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Study on Cracking Mechanism of Hardened Planetary frame

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Abstract. Planetary carrier made by 45 steel appear quenching crack, which is analyzed in chemical composition, hardness test and metallographic microscopic structure. The reasons of quenching crack of planetary gear include the unreasonable structure of the planetary carrier, thinner annular wall on the base of the upper part, and in dangerous area of the 45 steel in the process of quenching. The faster cooling rate of quenching results in a centripetal stress with the thick-wall part, which is greater than the ultimate bearing capacity of the material.

1. The macroscopic morphology of quenching crack of the planetary carrier

The crack of 45 steel planetary carrier material in the quenching process, its location and morphology is shown in figure 1.

Figure 1. Position and morphology of quenching crack of planetary carrier.

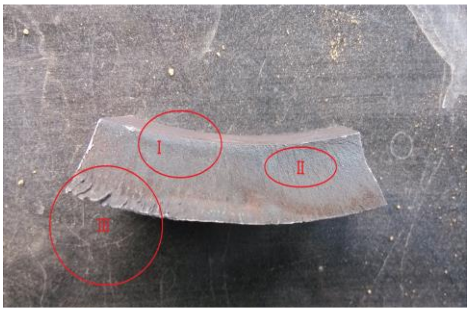

Figure 2 Macroscopic morphology of quenching crack.

Quenching crack appears on the inside of the annular upper part of the base of the planet carrier (thickness 10mm, depth 17mm, see figure 1). The crack extends radially to the inside of the annular portion at about 45 °and along the circumferential direction, upwards and towards both sides, causing large crack of the annular portion. The macroscopic morphology of the quenching crack is shown in figure 2.

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It can be seen in figure 2, the crack starts at position I, rapidly expands outward at position II, cracks at position III, which is a significant final rupture region.

2. Chemical composition of steel of planetary carrier

After analyzing spectrum of steel component of planetary carrier, the analytical results are shown in table 1.Table 1 shows that the chemical composition of the steel is in line with the 45 steel technical requirements in GB699-1988 "steel technical conditions of high-quality carbon structure"[1].

Table 1. Chemical composition of steel for planetary carrier (wt%).

Chemical composition	C	Si	Mn	P	S	Cr
Content	0.46	0.21	0.70	0.026	0.009	0.10
StandardGB 699－88	0.42～0.50	0.17～0.37	0.50～0.80	≤0.035	≤0.035	≤0.25

3. The hardness test of the planetary carrier

With the hardness test of the cracked parts, the average hardness of six parts is HRC31.2 (see table 2), in line with quenching and tempering requirements of 45 steel plate[2].

Table 2. Hardness test results.

Hardness /HRC	Average value /HRC
31，30，32，31，32，31	31.2

4. Metallographic microscopic structure of planetary carrier and its analysis

Choosing the crack site samples for metallographic microscopic structure analysis[3], as shown in figures 3 and 4, figure 3 shows the metallographic microscopic structure in the center of the annular site, and figure 4 shows the metallographic microscopic structure at the initial stage (Position I, figures 2).

(a) ×200

(b) ×500

Figure 3. Metallographic microscopic structure in the center of the annular site.

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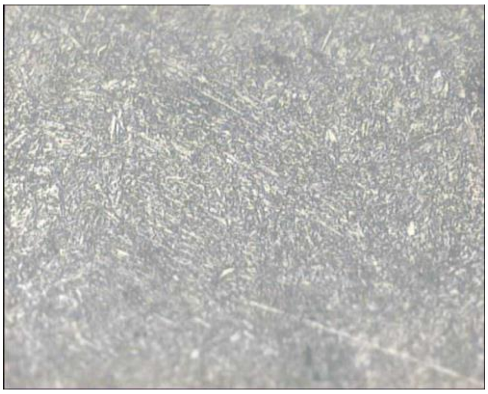
The Metallographic microscopic structure of the crack at the initial stage is also the tempered sorbite structure with homogeneous distribution(see figure. 4), consistent with the theoretical results.



×500

Figure 4. Metallographic microscopic structure of crack at the initial stage.

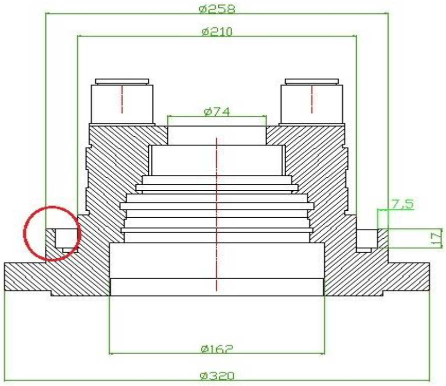


Figure 5 . Structure Dimension Drawing of the planet carrier.

Comparision of figure 3 and figure 4, the metallographic microscopic structure is completely the same in the crack at the initial stage and the center of the annular site, namely, the tempered sorbite structure with homogeneous distribution, without uneven organization and impurity that may cause cracks in the metallographic microscopic structure. Therefore, it is possible to eliminate the potential of quenching crack due to harmful tissue[4].

5. Analyzing the reason for hardening break of planet carrier

Under normal conditions, the position of NO.45 steel easy to cause hardening break, including the part with thick wall and mutation, sharp coner of stage(Radius of round angle is smaller)[5]. Figure 5 is the Structure Dimension Drawing of the planet carrier.

The position with red circle in figure 5 is actual position of quenching cracking, the thickness of wall, smaller than other position clearly, belong the position easy to cause hardening break. Due to the small thickness of the wall, the actual cooling rate will be faster than that with the thicker wall (Lampstand of Planet carrier).In the process of quenching cooling, the cooling contraction of the annular part will precede the lower part (Lampstand of the Planet carrier), resulting in the asynchronism of cooling shrinkage.

In a moment, when the annular part nearly finish the cooling shrinkage, due to slower cooling rate of the bottom(Lampstand of planet carrier), its cooling shrinkage behavior fall behind the annular parts, and then the bottom(Lampstand of planet carrier) will continue to cooling contraction; meanwhile, the cooling contraction of the bottom will be limited by the annular parts, there will be a centripetal (contraction) stress on the root, when the stress exceeds the ultimate strength of hardened and tempered NO.steel, which will cause quenching crack; The quenching crack will start from the weakest part of the annular part, and then rapidly expand, eventually complete crack. On the other hand, the NO.45 steel dangerous size of quenching is 8~15mm, the wall’s thickness of annular part is just in the range, so that the possibility of quenching cracking greatly increased.Therefore, the size of the planet carrier is the direct reason to cause the quenching crack.

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6. **Conclusion**

The chemical composition of the planet carrier's NO.45 steel meet the standard; The hardness after quenching and tempering meets the requirements; Through metallographic analysis, the metallurgical structure of the planetary wheel is tempered martensite structure distributed evenly, there is no proeutectoid ferrite, inhomogeneous microstructure, impurity distribution and other phenomena, it can be excluded the possibility that quenching crack caused by abnormal microstructure.

The reason for quenching crack of planet wheel is that: In the process of quenching, due to the thickness of the annular position on the Lampstand is flimsy and the cooling rate is faster, which leads to the asynchronism between the cooling contraction of the position with thick wall and the annular position. The cooling and contraction of annular part limit the cooling and contraction of the position with thick wall, producing a centripetal stress, it will crack when the stress is greater than the ultimate capacity of the material. The thickness of the wall is in the dangerous dimension of quenching, which may lead to it crack after quenching. Therefore, the structure size of the planetary carrier is the direct reason to cause the quenching crack.

7. Comments and suggestions

7.1. Optimize the size of planet carrier's structure

The annular groove on the upper part of the Lampstand should be processed after quenching and tempering.Or enlarge the radius of the fillet on the root of the annular groove.

7.2 .Reduce the cooling speed of the annular part on the Lampstand

Adding an annular flat steel in the annular groove on the Lampstand before quenching .Or improve the placement of the workpiece in the quenching basket.

8. Reference

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