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RESEARCH ON THE CYCLIC LOAD LIFE OF AUTOMOBILE BELLOWS

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In this study, a Finite Element Computational (FEC) model for automotive bellows exhaust pipes is established, and the impact of displacement loads on their fatigue life is investigated. The relationships between various structural parameters of the exhaust pipes and stress, strain, and cycle counts are elucidated. Furthermore, the bellows' structure is optimized through an orthogonal experiment. A microscopic morphological analysis is conducted on 309S stainless steel automotive bellows exhaust pipes after fatigue failure. The findings indicate that as displacement loads increase, the fatigue life of the bellows exhaust pipes decreases. The error between finite element analysis and experimental results is found to be less than 8,8 %. During the water swell forming stage, partial martensite is produced due to cold deformation. Under alternating loads, with noticeable cracks at the wave peaks, indicating the presence of internal fatigue characteristics.

Keywords: 309s steal automobile corrugated pipe, fatigue, microstructure

INTRODUCTION

The bellows located in the engine bay is a thin-wall flexible component used to connect the three-way catalytic converter and the exhaust system [1, 2]. EJMA (American Expansion Joint Manufacturers Association) has given the austenitic stainless steel bellows life calculation formula and life curve (S-N curve) [3]. In recent years, many scholars have studied the structural parameters and fatigue life of bellows under different working environments [4-6]. It will have a certain influence on the life curve of automobile bellows. Therefore, it is difficult to unify the simulation analysis and experiment of the fatigue life of automotive bellows, and the diversity of bellows also leads to the great influence of the corrugated structure of bellows on the life.

In this paper, the axial displacement load of automotive bellows is simulated and analyzed, and the stress, strain and life under axial displacement load are discussed. In addition, the influence of different parameter structure of bellows on life is analyzed. In the range of safety design, the structural parameters of bellows are optimized by orthogonal experiment method, and the stress and life are optimized. The microstructure of bellows fracture region was observed by metallographic microscope and scanning electron microscope, and the reason of bellows fracture failure was revealed.

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EXPERIMENTAL MATERIALS AND METHODS

Materials

The experimental material is 309S austenitic stainless steel. The tensile sample was obtained by cutting along the axial line of the automobile bellows. The micro-controlled electronic universal tensile test machine was used to stretch at 5mm/min. The structural parameters of the bellows are respectively Φ 24 mm in diameter, 0,4 mm in wall thickness, 4 mm in wave height, 1mm in wave width, 4mm in wave distance and 28 in number of ripples. There are 90° bends in the straight pipe part and 30° bends in the ripple area. In order to facilitate assembly with the engine, the automobile bellows are equipped with flanges on both sides. Figure 1 shows the bellows and 3D model.

EXPERIMENTAL RESULTS AND ANALYSIS

Cycle load life analysis of automotive bellows

Figure 2 shows the equivalent stress cloud diagram under different displacement loads. It can be seen from the figure that the maximum equivalent stress points appear at the wave crest of the bellows bend, which are 416 MPa, 490 MPa, 670 MPa and 804 MPa respectively, indicating that stress concentration is easy to occur at the bellows crest, which will affect the service life of the automotive bellows. With the increase of displacement, the equivalent stress of the bellows also increases.

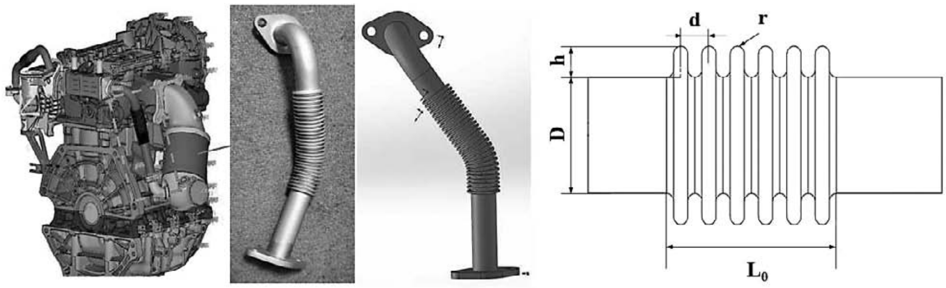

Figure 1 Bellows and 3D model

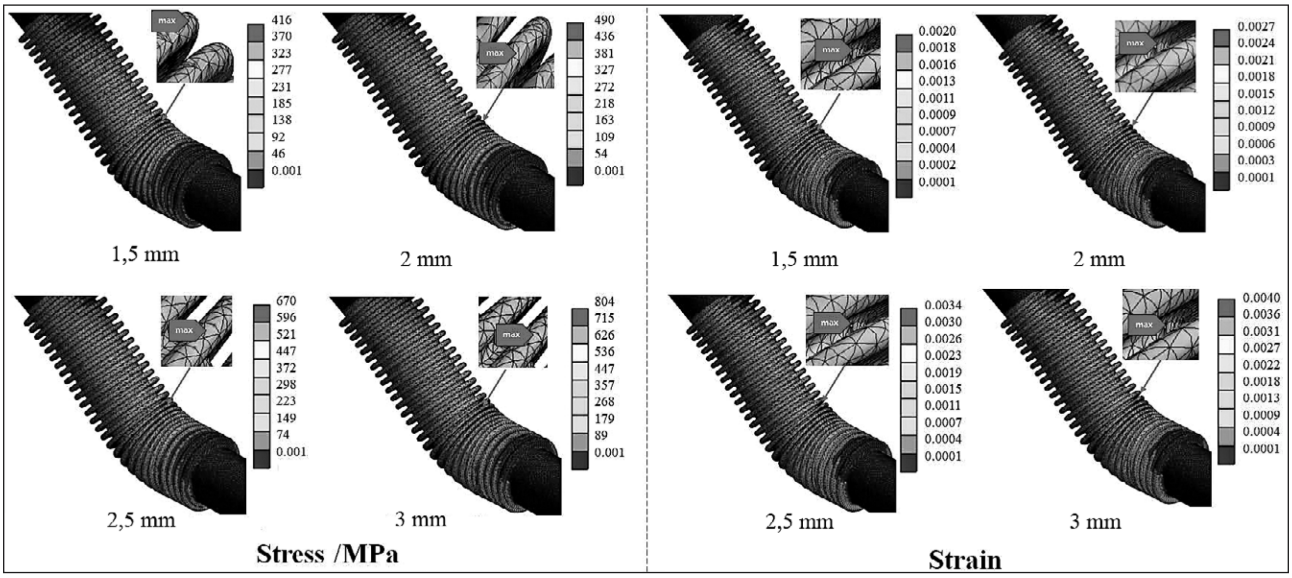

Figure 2 Equivalent stress and strain under different cyclic loads

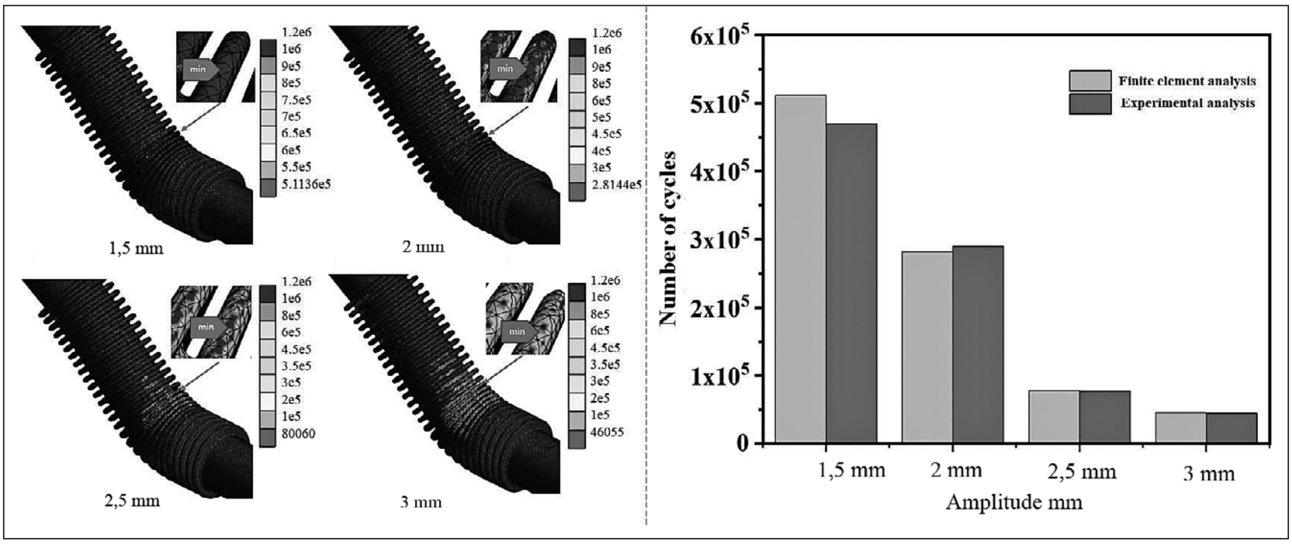

Figure 3 Fatigue life under different cyclic loads

When the displacement reaches 2 mm, the equivalent stress amplitude exceeds the yield stress of the automobile bellows (419 MPa), and plastic deformation occurs at the wave peak of the bellows. When the displacement reaches 3 mm, the equivalent stress amplitude exceeds the tensile strength (720 MPa), and the wave crest of the bellows is prone to damage. It can be seen that under different displacement loads, the maximum equivalent strain point of the bellows appears at the trough. The maximum stress point and the maximum strain point do not appear in the same position because of the wavy structure of the bellows. The corrugated pipe deforms under the action of load. At the crest of the wave, the material is subjected to greater force due to the bulge of the ripple, which results in the maximum stress point. At the trough, due to the depression of the ripple, the material is subjected to less force, resulting in a maximum strain point. This distribution of stress and strain allows the ripples to withstand greater external loads, reducing stress concentration at the point of maximum stress, and greater strain at the trough, which can withstand large compression and tension. There is a large strain at the trough, which can make the bellows have better elasticity and flexibility. Therefore, this stress and strain distribution characteristics should be considered in the design process of the bellows to ensure that the bellows can withstand the required stress and deformation during the working process.

Fatigue life under different cyclic loads

Figure 3 shows the cycle life of the bellows under different cyclic loads, which are 511 360 times, 281 440 times, 80 060 times and 46 055 times respectively. The minimum cycle life point and maximum stress point are at the wave peak, which indicates that the fatigue failure of the bellows is caused by the stress concentration at the wave peak. It can be seen that the maximum equivalent stress of automotive bellows is the key factor when studying the fatigue life of automotive bellows. When the bellows are under cyclic load of 1,5 mm, the maximum stress is less than the yield strength of the bellows, and the bellows can cycle 511 360 times. When the maximum stress of the bellows is greater than the yield strength under 2 mm load, the plastic deformation of the bellows occurs, and the maximum cycle life of the bellows drops sharply, and the number of cycles is 281 440. Under the load of 2,5 mm, the stress of the bellows is greater than the yield strength and less than the tensile strength, and the number of cycles is 80060. When the maximum stress of the bellows is greater than the maximum tensile strength under the load of 3 mm, the cycle life of the bellows is 46 055 times, and the bellows are extremely vulnerable to damage. In order to verify the accuracy of the life prediction of bellows by displacement load, the simulation data and the experimental data are compared.

The maximum error between the simulation results and the experimental results of the fatigue life is 8,8 %, and the error meets the engineering application. The error may be caused by factors such as air humidity, ambient temperature and insufficient finite-element mesh division during the experiment.

ANNEALING MICROSTRUCTURE ANALYSIS OF FATIGUE FAILURE AUTOMOTIVE BELLOWS

Figure 4 shows the metallographic structure of 309S stainless steel automotive bellows, which were cut at the fatigue failure position of the bellows by wire cutting and observed under 100 and 200 times metallographic microstructure microscope after inlaying, grinding, polishing and (HNO_3:H_2SO_4 = 3:1) corrosion. It can be seen from the figure that the microstructure of 309S stainless steel is relatively uniform, the grain arrangement is relatively tight, and the crystals are mostly austenite, but there are a large number of slats inside the crystals, which is because the automotive bellows are deformed in different degrees under the action of cold working, while the surface tension of water and the mold pressure are exerted during the water swelling molding process. This energy transforms austenite into martensite. Figure 4 is a comparison between simulation and experiment. As shown in the figure, the maximum stress amplitude point is the same as the experimental fracture position and appears at the bending crest of the bellows, which verifies the accuracy of the simulation model. Figure 4 shows the low-power macroscopic morphology of the bellows fracture, which cracks at the inner and outer surfaces. Under cyclic load, the bellows formed a crack source due to excessive local stress, and the crack source expanded to the left and right sides. Figure 4 shows the fatigue characteristics observed on the inner surface. At the same time, it can be seen that secondary cracks occur in the process of crack propagation, which seriously harms the fatigue life of the bellows. In summary, the fatigue source is cracking inside and outside the wave crest, the crack direction extends to the inside, and the bellows fatigue fracture occurs under the bidirectional alternating load.

CONCLUSION

Based on finite element analysis and axial fatigue testing machine, the S-N curve considering the automotive bellows structure is obtained, which can accurately predict the fatigue life of automotive bellows compared with the S-N curve obtained by empirical formula.

The stress, strain and cycle life of automotive bellows under different displacement loads are studied. The results show that under different displacement loads, the maximum equal effect force point is concentrated at the peak, the maximum equivalent strain point is concentrated at the trough, and the maximum stress point is consistent with the minimum life point. The finite element and experimental comparison analysis of the cycle life under different loads is carried out, and the error is less than 8,8 %. Meet engineering requirements.

Different structural parameters of automotive bellows are studied and analyzed. The results show that increasing wave height, wave distance and wave diameter helps to reduce stress and increase cycle life, while decreasing wall thickness helps to increase life of bellows. Orthogonal tests were carried out on the four structural parameters of wave height, wall thickness, wave diameter and wave distance. Compared with the original data, the stress of the optimized scheme was reduced by 21,2 % and the cycle life was increased by 167 %.

The microstructure of 309S stainless steel automotive bellows was studied. In the forming stage, the cold deformation led to the appearance of slat bundles inside the bellows. There were obvious cracks at the wave crest of the bellows, and obvious fatigue characteristics were observed inside the wave crest, indicating that the

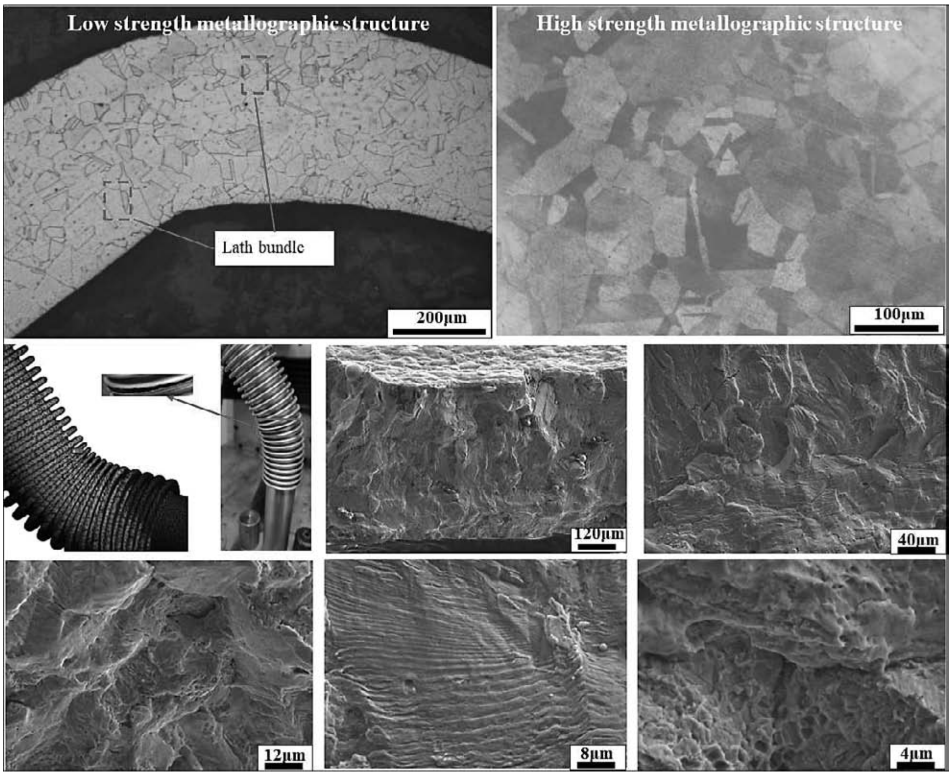

Figure 4 Metallographic scanning electron microscopes (SEM) fracture analysis

bellows fatigue failure occurred under the action of alternating loads.

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Note: The responsible translator for English language is X. Wu, Ningbo, China