,Y with element type C3D8R. The basic unit size of the fuel tank is 20mm, and the basic unit size of the other parts is 5mm. The part mesh model is shown in Fig. 2. The fuel tank is treated as a discrete rigid body with a center of 700KG particles (approximately equal to the total mass after filling up). The fuel tank is in hard contact with the strap and bracket body; Hoops and bolts are hinged, bolts are hinged to the bracket body, and bolts are bound to the main beam; The pre tightening force of the bracket and clamp bolt is 15000N. The bolt holes connecting the bracket to the frame serve as boundary strips Item [4], as shown in Fig. 3.

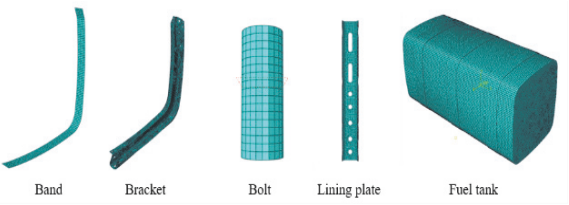


Fig. 2. Component Grid Model Diagram.

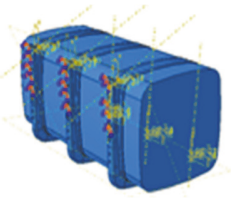


Fig. 3. Model boundary conditions

3.2. *Analyze working conditions*

In the car coordinate system, X, Y, and Z are the coordinate values of the three directions in the coordinate system (positive values indicate positive direction, negative values indicate negative direction), where x is the opposite direction of car driving, y is pointing to the right side of the car, and z is pointing above the car [5]. The fuel tank particle is subjected to a full load mass of 700kg. According to the typical braking, steering, and impact conditions of the fuel tank, the acceleration in the Z direction is -1g, and the acceleration in the X direction is -1g, Steering condition: Z-direction gravity acceleration -1g, Y-direction gravity acceleration 0.6g; Load of -7g in the Z-direction under impact conditions.

3.3. *Analysis results*

The stress cloud map and displacement cloud map of the original plan and hot forming plan under various working conditions are shown in Fig. 4 and Fig. 5, and the analysis results are shown in Table 3.

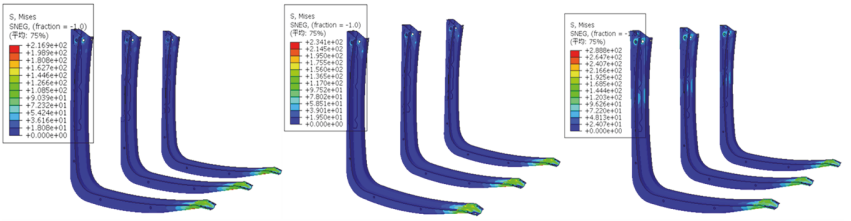


Fig. 4. Stress cloud map of braking, steering, and impact conditions in the original plan.

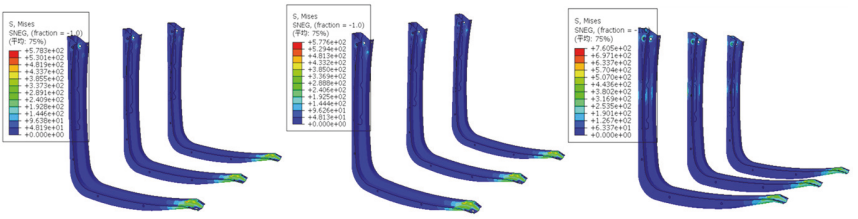


Fig. 5. Displacement cloud map of braking, steering, and impact conditions for hot forming scheme.

Table 2. Comparison of analysis results.

Project	Gravitational acceleration			Original plan			Hot forming scheme			Conclusion
	X	Y	Z	Maximum stress（MPa）	Security coeffici ent	Material yield strength（MPa）	Maximum stress（MPa）	Safety factor	Material yield strength（MPa）	
Braking conditions	-1g	/	-1g	216.9	1.64	≥355	578.3	2.075	1200	Meet a requirement
Turning conditions	/	0.6g	-1g	234.1	1.52	≥355	577.6	2.078	1200	Meet a requirement
Impact working condition	/	/	-7g	288.8	1.23	≥355	760.5	1.578	1200	Meet a requirement

The hot press forming lightweight fuel tank bracket designed by theoretical calculations and other generations reduces weight by 5.54kg and 43.87% compared to the original plan. According to CAE analysis, the safety factor is the smallest under impact conditions, with a safety factor of 1.599, which is greater than the design requirement of 1.3 and meets the design requirements.

4. Conclusion

After CAE analysis and verification, the weight reduction effect of the hot press forming fuel tank bracket designed according to the general relationship calculation is significant, and the strength analysis results meet the design requirements. Using this method for equivalent design is feasible and can save design time.

When designing the structure of the hot press forming lightweight fuel tank bracket product, it is also necessary to comprehensively evaluate the results of strength analysis and forming process analysis to ensure that the product structure matches the forming process.

The optimization design and finite element analysis of the hot press forming lightweight fuel tank bracket in this article provide a certain reference for the structural and process design of subsequent products. In practical work, when designing products, it is necessary to comprehensively evaluate and select the optimal solution based on the weight requirements, material properties, fatigue limits, loads, costs, forming processes, and other factors of the fuel tank bracket.

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