

Analysis of Residual Stress and Deformation of Rolling Strengthen Crankshaft Fillet

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Abstract. Based on the analysis of crankshaft fillet rolling process, used ANSYS finite element analysis software to conduct the elastic-plastic mechanical simulation of crankshaft rolling process, and gained the variation law of the residual stress and plastic deformation in the radial path of the fillet under different rolling laps and rolling pressure. Established the relationship between the rolling pressure and the plastic deformation and residual stress of the fillet, and provided theoretical support for the evaluation and detection of the crankshaft rolling quality.

Keywords: Fillet rolling, Residual stress, Plastic deformation, Rolling pressure

1 Introduction

The maximum load and fatigue strength that crankshaft can bear directly determine the quality and life of the engine, therefore, the requirement for the quality of the crankshaft is higher and higher. At present, the fillet rolling process is one of the important means of improving the fatigue strength of crankshaft. Rolling process makes the shallow layer of crankshaft fillet produce intense plastic deformation, and grain dislocation density is increased, then compressive stress comes into being, which can counteract alternating tensile stress in the working process in order to improve the fatigue strength^[1,2]. The distribution of the residual compressive stress generated by the crankshaft after rolling is the important evaluation of the rolling effect, but it is very difficult to determine the residual stress generated by the rolling reinforcement. Therefore, the study on the changing law of residual stress and plastic deformation in the process of crankshaft fillet rolling is of great significance for further perfecting the theory of crankshaft rolling reinforcement and improving the quality of rolling processing^[3,4]. In this paper, the ANSYS / LS-DYNA is used to simulate and analyze the crankshaft rolling process, and to study the size and distribution of the radial residual stress and the plastic deformation of fillet at the neck of crankshaft connecting rod under different rolling pressure and rolling laps, which provides reference and theoretical support for the evaluation and detection of rolling quality of crankshaft fillet.

2 The Establishment of Finite Element Analysis Model of Crankshaft Rolling

2.1 Simplified Crankshaft Rolling Model.

According to the symmetry of the single-throw crankshaft model, the crankshaft is simplified to a half single-throw structure model that consists the neck of connecting rod and the crank arm, and the models of the half single-throw, roller and roller pin are set up in LS-DYNA, and the compositive rolling model is as shown in Fig. 1^[5]. The key parameters of ductile iron crankshaft are as follows: the diameter of connecting rod neck is 39mm, the radius of the connecting rod neck fillet is 1.6mm, the density is 7830 kg/m³, the elastic modulus is 1.69×10^{11} Pa, the Poisson's ratio is 0.28. The roller model is set a rigid body, and the key parameters are: the roller diameter is 15mm, the density is 7800 kg/m³, the elastic modulus is 2.1×10^{11} Pa, the Poisson's ratio is 0.3, the angle is 30°.

2.2 Crankshaft Rolling Finite Element Model and Related Conditions Definition.

Define the unit type of the neck of connecting rod and the crank arm as SOLID164 unit, the two end faces of the crankshaft as SHELL163 unit, the unit type of roller and roller pin as SOLID164 unit. Set the material properties. Respectively adopt the mesh division methods of mapping, freedom and sweeping for the crankshaft model.

The rolling model contains contact of fillet with roller, and contact of roller with roller pin, and choose the automatic contact way for both of the two contacts. The static and dynamic friction coefficient of the contact of the fillet and the roller are respectively set 0.1 and 0.05, and the friction coefficient of the contact of the roller and the roller pin is neglected.

In order to make the crankshaft rotate around its center line in the rolling process, constraining all the sliding pairs of the crankshaft and the revolute pairs in the radial and circumferential directions. Constraining the sliding pairs and the revolute pairs in the radial direction of the roller to ensure it rotates around its center line; At the same time constraining the sliding pairs in the radial direction of the roller pin and all revolute pairs of the roller pin to get the constrained finite element model as shown in Fig. 2.

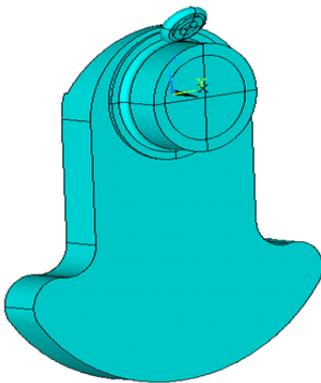


Fig. 1 Simplified rolling model

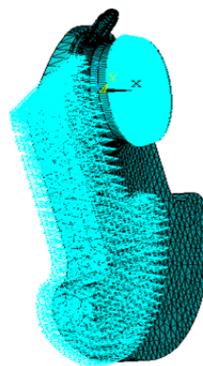


Fig. 2 Constrained finite element model of crankshaft rolling

The loads infliction includes the crankshaft rotation speed and the rolling pressure of the roller. In the first lap of rolling the speed linearly increased from 0 to 60r/min, linearly down to 0 in the last lap, and the speed of the rest of the rolling process was kept at 60r/min. Rolling pressure was respectively chosen 4500N, 5500N, 6500N, 7500N, 8500N, and the rolling pressure on the roller was decomposed to the axial and radial directions^[6].

3 Results Analysis

In this paper, the variation of the residual stress and plastic deformation of the fillet after crankshaft rolling is analyzed by changing rolling laps and rolling pressure. Choose the variation of each node in radial path of the fillet that can be more directly response to the rolling effect as the research target, and the change of this direction is also the key to measuring the quality of crankshaft rolling, and the path where point A is the starting point, point B is the end point is shown in Fig. 3^[7].

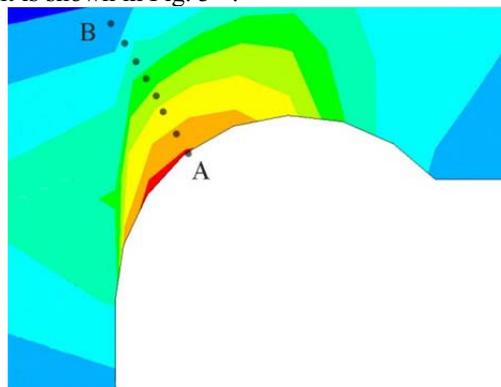
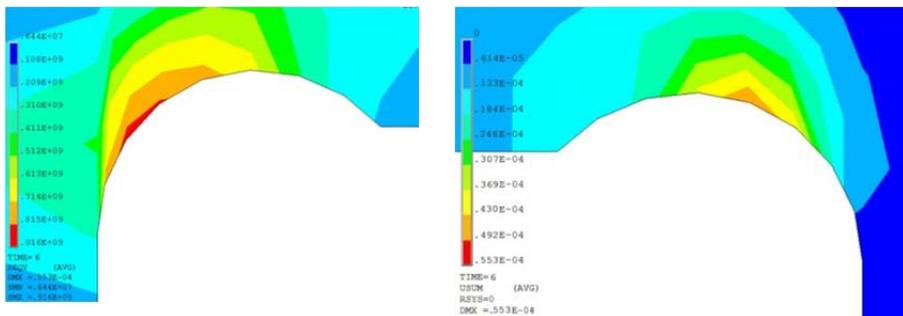


Fig. 3 Diagram of the radial path of the fillet

3.1 The Influence of the Rolling Laps on Rolling Quality.

Fig. 4 is the residual stress and plastic deformation nephograms of the crankshaft fillet after rolling for six laps under 6500N rolling pressure. It can be seen from the diagram that the residual stress and plastic deformation of the crankshaft after rolling are concentrated on contact points of the fillet, and the closer the point is to the surface, the larger the value will be.



The residual stress nephogram The plastic deformation nephogram
Fig. 4 The equivalent residual stress and plastic deformation nephogram of the fillet
in radial path after six laps

The residual stress and plastic deformation of the crankshaft in different rolling laps are mapped to the radial path, and the corresponding numerical curves are shown in Fig. 5 and Fig. 6.

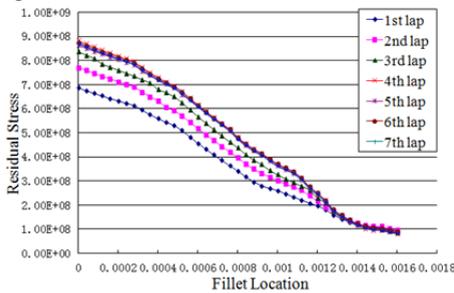


Fig. 5 Diagram of residual stress under different laps in radial path

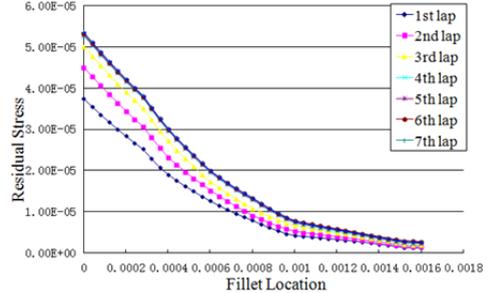


Fig. 6 Diagram of plastic deformation under different laps in radial path

It can be seen from Fig. 5 that the residual stress decreases with the increase of depth, and the stress tends to be stable when the depth reaches 1.60mm. At the same time, with the increase of the rolling laps, the residual stress in the contact area of the fillet is increased obviously, and the residual stress in the fourth lap to the sixth lap is fluctuating within a small area, and the residual stress tends to be stable after 6 laps. It can be seen that the significance of increasing rolling laps after it reaches a certain number of laps is to maintain the acquired residual stress.

It can be seen from Fig. 6 that the plastic deformation of the fillet after rolling is gradually decreased with the increase of depth, and the plastic deformation is very small when the depth is 1.60mm. At the same time, with the increase of the rolling laps, the plastic deformation of the fillet surface increases gradually, and the plastic deformation tends to be stable after 4 laps. The plastic deformation is closely related to the residual stress of the crankshaft fillet, the change rule of both is basically the same, the difference is that after 4 laps, the convergence of the plastic deformation is fast and tends to be stable.

3.2 Influence of the Rolling Pressure on Rolling Quality.

Fig. 7 is the residual stress and plastic deformation nephograms of the crankshaft fillet under 6500N rolling pressure with a setting of rolling laps for 7 laps, and it can be seen from the diagram that the deformation distribution layer is uniform.

The residual stress and plastic deformation of the crankshaft under different rolling pressure are mapped to the radial path, and the corresponding numerical curves are shown in Fig. 8 and Fig. 9.

The relationship between the residual stress and depth shown in Fig. 8 is consistent with that in Fig. 5. At the same time, with the increase of rolling pressure, the residual stress on the fillet surface gradually increases, and the increase of the residual stress is more obvious when the rolling force is within 4500N to 6500N, and the residual stress changes little and tends to be stable after the rolling pressure reaches 6500N.

The relationship between the plastic deformation and depth shown in Fig. 9 is consistent with that in Fig. 6. At the same time, with the increase of rolling pressure, the change tendency of the plastic deformation on the fillet surface is basically the same as that of the residual stress.

By analyzing the effects of rolling pressure on plastic deformation and residual stress, the relationship among the rolling pressure and the maximum plastic deformation and residual stress of the fillet are established, as shown in Table 1.

Table 1 the maximum plastic deformation and residual stress of the fillet contact area under different rolling pressure

rolling pressure (N)	4500	5500	6500	7500	8500
plastic deformation (μm)	23~25	40~42	52~54	55~57	58~59
residual stress (MPa)	530~560	720~750	850~880	890~910	920~930

3.3 The Comparison of the Results of the Simulation and the Profile Measurement.

The crankshaft after rolling is often judged by detecting the plastic deformation of fillet to decide whether it is qualified or not, and by intercepting the effective part of the fillet profile manually, the measurement software fits out the fillet arc before and after rolling to obtain the coordinate of the circle center and radius, and the plastic deformation is obtained^[8]. Fig. 10 is the measurement results of a crankshaft fillet before and after rolling under 6500N rolling pressure, and the press-in also called the plastic deformation is 54 μm , and the pressure angle is 28.70°, and the results are consistent with that of finite element analysis, which verifies the accuracy of the analysis.

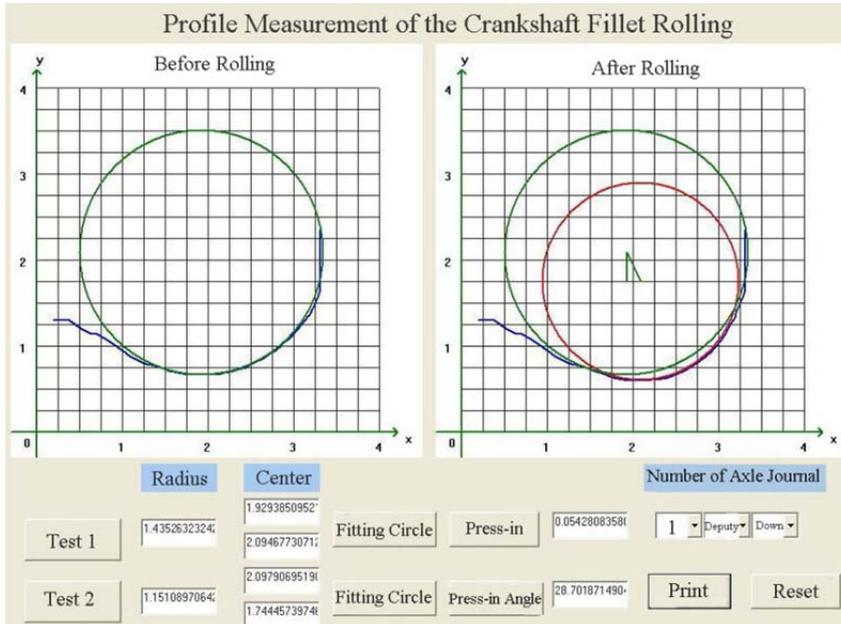


Fig. 10 The measurement results of the deformation of the crankshaft fillet before and after rolling under 6500N rolling pressure

4 Summary

In this paper, the changes of the residual stress and plastic deformation of the fillet under different rolling force and rolling laps are obtained by simulating and analyzing the rolling process of the crankshaft fillet.

(1) with the increase of the rolling laps, the residual stress and plastic deformation of the crankshaft fillet are increased, and respectively tend to be stable after a certain number of laps.

(2) with the increase of the rolling pressure, the plastic deformation of the crankshaft fillet intensifies, and the residual compressive stress on the surface increases continuously. When the rolling pressure increases to a certain extent, the plastic deformation of the fillet material has been very sufficient, and the residual stress tends to be stable. The study provides theoretical support for the selection of the rolling pressure and the detection of the quality of the crankshaft rolling.

References

1. Xiaoqiang Shi, Xudong Zhou. Summary of Surface Rolling Techniques for Crankshaft, *J. Internal Combustion Engine & Parts*, 2005, (6):26-29. In Chinese.
2. Hongbing Zhao, Chenhai Guo, Fuxiang Liang. The Research on Residual Stress Distribution of Rolled Crankshaft Fillet, *J. Small Internal Combustion Engine and Motorcycle*, 2012, 41(2):33-36. In Chinese.
3. Xiaobing Sheng. The Research of The Deformation in the Rolling Process for Strengthen Crankshaft[D]. Wuhan: Wuhan University of Technology (2008). In Chinese.

4. Zhenhua Lai. Research on Variable Force Crankshaft Rolling and Deformation Rule[D]. Wuhan: Wuhan University of Technology (2006). In Chinese.
5. Rui Zhang, Rongqiang Hu, Peiyi Wang, Xiuzhi Yang. Simulation of Fillet Rolling Processing for Crankshaft, *J. Hot Working Technology*, 2009, 38(19):101-104. In Chinese.
6. Rongchang Liu. Research on Crankshaft Parametric Finite element Analysis System and Design Theory of Key Parameters in Crankshaft Rolling Process[D]. Xi'an:Xi'an University of Technology (2005). In Chinese.
7. Rui Zhang. Study on Strengthen Theory and Key Technologies of Crankshaft Fillet Rolling[D]. Wuhan: Wuhan University of Technology (2010). In Chinese.
8. Xiaoqiang Wang, Bing Li, Zhuangde Jiang. Development of Software System for 2D Profilograph with Stylus, *J. Bearing*, 2007, (7):37-40. In Chinese.