



Fracture analysis of chilled cast iron camshaft

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Abstract:

The fracture of a camshaft made of chilled cast iron, installed in a home-made Fukang car, happened only after running over a distance of 6,200 km. The fractured camshaft was received to conduct a series of failure analyses using visual inspection, SEM observation of fracture section, microstructure analysis, chemical composition analysis and hardness examination and so on, while those of CKD camshaft made by Citroën Company in France was also simultaneously analyzed to compare the difference between them. The results showed that the fracture of the camshaft mainly results from white section in macrostructure and Ledeburite in microstructure; the crack in the fractured camshaft should be recognized to initiate at the boundary of coarser needle-like carbide and matrix, and then propagate through the transverse section. At the same time, the casting defects such as dendritic shrinkage, accumulated inclusion and initiated crack and abnormal external force might stimulate the fracture of camshaft as well. Based on failure analysis, some measures have been employed, and as a result, the fracture of home-made camshafts has been effectively prevented.

Key words: camshaft; car; chilled cast iron; fracture; Ledeburite

Camshaft is one of the key parts or components in the engines of automobile and other vehicles. The performance is to control the open and close intervals of the inlet and exhaust poppet valves by its cams.

Due to the cyclic impact loading on the contacting surfaces of the cam and the follower, it often gives rise to premature wear of cam profile and affects a routine run of the valve gear such as the rotational speed, valve displacement and the torque. On the other hand, simultaneously the most serious, under cyclic bending and torsion, fatigue fracture of camshaft initiating at stress concentration easily occurs. Therefore it demands the camshaft has not only excellent wear resistance but also adequate anti-impact toughness^[1-2].

Many researches on improving wear resistance of cam and the follower by surface hardening have been reported in recent decades. The measures of surface hardening include phase transformation such as surface chilling and heat treatment, and precipitation processes occurring in the material during surface thermochemical treatment by ion nitriding and nitrosulphurizing or spraying of multicomponent layers and soon.

At present, almost all of camshafts are made of cast iron (chilled cast iron, nodular cast iron, surface hardened, and malleable cast iron, etc), steel (ion nitrided and nitrosulphurized, hardened steel) and so on. Moreover, chilled grey cast iron is commonly used worldwide for camshaft production^[6-7]. For such camshaft, just the cam surface is chilled to get high hardness containing transformed ledeburite without graphite during primary crystallization, while the crank does not need to be chilled to keep fatigue performance well with higher tensile strength and lower hardness. The material used for camshaft of Citroën car assembled by Dongfeng Citroën Automobile Company (DCAC) in Wuhan, China, is required to meet GLA1 chilled grey cast iron of PSA Group specification in France. The fracture failure of one camshaft occurred only after a running distance of 6,200 km. This paper presents the fracture analyses of the car camshaft and an improved measure to be recommended.

1 Experimental procedures

The chemical composition of the failed camshaft material was determined by using a standard spectrum analyzer. The fracture characteristic of the camshaft was studied by visual inspection and optical microscope and SEM observation. The microstructure was observed under optical microscope. Hardness test was performed by using Vickers Hardness



testing machine and HB 3000 Brinell hardness machine, respectively. Hardness (HB) test of the material for the failed camshaft was conducted with a steel ball of 10 mm (load of 3000 kg).

2 Results

2.1 Visual inspection

The fractured camshaft is shown in Fig.1. From Fig.1, it is found that the fracture had taken place in the journal region between exhaust cam and admission cam of the 2nd cylinder in the engine. Adherent fins at the molding parting of the fractured camshaft was not thoroughly trimmed, yet, as shown in Fig.2. In addition, there was obvious extruded trace on the interior wall surface of camshaft hole of cylinder head. White macroscopical section of the fracture zone shown in Fig.3 is significantly different from the camshaft from France shown in Fig 4

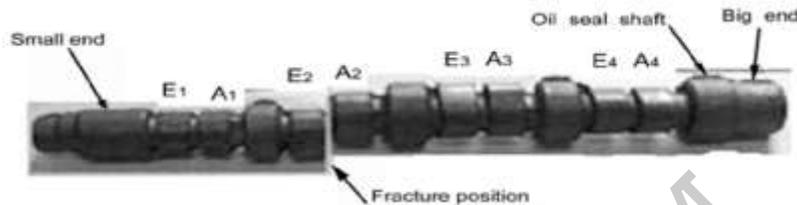


Fig.1 The photograph of the fracture camshaft

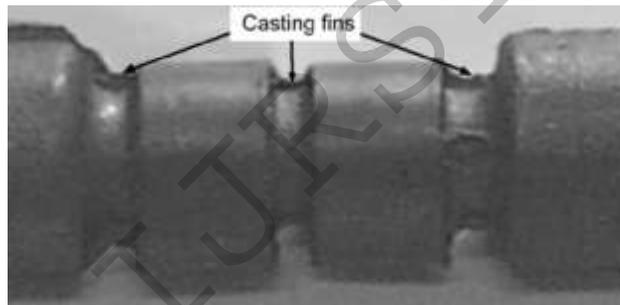


Fig.2 Casting fins at the molding parting

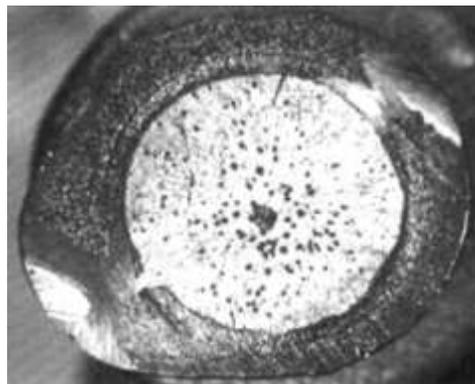


Fig.3 Macroscopical fracture section of the failed camshaft

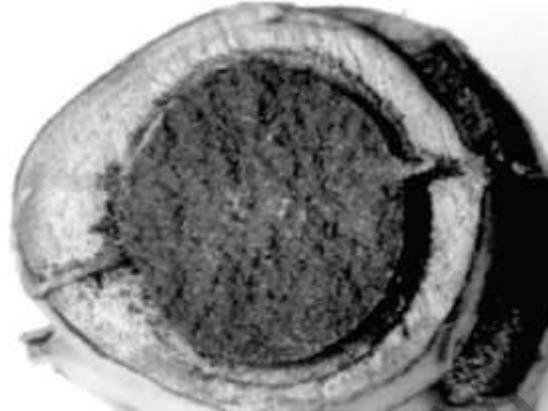


Fig.4 Macroscopical fracture section of the camshaft made by Citroen Company in France

2.2 SEM observation of fracture section

SEM image of fracture section of the failure camshaft is shown in Fig.5. From Fig.5, we can find the casting defects such as dendritic shrinkage and accumulated inclusion, together with initiated crack. The characteristics of the fracture section indicate the mechanism of brittle fracture of the camshaft material.

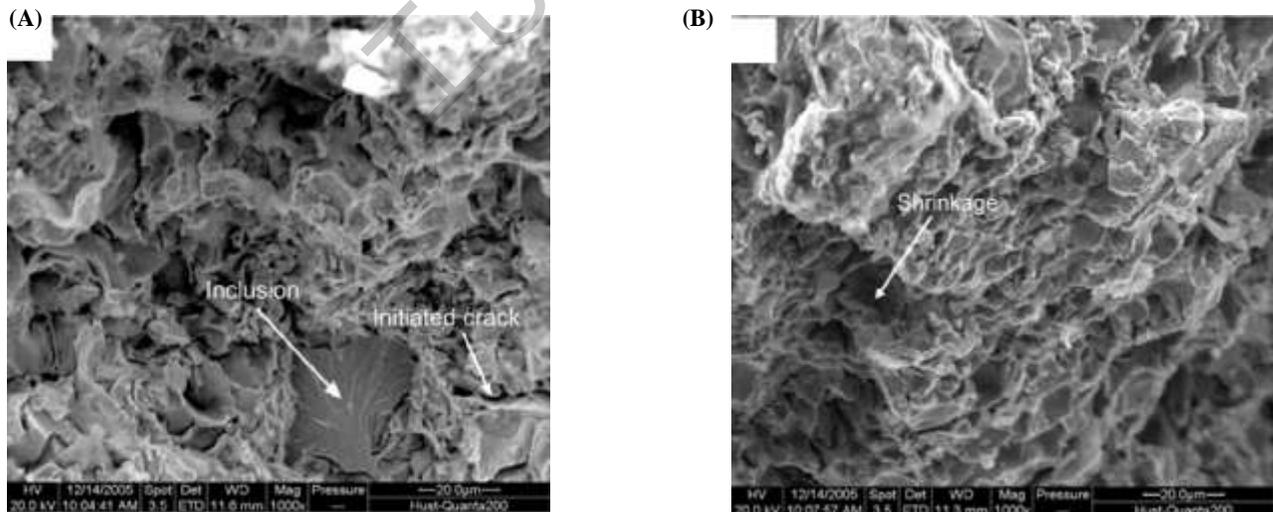


Fig.6 SEM images of fracture section of the camshaft



2.3 Microstructure observation

The specimens for the metallographic investigation were taken from the fractured zone of the failed camshaft and the corresponding position of the camshaft imported from France. The results are shown in Figs.6 –9, respectively. Graphitization degree of the fractured zone of the failed camshaft showed very slight, only a few D-type graphite and coarse Ledeburite were found in Fig.6 and Fig.7, respectively. The microstructure was out of specification required by the material standard of

PSA group of France, as shown in Table 1 and Figs.8 and 9

Table 1 Microstructure of car camshaft from material standard of PSA group in France

Position	Graphite	Matrix
Journal	A type + few D, E type	Pearlite + Ferrite, ≤ Carbide 5%
Cam	0.2% (Max)	Carbide + Pearlite

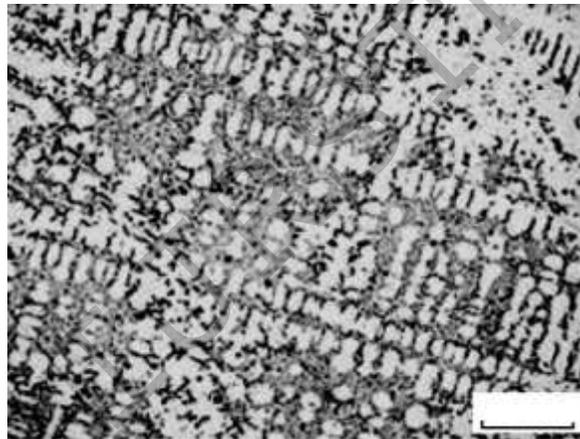


Fig.8 Graphite shape of the corresponding zone of CKD camshaft from France

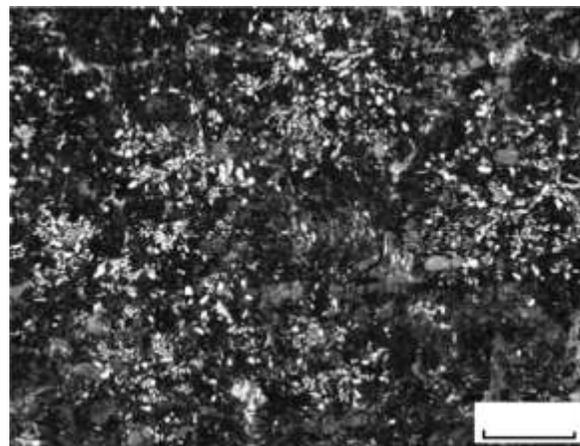


Fig 9. Matrix structure of the corresponding Zone of CKD Camshaft from France

		C	Si	Mn	S,max	P,max	Fe	
2.4 Chemical	Failed	3.52	1.78	0.81	0.10	0.07	Bal.	composition analysis
The chemical composition of the material from the failed camshaft, by using a spectroscopic metal analyzer, is reported in Table 2. At the same time, Table 2 also gives the specified chemical compositions of the camshaft material. It can be seen from Table 2 that all of the chemical compositions of the failed camshaft are within the specified range.	Normal	3.20–3.70	1.70–2.20	0.60–1.10	0.15	0.18	Bal.	of the material from the spectroscopic metal

Table 2 Chemical composition of camshaft material (wt.%)

2.5 Hardness inspection

Hardness inspection results at sectional position is in the range of 352–363 HB that is significantly not in accordance with the specified value of 170–255 HB in the material standard of PSA group.

3 Analysis and discussion on fracture of camshaft

Camshaft TU3/TU5 of Citroën car was cast in Foundry No.1 of Dongfeng Automobile Corporation of Shiyan, China and the shell-mold casting technology was used to produce the components with a layout of two cavities per mould. All eight cams were chilled using grey cast iron chills, and each of the cams was rapidly chilled by two divided chills circled in the degree of 360°, as shown in Fig. 10(a). Camshaft material was required to meet GLA1 chilled cast iron standard of B511110 for PSA Group of France. The hardness for chilled zone is required to measure within the zones of 2 mm beneath the surface, as shown in Fig. 10(b), where the value specified on the top of a cam should be in excess of HRC 48, and the value at the other zones of each cam should be higher than HRC42. And, the hardness values at the non-chilled zones such as the center of the cam and the transition region of the journal, are specified approximately 170–255 HB. The intermediate frequency induction furnace with a capacity of 1 ton was used to melt the molten iron. The pouring temperature was approximately 1,400 °C. Inoculation treatment was operated in a ladle.

In order to obtain an excellent wear-resistance of cam surface of cast camshafts, chills are usually used to increase the cooling rate and create a hard ledeburitic structure layer on the surface, while the center of the cam still keep grey cast is prerequisite to keeping better resistance and long service life of cam. A too-thin chilled depth would result in short service life of cam; however, a too-thick chilled depth would lead to increase the large brittleness, namely, high inclination to fracture of camshaft casting. Transition regions situated between two cams are required to have the approximate microstructure of grey cast iron and keep good toughness as that of the center of the cam. The chilling tendency of the transition regions increases significantly due to the small interval of about 4 mm between the cams, therefore it is very necessary that casting process of camshaft keep under adequate control. The measuring method of chilled depth in the sample, the main reason for the fracture failure of the camshaft is that an over-chilling impacted in the transition region. As the evidences from the above inspection

Based on the analyses above, some optimization measures taken to prevent the abnormal microstructure at the cam necks can be recommended below:

- (a) Improve casting process design parameters, for example, chilled depth of chilled samples has been reduced to 11–13 mm from about 15 mm. Furthermore, thermal analysis method has been used to rapidly analyze C, Si



content and supercooling degree of melted iron of camshaft for helping effective control of chilled depth of chilled samples

- (b) Purify the melt iron to remove inclusion, and improve gating and riser system to prevent shrinkage defect and so on.
- (c) Prevent the crack from initiation by carefully trimming adherent fins at the parting line of camshaft and avoid hard particle enter into the engine.

4 Conclusions

(1) The failure camshaft suffered from extruded force and the working order of the camshaft was destroyed since hard particles entered into the clearance between the camshaft and the corresponding hole of cylinder head before the fracture failure of the camshaft.

(2) Some process measures, such as the improvement of charging proportion, the removal of inclusion and shrinkage, the avoidance of hard particle to enter into the engine, have been employed. As a result the fracture of home-made camshafts has been effectively prevented.

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