Spot Weld Fatigue Life Prediction of Commercial Vehicle Cab

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***Abstract*—A new engineering method for spot welds fatigue life prediction of commercial vehicle cab is presented. The method stars with the establishment of 3D FE model and spot weld model of the cab using the MSC. Nastran, the verification of the model is performed through modal analysis results comparation between the experiment and the simulation. Then the general fatigue life prediction method of the virtual commercial vehicle cab with spot weld is introduced. The unit force stress response of the cab is calculated by inertia relief method. At last, the cab stress response, the cab input load spectrum, cab structure and spot weld S-N curves, are imported into the MSC. Fatigue. The fatigue life prediction results indicate that the fatigue strength of most locations of the cab structure and spot welds is high and local positions such as the cab front window corners and the cab mounts are a little bit lower. And also, the influence of the metal material and the spot weld diameter to the vehicle cab fatigue life is analyzed.**

Keywords-commercial Vehicle Cab, spot Weld, fatigue Life Prediction, finite Element Method.

I. Introduction

Lightweight design has become a trend in automotive development and primary means of reducing fuel consumption. However, as a means of transportation, lightweight design of the vehicle structure should ensure high reliability and adequate security [1]. Most external loads of vehicles are random dynamic cyclic loading, the dynamic stress generated in many components under this kind of load will cause fatigue damage. When damage accumulated to a certain degree, fatigue fracture occurs. According to statistics, about 80% of the mechanical structure failures are caused by fatigue fracture.

Spot welds are the dominant joining method in the vehicle assembly process [2]. However, due to the presence of welding defects residual stresses and stress concentration, fatigue strength in weld nugget area is often lower than that of base material, so the fatigue failure of welded structures occurs in the welding joints[3].

Many scholars have studied the fatigue life analysis method of vehicle structural parts [4-5]. And done a lot of research on fatigue characteristics and durability of welding joints[6-9]. But research on fatigue performance of commercial vehicle cab structure and spot welds relatively rare. This paper focuses on the analysis of fatigue life and influence factors of the commercial vehicle cab structure and spot welds, and assessment of the fatigue life results.

II. FE Model Of Cab Structure And Spot Welds

The shell element is used to simulate the cab structure, there are 190904 elements in the model which include 7607 triangle elements and 174977 quadrangle elements. There are 7088 spot welds in the cab and the Cbeam element is used to simulate it. The cab finite element model and spot welds layout are shown in Fig.1 and Fig.2.

Figure 1. FE model of Cab

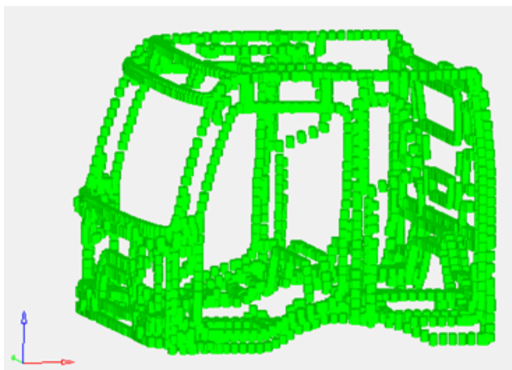

Figure 2. Layout of Spot welds

The spot welds diameter is significant parameter in the spot welds model and is selected based on experience usually with the range of 1 <d <10mm. But the tests showed that the spot welds diameter is proportional to the weld strength approximately, which can be selected according to the thickness and size of the component strength requirements, the empirical equation is:

$$d = 2\delta + 3(mm) \tag{1}$$

d- spot welds diameter; δ-Thickness of weldments.

The thickness of the cab sheets studied in this paper most are 1.5mm and 1.0mm besides the 2.0mm in the cab floor frame. So the spot welds diameter are selected to 5mm and 7mm in the simulate analysis.

III. Modal Analysis Of Cab Structure

The spot welds element is set to Rigid, Cbeam (5mm, 7mm) respectively in modal analysis, the modal results are shown in Table 1. Under three types of spot welds elements, mode shapes of cab are basically the same, there are almost no difference in modal frequency values. So Cbeam element is feasible and reasonable to simulate the cab spot welds.

TABLE 1 CAB MODAL CONTRAST BETWEEN EXPERIMENTAL AND NUMERICAL RESULTS

		Test	Rigid	Cbeam_7mm	Cbeam
First torsional frequency (Hz)		20.7	20.9	20.26	20.13
First bending frequency (Hz)		43.55	50.15	49.03	48.92
Error	Firsttorsional		1.0	-2.1	-2.8
	First bending		15.2	12.6	12.3

IV. Fatigue Life Analysis Of The Cab Structure And Spot Welds

According to the fatigue damage parameter fatigue life analysis methods can be divided to: the Nominal Stress method, Linear Elastic Fracture Mechanics, Local Strain method, energy law, etc[10]. In practical engineering applications, the first three methods are commonly used. Nominal stress method uses alternating nominal stress as main parameters to predict the fatigue life of mechanical components. It takes the material SN curve as the basis of fatigue life calculation and modifies the curve according to the difference between the actual components and sample (size effect, surface condition, and the average stress and other factors). Furthermore, the rain flow cycle counting method is applied to count the stress changes and combined with Miner cumulative damage theory to calculate the fatigue life. This method is not strictly distinguish between crack initiation and propagation, can predict the total fatigue life of components with greater damage or destruction, and is more suitable for fatigue life prediction with low stress and high cycle fatigue conditions, especially for complex structures or welding parts.

When using the nominal stress method for the commercial vehicle cab structure and spot welds fatigue life analysis, you first need to get road load spectrum input and stress time history. In fact, Stress time history of cab can be obtained directly through transient analysis method. But because of the complexity of the analyzed cab model in this paper, the transient analysis method is not suitable for getting its stress time history. So a more efficiency -the quasi-static method is applied to obtain the stress time history of commercial vehicle cab in this paper. First, the unit excitation response of stress on cab suspension should be calculated, and then carry on mode superposition with the input load time history. At last the stress and fatigue life distribution of cab structure and spot welds on real road load can be obtained.

A. *Input load spectrum of commercial vehicle cab*

Load spectrum, also known as load time histories, usually able to be presented by a load - time relationship diagram. Real vehicle's load spectrum acquisition is an important part of the fatigue analysis, the accuracy of load spectrum is also directly affecting the fatigue life reliability of the results. The required load time histories for analyzing the fatigue life of the cab in this paper is obtained by a real vehicle durability test on Dingyuan testing ground in China. The input load time histories on cab suspension are showed in Fig.3~Fig.6.

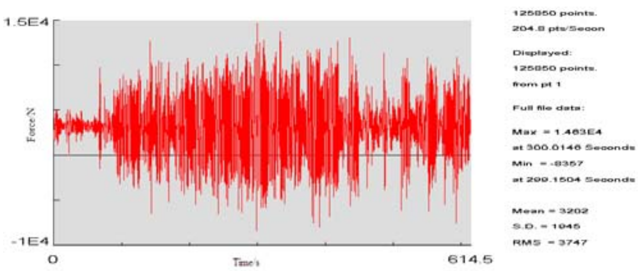

Figure 3. Load history of left front cab mounting

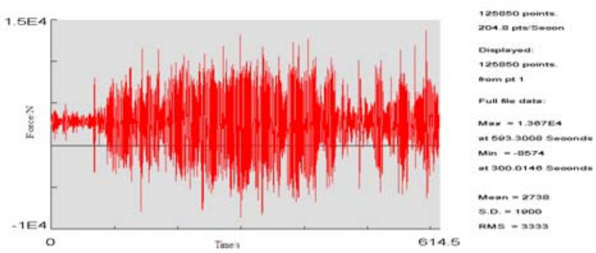

Figure 4. Load history of right front cab mounting

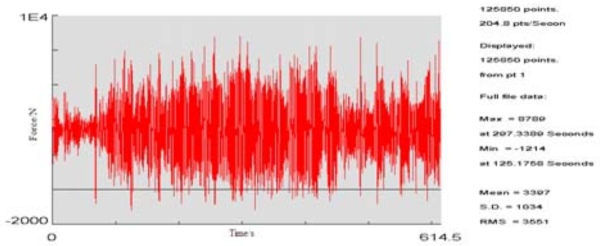

Figure 5. Load history of left rear cab mounting

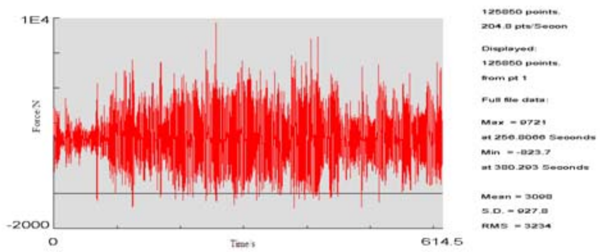

Figure 6. Load history of right rear cab mounting

B. S-N curve of cab structure and spot welds

The material for analyzing the commercial vehicle cab structure is a typical steel material. Due to the effect of high temperature and pressure in the welding process, the fatigue strength of spot welds is slightly lower than the base metal. The SN curve used herein is provided by the MSC. Fatigue library(shown in Fig.7), the Certainty of Survival is select to the default value of 50%.

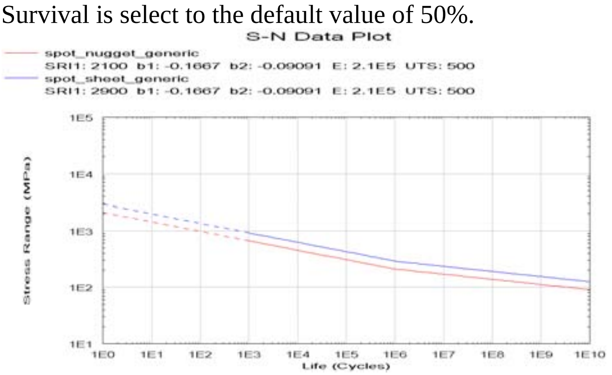

Figure 7. S-N curve of cab structure and spot welds

C. Unit stress excitation response analysis of cab

The main force at the cab mountings is vertical direction (Z direction) excitation. The forces on X and Y directions of the cab have little effect on cab fatigue, so can be neglected. In the finite element pre-processing software Hypermesh, unit excitation of Z direction on the four cab mountings is applied respectively with four load steps for static response analysis. The results are shown in Fig. 8 which include nodal displacement, element force and stress distribution of cab structure, as well as beam strength and stress of spot welds.

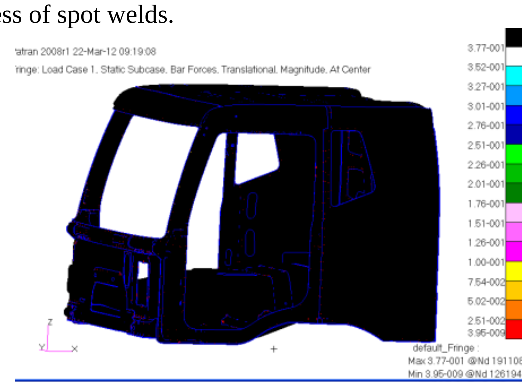

Figure 8. Unit excitation response results of cab structure

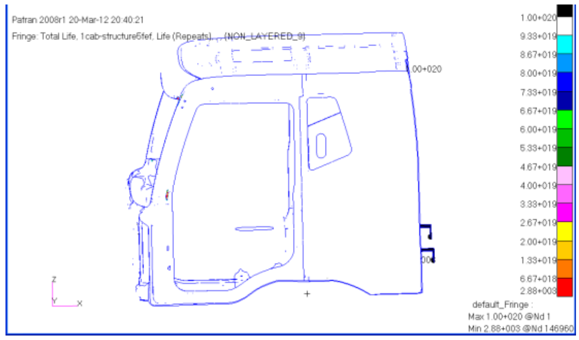

Figure 9. Fatigue life distribution of cab structure

D. Fatigue life analysis of cab structure

Since commercial vehicle cab subjects to random load, after importing the load spectrum into fatigue analysis software, the system will first calculate the stress distribution of cab according to unit excitation stress response results. Then counts stress cycles using rain flow method, finally applies Miner's theory to calculate the fatigue life distribution of the cab structure (shown in Fig. 9).

It can be seen from the Fig.9 that the overall fatigue lives of the cab are almost at 1×10^{19} cycles or more, close to no damage. Local areas, such as corner of front windshield and cab mounting connection have lower life expectancy with the minimum value of 2880 life repeats at node No. 146960. With the cab input load history time of 614.5s and general speed of 70km / h, the fatigue life expectancy of cab structure is checked according to truck's 30,000 km durability test standards. It can meet the requirements when the life repeats of the cab structure reaches 2511. So, the overall life expectancies of commercial vehicle cab structure are qualified.

E. Fatigue life analysis of spot welds

To calculate the fatigue life of spot welds, you need to know the SN curve (cycle characteristic R = 0) of plate and weld nugget. But the effects of standard deviation parameters and the stress sensitivity coefficients cannot be ignored. The typical SN curve of spit weld is different from the base metal's, which can be expressed as Eq.2:

$$\Delta S = SRI1(N_f)^{b1} \quad (2)$$

*SRI*1——vertical coordinate of S-N curve on S axis ; *b*1——Material constant.

The mean stress S_m is corrected and the equivalent stress amplitude can be expressed as Eq.3 at R = 0:

$$S_0 = \frac{S + MS_m}{M + 1} \quad (3)$$

M——average stress sensitivity factor.

After obtaining the structural stress at the connecting plate and weld nugget, the effective stress history can be calculated through modal superposition method. After the rain-flow cycle counting, Miner's accumulative damage rule(shown in Eq.4) is applied to calculate fatigue life and damage of spot welds by MSC. Fatigue module.

$$\sum D_i = \sum \frac{n_i}{N_{i,f}} \geq 1 \quad (4)$$

D_i——Damage of each load level; $N_{i,f}$——Fatigue limit of each load level;

n_i——Repeat cycles of each load level.

Spot welds elements are divided to different group based on plate thickness, spot welds diameter is varied with plate thickness which it connects and is determined according to formula 1.The spot welds diameter at cab floor frame is 8mm and 7mm at front windshield corner and 6mm for the remaining. The fatigue life distributions of spot welds are calculated. Due to spot welds are very small relative to the entire commercial vehicle cab structure, ordinary display is not appreciable. So the Insight amplifier module is used to magnify the overall life results of spot welds individually shown in Fig.10. The fatigue life is low in yellow areas and high in blue areas.

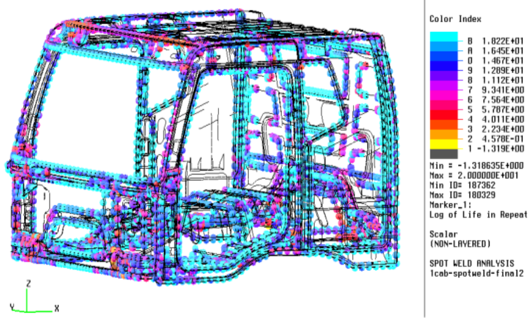

Figure 10. Fatigue life results of spot welds

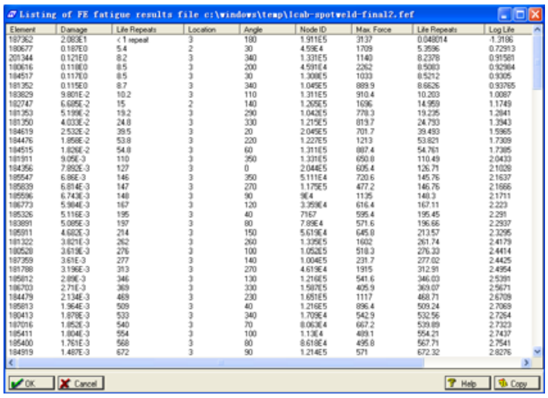

Figure 11. Fatigue life results of spot welds

It can be seen from Fig.10 that the fatigue life distribution of spot welds is almost the same at that's of cab structure. The fatigue lives at front windshield corner, rear cab mountings, roof and top beam connection at front windshield are lower than others. The number of spot welds with lower fatigue lives is 124. So the overall lives of the commercial vehicle cab spot welds are relatively high.

The same evaluation method of reliable truck 30,000 km durability test standards as cab structure are also used to assess fatigue life of spot welds. Only if the number of each spot welds life repeat reaches 2511, it can meet the durability requirements, then the logarithm value of life repeat is 3.4. Figures 11 shows the fatigue life results of spot welds which are not consistent with the standard. The number of defective spot welds is 73.

V. Fatigue Life Influencing Factors

A. *Influence of cab material*

In the above fatigue life analysis for cab structure, the selected material is ordinary steel with ultimate tensile strength (UTS) of 500Mpa. If the choice is MANTEN material with 552Mpa UTS, the fatigue life repeats at weakest part s can reach 10^5. The fatigue life of the original lowest life expectancy element 146,960 in new material is 3.58×10^5 cycles, which is significantly greater than 2880 cycles of ordinary steel. The fatigue life of other elements have also been significantly improved .So cab material has great impact on the fatigue life of cab structure, using high-strength steel material can effectively improve the fatigue performance of commercial vehicle cab.

Table 2 Fatigue Life Results Of Spot Welds Under Different Diameters

	spot welds diameter						
	original	Decreasing 1mm		Increasing 1mm		Increasing 2mm	
			Improvements (%)		Improvements (%)		Improvements (%)
Number of failure spot welds	73	85	-16.4	68	6.8	62	15.1
Number of spot welds with life repeats less than 1×10^4	124	138	-11.3	112	9.7	104	16.1
Number of spot welds with life repeats more than 1×10^{10}	6020	5907	-1.9	6103	1.4	6146	2.1

B. *Influence of spot welds diameter*

Diameter is an important parameter for spot welds, the diameter of spot welds will directly affect the fatigue strength. Generally, in the case of reasonable spot welds layout, increasing the diameter properly can improve the fatigue life of spot welds. The fatigue life is recalculated as the diameter of spot welds decreasing 1mm and increasing 2mm respectively in this paper. Table 2 shows the fatigue life results of spot welds under different diameters. As the diameter of spot welds is increased, the number of failure spot welds is reduced gradually , the overall fatigue life of spot welds is increased and fatigue strength is also improved; If the diameter is reduced from the original ones, the number of failure spot welds will be increased significantly.

VI. CONCLUSIONS

A more efficiency and comprehensive beam element is used to simulate and calculate the fatigue life of cab spot welds in this paper.

In MSC. Fatigue software, fatigue life distributions of cab structure and spot welds are calculated through rain flow counting and Miner's fatigue damage accumulation theory. The fatigue life results are evaluated according to reliable 30,000 km durability truck test standards. The results show that: the fatigue life of commercial vehicle cab structure can meet the requirements, life repeats at cab mountings and front windshield corner are little lower. The failure spot welds number is 73, which mainly distribute in the front windshield corner, rear cab mountings and connections between roof and top beam of front windshield.

Material has great influence on fatigue life of cab structure. In the reasonable spot welds diameter ranges, increasing the spot welds diameter can increase the fatigue life of spot welds, and improve fatigue performance of spot welds.

VII. SUMMARY

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The authors would like to express their appreciations to China Automobile (Beijing) Vehicle Lightweight Technology Institute for their project support to the research.

REFERENCES

[1] Pettersson G. Fatigue analysis of a welded component based on different methods. Weld World (2002).

[2] Yang Nianjiong, Qian Lijun, GuangChangming. Review on spot welds FE modeling method for car body [J].Welding Technology. Vol. 38(2009), p.7~9.

[3] Y. Chao, Ultimate strength and failure mechanism of resistance spot weld subjected to tensile, shear or combined tensile/shear loads, J. Eng.Mater. Tech.-Trans. ASME 125 (2003), p. 125~132.

[4] Sridhar Srikantan, ShekarYerraPalli, Hamid Keshtkar. Durability design process for truck body structures.International Journal of Vehicle Design. Vol. 23(2000), p.95-108.

[5] Henrysson HF. Effects of mean stress and crack closure on fatigue life of spot welds.Fatigue and Fracture of Enginnering Materials and Structures. Vol. 25(2002). p.1175~1185.

[6] Yi Gao, Darren Chucas, Colin Lewis, Iain J.McGregor. Review of CAE Fatigue Analysis Techniques for Spot-Welded High Strength Steel Automotive Structures. SAE Technical Paper Series 2001-01-0835.

[7] S.Donders, M.Brughmans, L.Hermans, C.Liefooghe, H.Van der Auweraer, W.Desmet. The robustness of dynamic vehicle performance to spot weld failures. Finite Elements in Analysis and Design. Vol. 42(2006), p.670~682.

[8] D.Radaja,C.M.Sonsinob,W.Fricke. Recent developments in local concepts of fatigue assessment of welded joints. International Journal of Fatigue. Vol. 31(2009), p.2~11.

[9] Henrysson HF. Effects of mean stress and crack closure on fatigue life of spot welds.Fatigue and Fracture of Enginnering Materials and Structures.Vol.25 (2002), p.1175~1185.

[10] S. Mahadevan, K. Ni, Damage tolerance reliability analysis of automotive spot-welded joints, Reliab. Eng. System Safety. Vol. 81 (2003), p. 9~21.