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Research on the stamping residual stress of steel wheel disc and its effect on the fatigue life of wheel

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A B S T R A C T

The steel wheel is an important safety component of a passenger car, which mainly consists of wheel disc and rim. The steel wheel disc is generally formed by the stamping process, and in this process the great residual stress is generated in the surface which may significantly affects the fatigue life of the wheel. In this paper, a method is proposed to introduce the stamping residual stress of steel wheel disc so as to predict the fatigue life of the wheel accurately. Firstly, the residual stress is obtained from the simulation of stamping process, and the experimental verification is conducted. Then the operating stress is simulated based on the cornering fatigue test. Finally, these two stresses are superposed to predict the fatigue life of the steel wheel. The results show that the predicted fatigue life using this method is closer to the experimental one than the fatigue life without considering the residual stress. The proposed method may provide an accurate and effective tool for predicting the fatigue life of the steel wheel in the cornering fatigue test.

1. Introduction

As an important safety component of a vehicle, the steel wheel mainly consists of wheel disc and rim. The wheel disc is generally manufactured through the forming processes such as stamping process and spinning process, which is assembled with the rim by interference assembling process and welding process. The state of the residual stress is changed and redistributed in each process. Thus the comprehensive and complex residual stress is produced in the manufacturing process. After installed to the vehicle, the automotive wheel will bear the load from the vehicle gravity and the dynamic loads from starting, braking, turning and road roughness. Therefore, in the running process, a great operating stress is generated. When the operating stress and the residual stress exist simultaneously, the original operating stress distribution of the steel wheel disc is changed. Obviously, to investigate the residual stress and its effect on the fatigue life is necessary.

Nowadays, few literatures about the effects of the residual stress on the fatigue life of steel wheel are published. Seo et al. [1] evaluated residual stress of web plate in railway wheel by heat treatment due to the manufacturing process and changes of residual stress using finite element analysis. They determined the cyclic stress history for fatigue analysis by applying finite element method and then performed the fatigue strength evaluations of the web plate to investigate the effects of the residual stress. Liao et al. [2] proposed a grid mapping method to consider the forming effects and imposed the residual stress as initial stress. The study results indicated that the analysis considering forming effects may give good results more approaching the test ones. Wang et al. [3] proved residual stress in the sizes after unloading of the specimen through the experiments of loading-unloading on some weld specimens, obtained the distribution coefficient of residual stress and brought forth general formulas of the dimensional change of welded structure caused by the superposition of residual stress and working stress. Shiozaki et al. [4] studied the effect of residual stress on the reverse bending fatigue strength of steel sheets with tensile strength grades of 540 MPa and 780 MPa and estimated the effect of the residual stress on fatigue limits of the edges by the modified Goodman relation.

But up to present, authors do not find a literature on the effects of the residual stress on predicting the fatigue life of the steel wheel of a vehicle although it is important. In this paper, a method is proposed to introduce the stamping residual stress of steel wheel disc so as to predict the fatigue life of the wheel accurately, in which the simulation of cornering fatigue test and fatigue life estimation considering the effects of the residual stress are performed

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by applying the residual stress to the wheel. The residual stress and the operating stress of wheel disc are simulated using PAM-Stamp software and ABAQUS software respectively, and then the two stresses are superposed to predict the fatigue life. The effects of the residual stress on the fatigue life prediction of the wheel is analyzed, and the predicted life is compared with the experimental one in order to verify the feasibility of the method.

2. Research on the residual stress of steel wheel disc in stamping process

The residual stress is easily produced in the surface of the wheel disc in stamping process since the recovery of plastic deformation is restricted when the external force is removed [5]. Usually this kind of residual stress caused by local plastic deformation is large and affects the stress state of the wheel disc. In this section, the residual stress of one type of wheel disc is obtained by the simulation of stamping process. There are four typical stamping processes in forming the steel wheel disc: the first three processes form different shapes of the wheel disc, while the fourth process is for outer edge flanging. In order to verify the accuracy of the simulation method, the experiments are conducted using the X-ray diffraction method.

2.1. Simulation of the residual stress

The thickness of the wheel disc can be accurately simulated and the cracking positions can be effectively predicted using PAM-Stamp software [6]. Here, this software is also used to obtain the residual stress of the wheel disc in the stamping process. The first three processes are simulated step by step in order to get the distribution of the residual stress of the wheel disc.

The material of the wheel disc is DP600 advanced high-strength steel with the initial thickness of 4 mm, and the other significant mechanical parameters affecting the forming results include density, elastic modulus, Poisson's ratio, yield stress, hardening coefficient and anisotropy parameters are shown in Table 1. The friction coefficient between the tool and wheel disc is 0.12 and the stamping speed is 40 mm/s. Hill48 anisotropic yield model of the steel material and Kinematic(Voce) law [7] are used in the finite element analysis of stamping process. The flow curve is shown in Fig. 1. The dynamic explicit algorithm is selected for the simulations of stamping process [8].

The stress distribution of the wheel disc after the first process is shown in Fig. 2, in which the residual stress of one circle is approximately invariant. The two principal stresses in radial and circumferential directions are shown in Fig. 3.

Then, the simulation results in first process including thickness, strain, stress et al. are transferred into the second process for further forming analysis. Similarly, the second and the third processes are also simulated, and the corresponding results are also transferred into the next process. Figs. 4 and 5 show the distribution of two principal stresses of the residual stress after the second and third stamping processes. The results of the three processes show that the areas with large residual stress mainly locate at

Table 1
DP600 material parameters.

Density (g/cm^3)	7.8	Hardening coefficient	0.23
Elastic modulus (MPa)	210	Anisotropy parameters	R_0: 0.96
Poisson's ratio	0.3		R_{45}: 0.74 R_{90}: 1.05
Yield stress (MPa)	582	Thickness (mm)	4

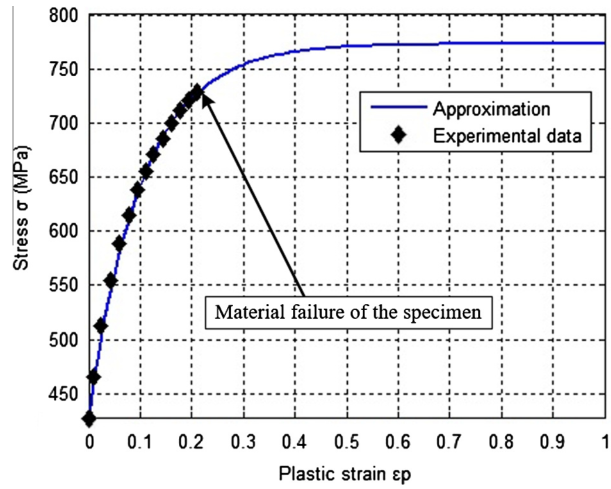

Fig. 1. Approximation and extrapolation of tensile test results.

the complex deformed positions near the bump ring and the bolt holes (shown in Figs. 4 and 5).

2.2. X-ray diffraction method measurement of the wheel disc

The testing methods of the residual stress are divided into two categories: the destructive testing method (stress release method) and the nondestructive testing method (physical method). As one of the nondestructive testing methods, the X-ray diffraction method is most commonly used. The basic principle of X-ray diffraction method is: the crystalline interplanar spacing of the material is inevitably changed when there are internal stresses in polycrystalline materials, which can be reflected in the X-ray diffraction line, and then the measurement of the residual stress is achieved through the analysis of this diffraction information [9]. The relation by which diffraction occurs is known as the Bragg law or equation [10]:

$$n\lambda = 2d\sin\theta \qquad (1)$$

Here the X-ray diffraction method is used to measure the residual stress of the wheel disc. The method for determining peak position is parabola method, which has high precision when the peak shape of the X-ray diffraction is diffused. The X-ray diffractometer is made by Rigaku Corporation, and its model is MSF-2M. The area of measured point is ϕ5 mm. Since the X-ray penetration depth is very small for general metal plate (about 10 μm), the residual stress component in the normal direction of the surface is not taken into account.

A local coordinate system is set up for each measured point, of which the X-axis along the radial direction and the Y-axis along the circumferential direction. The residual stresses on two directions are measured, as shown in Fig. 6.

In the test process, the X-ray emitter and receiver rotate at a certain angle (depending on the tested materials) along the specific direction of the residual stress. A great bending deformation near the measured points may cause that the X-ray emitter and receiver impact the wheel disc. Therefore, the principle of choosing the measured points is: there is no great bending deformation near the measured points. So some representative points of three processes are selected to be shown in Figs. 7–9, of which three points, four points and six points are selected in the first, second and third stamping processes, respectively.

The principal stresses of the residual stress and its directions need to be measured and calculated by experiment. Although there are thirteen points are measured to obtain the residual stress, for