Study of Strength and Shear Behavior of Fracture Splitting Connecting Rod

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Abstract. By reverse engineering, this paper restores three-dimensional joint surface of fracture splitting con-rod, according to the morphological features of the fracture surface. Then the finite element model is gained to calculate the stress and deformation of the fracture splitting con-rod, fracture surface and bolt. Compared with traditional machined planar con-rod, the strength, bearing capacity and shear strength of the fracture splitting connecting rod are analyzed and evaluated.

Introduction

Connecting rod is an important component of the engine which mainly bears the gas pressure, bolt preload and tensile, compression, bending and other high-frequency alternating load [1]. The service conditions are harsh and motion states are complex.

Fracture splitting is the latest technology of connecting rod production. Compared with the traditional manufacturing process, it improves production efficiency, reduces processing procedures, lowers production costs [2]. The biggest difference between the fracture splitting con-rod and the machined con-rod is the morphology of the junction surface. The strength analysis of traditional con-rod can not reflect the situation of the fracture splitting con-rod. In this paper, according to the morphological characteristics of the fracture surface, the joint surface is restored. The three-dimensional model of fracture splitting con-rod is established. The finite element simulation software is used to calculate and analyze the force and deformation of fracture splitting con-rod. Compared with the traditional con-rod, the strength, load-bearing capacity and shear resistance of the fracture splitting connecting rod are studied.

Three-dimensional Model of Fracture Splitting Con-rod

Because of the irregularity and complexity of the fracture surface, how to real and effective restore the fracture surface is a very critical problem. By scanning the fracture surface, point cloud data are obtained. And then by quantitative analysis, the area of fracture surface is gained. Finally, the 3D model of the fracture surface con-rod is established.

Digital Fracture Surface

After con-rod splitting processing, a small part including the fracture surface is cut off from cap or rod whose quality are qualified and have no defect, as shown in Figure 1.

![Figure 1. The experimental scan sample.](image-url)
Using a non-contact measurement method, the three-dimensional point cloud data of the fracture surface are collected by scanning system. After removed the noise points, the data of point cloud are obtained as shown in Figure 2.

![Figure 2. Graphic of point cloud data.](image)

Area of fracture surface are obtained through the data processing and three-dimensional surface reconstruction [3]. Through data statistics, the maximum distance from crest to trough is \( \pm 1 \text{mm} \). Comparison area of fracture surface and machined, the statistical calculation results are as follows table 1. The area processed by fracture splitting than the machined average increase of 13.28\% [4].

<table>
<thead>
<tr>
<th>sample number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>reconstructed area((\text{mm}^2))</td>
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<td>169.14</td>
<td>163.65</td>
<td>171.23</td>
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<tr>
<td>plane area((\text{mm}^2))</td>
<td>148.94</td>
<td>149.88</td>
<td>143.84</td>
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<tr>
<td>increased area((\text{mm}^2))</td>
<td>19.55</td>
<td>19.26</td>
<td>19.81</td>
<td>20.23</td>
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<td>Increase(%)</td>
<td>13.12</td>
<td>12.85</td>
<td>13.77</td>
<td>13.39</td>
</tr>
</tbody>
</table>

### Three-dimensional Model of Fracture Surface

The fracture surface is unique and three-dimensional morphology vary widely. Both the area of the fracture surface and the distance of crest and trough are taken into account. Then, on the basis of the theoretical interface, the UG is used to obtain the fracture surface by sweeping spline curve. The three-dimensional model of the bonding surface is shown in Figure 3.

![Figure 3. Three-dimensional diagram of junction surface.](image)

### Finite Element Modeling

#### Finite Element Model

In this paper, the finite element model of the engine connecting rod is established by ABAQUS software. The mesh is encrypted at the junction surface of big end and cap. The model is shown in Figure 4. The material of connecting rod is high carbon microalloyed non-quenched and tempered steel C70S6 whose stress-strain curve is shown in Figure 5. As can be seen, the tensile strength of C70S6 is 932MPa and the yield strength is 578MPa.
Contact and Boundary Conditions

The con-rod assembly includes rod, cap, bolt, bushing and a bearing pad. They are integrated into one unit and are connected to the piston pin and the crank pin. A total of 12 pairs of contact are established, respectively: piston pin and bushing, bushing and small end, upper bearing bush and big end, under bearing bush and cap, upper and lower bearing bush (two pairs), upper bushing and crank pin, lower bushing and crank pin, con-rod and cap, cap and bolts (two pairs) [5]. The bolts and con-rod are bound. And the degree of freedom in the six directions of the crank pin is limited.

Strength Calculation and Analysis of Connecting Rod

Force Analysis of Connecting Rod

During the operation of connecting rod, the two most dangerous conditions are the maximum compression caused by the cylinder pressure and the maximum tensile condition generated by reciprocating inertia force of connecting rod group [6]. One condition occurs at the ignition top dead center (produce maximum tension stress) and one at the exhaust top dead center (produce maximum compressive stress). It is considered that if the two most dangerous working conditions meet the strength requirements, the connecting rod meets the strength requirement during the whole working process [7]. For this reason, using the above-mentioned three-dimensional finite element model carries on the strength analysis to the maximum detonation pressure condition and the maximum tensile condition.

Strength Calculation of Connecting Rod

The key parts of the con-rod are included: small end; big end; shank; transition between shaft and small, big end. The stress distribution of the splitting con-rod and the traditional machined con-rod at the critical position are contrasted and analyzed.

Figure 6 shows the equivalent stress distribution of the two con-rods at maximum tensile condition. It can be seen, the equivalent stress distribution of two kinds of con-rods are similar, and
the maximum stress appears inside of the small hole. The maximum stress of the fracture splitting con-rod is 235MPa and the machined con-rod is 278MPa. The contact area of big head and nut also appears large stress concentration. The stress of the other parts of the connecting rod is relatively small. The stress of the machined connecting rod is greater than that of the fracture splitting con-rod at maximum tensile condition.

Figure 7 shows the equivalent stress distribution of the two con-rods at the maximum burst pressure condition. Small head hole connection with shaft, transition between shaft and big head all under high stress. The maximum stress appears at the transition between the small hole and the shaft. The fracture splitting con-rod is 279MPa, and the machining rod is 312MPa. The machining connecting rod is obviously larger than the fracture splitting con-rod.

The stress in the critical parts of fracture splitting con-rod are much less than the yield limit of C70S6. So it meets the static strength requirement. And in both cases, the stress of the various parts of the fracture splitting con-rod are less than that of the traditional processing rod. It can be concluded that the fracture splitting con-rod has higher strength, stability and reliability.

**Strength Analysis of Fracture Surface**

The fracture surface is the most important characteristic of the fracture splitting con-rod. Therefore, it is necessary to further analyze the stress distribution on the joint surface. Figure 8 shows the equivalent stress distribution of the two kinds of rods on the joint surface. It can be seen from figure that stress is reduced from the bolt hole to the upper and lower end, in the joint surface along the con-rod thickness direction (path 1 direction). Along the radial direction (path 2 direction), the stress of the joint surface decreases gradually. The stress of the surface of fracture splitting con-rod is greater than that of the machined con-rod. The stress on the two bonding surfaces are relatively small, all below 60MPa.

The stress on the fracture surface is slightly higher than the stress on the machined plane. It is because that the uneven bounding surface bears part of the force, hence the force on the bolt is significantly reduced. However, the stress of the connecting surface is far less than the other parts of con-rod.
Analysis of Shear Resistance of Bolt

The shear stress of the bolts is shown in Figure 9. It can be seen from the figure, bolts of con-rod under the shear stress is more complex. On the joint surface of the bolt, contact zone of screw and nut, the outer edge of the nut all have a greater shear stress. The bolt of fracture splitting con-rod bears the maximum shear stress is 48.39MPa, while the machined con-rod bolt is 95.45MPa. Bolt of machined connecting rod under shear stress is twice times that of fracture splitting con-rod. Therefore, the fracture splitting con-rod has better ability to resistance to shear. It is because the fracture splitting con-rod increases the area of bonding surface. And fracture surface bears part of the force, so that the force of the bolt is reduced. The bearing capacity of connecting rod, especially the shear capacity increased significantly. This increases the bolt safety, thereby increasing the reliability of the entire con-rod assembly.

Conclusions

1. Using reverse engineering to obtain point cloud data, the surface area is determined by surface reconstruction. The area of the bounding surface of the fracture splitting con-rod increased by 13% compared to plane con-rod.
2. Based on the area of fracture surface, the finite element 3D model of the splitting con-rod is established.
3. In the same working condition, the stress of all parts of the fracture splitting con-rod are lower than those of the traditional machining con-rod. The maximum stress appears at the transition between the small head hold and the shaft. Machined con-rod is 312MPa and fracture splitting con-rod is 279MPa which are far below the yield limit of 578MPa, meeting static strength requirements.
4. Bolt of machined connecting rod to withstand the shear stress is twice as the fracture splitting con-rod. The fracture splitting con-rod increases the area of the joint surface and bears part of the force, so the bearing capacity, especially the shear capacity increases significantly. It increases bolt safety and improves reliability of connecting rod groups.

In conclusion: fracture splitting con-rod has higher strength, better positioning accuracy, stronger load bearing capacity, shear capacity and is more reliable and safer than machined con-rod.

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References


