Selection of Weld Structure of Bogies Based on Sub-Model

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Abstract. In order to effectively deal with the problems in the allowable fatigue strength data of weld joints of steering structures, it is necessary to carry out comparative tests and analyses according to various structural stress methods and data. Therefore, on the basis of understanding the applied strength standard of bogie welded structure in China, and aiming at the application of weld structural stress at the present stage, this paper constructs the fatigue diagram and S-N curve of Q345 weld seam based on the actual tested structural stress, and starts with the result study.

1. Introduction
Since China has not put forward the specific data of allowable fatigue strength in the development of practice, the strength test standard of bogie welded structure in China still adopts the data information provided by the research report of European Railway Research Center B12/PR17. These contents are based on the actual stress analysis of the tested structure. Is the fatigue diagram of 2×106 cycles corresponding to different stress cycle characteristics. It should be noted that, because the data has been developed for a long time, the following problems do not need to be considered in practical application: second, the survival rate of the designed values is too low and the safety margin is not high; Second, fillet weld data is derived from butt weld data, so it is not scientific. Thirdly, only the welds can be used, and the improvement of fatigue strength in the welds reconstruction process is not studied. Fourthly, S-N curve data is not put forward for welds, which can only be used to analyze endurance limit evaluation, and it is difficult to carry out cumulative damage and life prediction analysis. Therefore, in this paper, according to the structural stress method proposed by Professor Hainach, the Japanese industrial standard and the research report of B12/PR17, the testing regulations of weld structural stress and the allowable fatigue strength data of weld structural stress are studied in depth. The effectiveness and suitability of weld structural stress were determined, and then the fatigue diagram and S-N curve corresponding to the measured structural stress of Q345 steel weld in China were obtained[1-3]. In this paper, a sub-model is used to study the welding seam structure selection of bogies. In essence, this model method refers to the finite element technique of obtaining more accurate analysis in part of the overall model. By defining the original model and the results of the analysis, get the user CARES about the parts of the model, and then planning more accurate and detailed
grid, eventually need to clear the area model under external load and boundary conditions, and then the original model in the cutting edge of displacement as a displacement force load on the edge of the local model, and then to analyze parsing. This helps to ensure that in practical application analysis, more accurate results of partial regional models can be obtained from the overall model[4-5].

2. Methods

2.1. Hainach structural stress method
According to the actual structural stress, Professor Hainach from Germany has carried out fatigue detection and evaluation on the transverse bearing welded joints with failure at the weld toe. Many methods are put forward based on this. From the Angle of practice, the research results of this method has been proved that with the weld toe edge distance between 2.0 to 2.5 mm area, installation are shown in figure 1 below the length of the strain gauge is 3 mm, you can clear through the analysis of the test weld high cycle fatigue strength under different conditions, in other words, test stress includes weld toe structure stress, The allowable fatigue strength only needs to consider the effect of toe notch area. For structural steels commonly used, the average value of allowable stress range corresponding to the number of 2×106 cycles can reach about 132MPa under the condition of high welding residual tensile stress, the actual survival rate $Ps=50.0\%$, and the safety factor $S=1.65$ under the condition of $Ps=99.9\%$. The actual design value can reach 80MPa. In the process of dealing with stress relief parts, the average value and the design value of allowable stress amplitude in the symmetric cycle process should be regarded as 106MPa and 64MPa, respectively, according to the average stress correction method proposed by the International Institute of Welding.

![Fig. 1 Strain gage installation based on HAINACH](image)

2.2. B12/PR17 study report
When dealing with the bogie welding structure, B12/PR17 research report proposes to use a 6mm strain gauge, and ensure that its front end and toe edge are closely together, and then test and analyze the weld structural stress. The research report of B12/PR17 was used to study the allowable fatigue stress of welds, which first appeared in Darmstadt Strength Laboratory in Germany. Multiple transverse bearing butt welds were required to be used. The final experimental results proved that $[\sigma_s,0]$, The average value of can reach about 114MPa; The butt weld can be designed as $PS=75.0\%$ and the safety factor $S$ is about 1.2, at which time the design value is 95MPa. The fillet weld can be designed as $PS=99.9\%$, the safety factor $S$ is about 1.3, and the design value at this time is 88MPa. The slope of allowable fatigue stress under different stress cycle characteristics should be guaranteed to reach 0.30, and the slope should be corrected and derived
accordingly. In the limit allowable tensile and compressive stress, the base metal yield limit should be used $[\sigma_a, 0]$, and divided by the safety factor of 1.50 and 1.65, respectively. As shown in Fig. 2 below, it is the Haigh fatigue diagram of the structural stress of the steel weld under the condition that the yield limit of the base metal is 360MPa[4-6].

![Fig. 2 Stress fatigue analysis diagram of weld structure based on B12/PR17 research report](image)

2.3. JIS standard 4208

In this application method, the 5mm strain gauge is mainly used to detect the overall structural stress. From a practical point of view, the JIS 4208 standard method can determine the allowable fatigue stress under the condition of grinding and non-grinding welds. Thus, the value of the yield limit of the base metal can be set as 355MPa and the value of the tensile strength can be set as 490MPa for the treatment of SMA490 structural steel. The design value within this area should reach 110Mpa and 70Mpa. The average value of the final experimental results should be divided by the safety factor of 1.5. At the same time, the allowable fatigue stress under different stress cycle conditions should be as follows $[\sigma_a, 0]/\sigma_s$. The slope formula is analyzed, and the linear mean stress correction method is used to derive. When the ultimate allowable tension-compression stress reaches ±350MPa, the value of the base metal's yield limit should be divided by the safety factor of 1.16.

2.4. IWS recommendation document

When dealing with complex welding structures, the former stress method generally needs to specify the nominal stress of the weld seam and select the appropriate target for classification treatment, which is very difficult to operate from the overall point of view. Therefore, a large number of experiments and theoretical analyses on hot spot stress have been put forward in the international market in view of this situation. Compared with the Hainach structural stress method proposed at the earliest, the hot spot stress method mainly concentrates the stress in the stress testing or calculation of the welded toe structure. Compared with the single strain gauge test condition selected in the previous research method, it can be seen that the hot spot stress method usually installed two or three strain gauges in front of the toe area, and then carried out linear or quadratic extrapolation on the actual test results until the hot spot stress was obtained in the toe edge area.

In the case of high welding residual tensile stress, the number of $2 \times 10^6$ cycles corresponds to that of the two $[\Delta \sigma]$. The design values are 100MPa and 90MPa respectively, and the PS is ±95.0%, and the safety factor S is about 1.47. In this case, when dealing with stress release parts, the equation formula for correcting average stress is as follows:

First, the formula of average tensile stress region is as follows:
\[ \sigma_{m} > 0, R = \sigma_{\text{min}} / \sigma_{\text{max}} \]

\[ [\sigma_{R_1}] = (0.2 - 0.4R)[\sigma_r], 1 \leq R < 0.5 \]

\[ [\sigma_{R_1}] = [\Delta \sigma] 0.5 \leq R \leq 1 \]

Second, the formula of compression average stress region is as follows:

\[ \sigma_{m} < 0, R = \sigma_{\text{min}} / \sigma_{\text{max}} \]

\[ [\sigma_{R_1}] = 1.6[\Delta \sigma], 1 \leq R \leq 1 \]

In the above formula, \( \sigma_{\text{max}} \), \( \sigma_{\text{min}} \), \( \sigma_{m} \) Represents maximum and minimum stresses and average stresses. \( R \) stands for stress ratio, \([\sigma_{R_1}] \) and \([\sigma_{R_2}] \) Refers to the allowable stress range within the average stress area of tension and compression under different stress ratios. According to the analysis of the above formula, the allowable stress range under different average stress conditions of tension and compression can be obtained \( \Delta[\sigma_{a,\sigma_{\text{max}}} \land \Delta[\sigma_{a,\sigma_{\text{min}}} \land \sigma_{m}] \)

Third, in the \( \sigma_{m} > 0, R = \sigma_{\text{min}} / \sigma_{\text{max}} \)
Under the condition of, can get:

\[ [\sigma_{a,\sigma_{\text{max}}} = \sqrt{(\sigma_{m} - 0.8[\Delta \sigma])^2 + 3.2[\sigma_{m}[\Delta \sigma] - (\sigma_{m} - 0.8[\Delta \sigma])}] / 2 \]

\[ -1 \leq R < 0.5, \]

\[ [\sigma_{a,\sigma_{\text{max}}} = 0.5[\Delta \sigma] 0.5 \leq R \leq 1 \]

The fourth, in the \( \sigma_{m} < 0, R = \sigma_{\text{max}} / \sigma_{\text{min}} \)
Under the condition of, can get:

\[ [\sigma_{a,\sigma_{\text{min}}} = 0.8[\Delta \sigma] 1 \leq R \leq 1 \]

2.5. German welding society DVS1612 standard
This method is a specific criterion for the design and durability strength evaluation of welded steel structures for railway locomotives and vehicles, which is obtained by the German Welding Society in years of practical exploration. It includes a large number of allowable strength data required for welded joints, as well as the transverse bearing butt weld joints that fail at the weld toe. At this time, the lowest design value needs to reach 83MPa, and the notch level is E1, PS is about 99.5%, and the safety factor S is 1.50. As shown in Fig. 3 below, it is the fatigue diagram of the transverse bearing butt weld joint when DVS1612 criterion is applied:

![Fatigue diagram of transverse bearing butt weld joints with DVS1612 criteria](image)
3. Result analysis

3.1. Enhance fatigue strength

Although the Japanese industrial standard proposed allowable fatigue stress for welding seam grinding correction, the variation of fatigue strength after welding seam grinding under different cycle conditions was also different because there was no uniform linear mean stress correction equation for shoes. Under the condition that the average compressive stress continues to decrease and the average tensile stress continues to increase, the increase range of fatigue strength will be smaller and smaller. Under the condition of symmetrical circulation, the fatigue strength can be increased by 57% by grinding the weld. The IWS recommendation document focuses more on various welding seam correction processes, such as shot peening, grinding, hammering, etc., and requires the use of structural steel with base metal not exceeding 355MPa, and the weld hot spot stress S-N curve should be increased by 2 grades. In other words, for FAT100 and FAT90 to rise to FAT125 and FAT112, the corresponding fatigue strength will also rise by 25%. In the research and analysis of DVS1612 criterion, the repair process of the redeemed weld is regarded as the main factor to distinguish the notch grade, and the increase of the actual fatigue strength is mainly reflected in the selection of higher notch grade. B12/PR17 does not put forward a clear provision for the fatigue strength of welding seam repair process, and it has become one of the most common methods used in the current bogie welding seam structure selection, so it is necessary to add the corresponding allowable fatigue stress. Since the average value of B12/PR17 welds is very close to the value range of the IWS recommendation document, the fatigue strength improvement of the weld modification process can be regulated accordingly.

3.2. Results

First, B12/PR17 is very close to the average value of the structural stress of FAT100 as stated in the IWS Recommendation Document, and a more idealized structural stress is more conservative. Secondly, the correction method of maximum allowable tension and compression stress and average stress proposed by DVS1612 criterion of German Welding Society is the best research result of the industry at present, and the former further improves the related content of B12/PR17 and promotes its development pace in practical application. The results produced by the latter are less different from those produced by the IWS Recommendation Document; Thirdly, the survivability of allowable fatigue stress design values proposed in IWS Recommendation Document meets the structural design requirements of current welding structures and has a very high safety margin. Fourth, according to the results of many practices, the recommended document of the International Institute of Welding puts forward the allowable fatigue stress in line with the butt-weld and fillet weld, and puts forward the improvement countermeasures for the weld treatment, so as to improve the fatigue strength. Fifth, the international society for welding proposal document show s-n curve is used to weld the allowable fatigue stress, so that both can thus calculated cumulative losses and life prediction of research, and could be changed according to the practical data clear the corresponding mean stress correction equation, thus obtains the corresponding fatigue diagram, in order to provide effective basis for endurance limit evaluation. As shown in Fig. 4 below, it is the S-N curve of the structural stress of Q345 steel weld. According to the parameter requirements proposed in the recommendation document of the International Institute of Welding, the slope of the curve is regarded as 3.0, the number of constant amplitude fatigue limit cycles is controlled as 1×107 times, and the actual average tensile
stress is $R \geq 0.50$. It plays a positive role in the actual bogie welding seam structure selection and life prediction[7].

![S-N curve of structural stress for Q345 steel weld](image)

**Fig. 4** S-N curve of structural stress for Q345 steel weld

**4. Conclusion**

To sum up, strength test verification, as an important work to ensure the service safety of bogie welded structure, requires the application of scientific data related to allowable fatigue strength. For the welding of structural stress in China at the present stage allowable fatigue stress data analysis methods used by more and more, but more problems, and combined with this paper, according to the practice to explore contrast to system in practical application, all kinds of structural stress method and the data, the difference and connection between the more appropriate correction method is put forward, in order to get more accurate fatigue strength data.

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