Simulation Analysis of Complex Aluminium Alloy Structural Component of High-Speed Train

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Abstract. High-speed trains are now the most important medium- and long-distance mode of transport in many countries, and green economy is one of the important directions of high-speed train design. Aluminium alloy material is widely used in various structural parts of high-speed trains due to its advantages of high strength and low density, etc. As the speed of high-speed trains is getting faster and faster, the load on the car body structure is getting bigger and bigger, the safety, reliability and longevity of aluminium alloy structure has received wide attention. In this paper, the stress distribution, maximum stress value and maximum stress point position of aluminium alloy structural members of high-speed trains are analyzed in detail based on the real load situation, and the influence of stress level on train operation is analyzed. The above work has certain reference significance for the design of high-speed train.

1. Introduction
Nowadays the high speed train is one of the most important transportsations in the world. More and more countries are planning to build high-speed rail lines. On the other hand, lightweight design is required in high-speed train body structures for economic and environmental protection purposes[1].

An aluminium alloy structure is usually an important part of HST body, and the failure of it can cause catastrophic results. Aluminium alloy structures are usually made from an alloy of aluminium. They are typically lighter for the same strength and provide better heat conduction and improved cosmetic appearance. Once these aluminium casting improvements were more widely adopted, the aluminium alloy structure took its rightful place as low cost high performance. Energy, environment and security are the three issues of concern; they are also the three problems restricted the development of the HST industry and the popularity of the HST. The HST safety and reliability depend largely on the performance of the aluminium alloy structure and service life. The aluminium alloy structure has many advantages such as light, heat dissipation faster, damping performance, long fatigue life, safe, reliable, beautiful exterior, precision size and easy to manufacture, and has a huge potential for development[2, 3]. The structure of HST aluminium alloy structure is complex, and when the HST at work the aluminium alloy structures bear many loads such as acceleration, gravity of suspension parts etc. Because there are stress concentrations, the true stress values of
aluminium alloy structures are much greater than the nominal stress. So the finite element analysis is necessary[4]. It is meaningful for aluminium alloy structures to do stress analysis, fatigue analysis and P-S-N curve fitting[5-7]. With the constant improvement of the modern product life, as well as some components are very expensive, it is increasingly difficult to obtain large samples in the laboratory. For long-life products, researchers often encounter that after a long time of laboratory tests, no valid failure data is obtained or only a small amount of failure data is obtained. For products whose samples are difficult to obtain, a large number of tests cannot be carried out. In the process of the operation of the product, will produce a lot of running and failure information, how to make full use of limited data and information, combined with the characteristics of product failure, establish a new method of fatigue reliability assessment of small sample, made under the condition of the premise of keep sample size is small, still can get higher accuracy of the evaluation results, is a widespread concern. The work of this article is a good basis for further in-depth research.[8-13].

2. Structural simulation analysis
Figure 1 is the mechanical engineering drawing of the structure. There are three slots and a weld bead with the structure. Figure 2 is the actual structural component. In order to do finite element analysis, a precise 3D model is built as Figure 3.

The structure material is alloy 6005A. It has medium strength, good corrosion resistance and finishing characteristics. The weldability of it is excellent. The material properties are listed in Table 1 and the chemical composition is listed in Table 2.

Table 1. Material parameters of structure material.

| Material parameters | Elastic module (MPa) | Poisson ratio | Density (t/mm³) |
|---------------------|---------------------|---------------|----------------|
| Value               | 70000               | 0.32          | 2.71E-9        |

Table 2. Chemical composition of the structure material.

| Material | Si  | Fe   | Cu   | Mg   | Mn   |
|----------|-----|------|------|------|------|
| 6005A    | 0.5 | 0.35 | 0.3  | 0.4  | 0.5  |
| Material | Cr  | Zn   | Ti   | Other| Al   |
| 6005A    | 0.3 | 0.2  | 0.1  | 0.15 | Balance |

Figure 1. Mechanical engineering drawing of the structure (Length unit: mm).
Figure 2. The actual structural component.

Figure 3. 3D model of structure.

Figure 4 is a meshed model of the structure, and Figure 5 is a local detailed picture of meshed model. In order to accurately control the quantity and size of the mesh, a sweep method is used to mesh the structure and the hexahedral element is used.

Figure 6 shows the loading and constraint of the FEM model. One side is fixed supported and the other side is X-displacement free. The loading is the force acting on the free side along with −X direction as showed in Figure 6, the applied force is 17.5KN.

The stress distribution of the structure are shown as Figs. 7, 8, 9, 10. From Figs. 7 and 8 it can be seen that the stress distributed unevenly. From Figs. 9 and 10, it can be seen that there are several sites where the stresses are relatively high. These sites include the location that near the weld bead and the locations that exist of stress concentration. From Figure 10, the maximum stress of the finite element analysis is 194.39MPa.
Figure 4. Meshed model of structure.

Figure 5. Local detail of meshed model.

Figure 6. Constraints and loading.
Figure 7. Stress distribution of structure of upper side.

Figure 8. Stress distribution of structure of bottom side.

Figure 9. Local stress distribution.
3. Conclusions

Aluminum alloy is increasingly used in the structural components of high-speed trains. In this paper, a fine-grained finite element model of a typical high-speed train structural part is established, and the grid refinement is carried out at the transition rounded corner and hanging slot locations. The stress distribution, maximum stress point locations, and maximum stress values of the high-speed train structural part under different loading conditions are analyzed based on the real loads measured in train operation. The results show that the stress distribution of train structural part is very uneven, and there is a stress concentration in the transition fillet of multiple structures, which leads to the maximum stress of the structure is much larger than the nominal stress the structure is subjected to, the maximum stress reaches 194 MPa, which is only 20% lower than the yield limit of the material, and there is a possibility of fatigue damage under the action of alternating loads. There is a need to focus on the fatigue resistance of the structure and the fatigue reliability of the structure in subsequent studies.

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References

[1] C. MadshusA and M. Kaynia 2000 High-Speed Railway Lines on Soft Ground: Dynamic Behaviour at Critical Train Speed *Journal of Sound and Vibration* **231**, 689-701

[2] Y. B. Unigovski, A. Grinberg, E. GerafiE and M. Outman 2013 Low-cycle fatigue of a multi-layered aluminum sheet alloy *Surface & Coatings Technology* **232** 695-702

[3] M. N. Desmukh, R. K. Pandey and A. K. Mukhopadhyay 2005 Fatigue behavior of 7010 aluminum alloy containing scandium *Scripta Materialia* **52** 645-50

[4] Petrašinović, Danilo, Boško Rašuo and Nikola Petrašinović 2012 Extended finite element method (XFEM) applied to aircraft duraluminum spar fatigue life estimation *Tehnički vjesnik* **19** 557-62

[5] Fan M, Zeng Z and Zio E 2017 Modelling dependent competing failure processes with degradation-shock dependence *Reliability Engineering & System Safety* **165** 422-30

[6] Jain N, Yadav O P and Rathore A P S 2017 Reliability assessment framework for a multi-state multi-component system *Journal of Industrial and Production Engineering* **34** 580-9
[7] Qingan Qiu and Lirong Cui 2018 Reliability evaluation based on a dependent two-stage failure process with competing failures Applied Mathematical Modelling 64 699–712
[8] J. D. Booker, M. Raines and K. G. Swift 2001 Designing Capable and Reliable Products Oxford UK
[9] D. S. Carter 1997 Mechanical Reliability and Design John Wiley & Sons Inc New Jersey USA
[10] Xie Liyang, Zhou Jinyu and Hao Changzhong 2004 System-level load–strength interference based reliability modeling of k-out-of-n system Reliability Engineering and System Safety 84 311–7
[11] Qian Wenxue, Yin Xiaowei and Xie Liyang 2012 System reliability allocation based on bayesian network Applied Mathematics & Information Sciences 6 681-7
[12] Xie Liyang, Zhou Jinyu and Wang Xuemin 2005 Data mapping and the prediction of common cause failure probability IEEE Transactions on Reliability 54 291-6
[13] Zhou JinYu and Xie LiYang 2009 Generating function approach to reliability analysis of structural systems Science in China Series E-Technological Sciences 52 2849-58
[14] Wang Zheng and Xie Liyang 2008 Dynamic reliability model of components under random load IEEE Transactions on Reliability 57,474-9
[15] Qian Wenxue, Yin Xiaowei and Xie Liyang 2014 Reliability modeling and assessment of component with multiple weak sites under complex loading Mathematical Problems in Engineering 1-9
[16] Gao Peng, Yan Shaoze and Xie Liyang 2013 Dynamic reliability analysis of mechanical components based on equivalent strength degradation paths Strojniški vestnik-Journal of Mechanical Engineering 59 387-99
[17] Freudenthal A. M, Carrelts M and Shinozuka M 1966 The analysis of structural safety Journal of Structure Division ASCE 92 267-325
[18] Wirsching PH and Wu YT 1985 Probabilistic and statistical methods of fatigue analysis and design Pressure vessel and piping technology–1985: a decade of progress 793-819
[19] Xie Liyang, Liu Jianzhong, Wu Ningxiang and Qian Wenxue 2014 Backwards statistical inference method for P-S-N curve fitting with small-sample experiment data International Journal of Fatigue 63 62-7