FAILURE ANALYSIS OF GREY IRON ENGINE FLYWHEEL

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ARTICLE INFO

***Article history*:**
Received: 24.10.2014.
Received in revised form: 20.01.2015.
Accepted: 28.01.2015.

Keywords:
Flywheel
Grey cast iron
Fracture
Failure analysis
Inclusion

Abstract:

Grey iron flywheels were often found to have been fractured during shakeout, surface cleaning, finishing, packing, dynamic balance measuring and so on. Among them, a failed flywheel was subjected to forensic failure analysis by visual inspection, chemical composition analysis, scanning electron microscopy, microstructure analysis, hardness measurements, etc. The results show that the internal crack was initiated near the centre of the flywheel and propagated toward its outer edge. Some inclusions containing Si, S, and Ca resulted in the fracture of the flywheel. The graphite plate length in the vicinity of the crack zone is longer than the range specified, and its ferrite content exceeds the one in the material as a whole. The average hardness near the crack zone is lower than the lowest limit of HB187-250 (the relevant material standard). The causes for the formation of the inclusions have been discussed and some measures such as: controlling the temperature of the molten iron, applying a ceramic filter, etc., have been implemented thus avoiding future flywheel fractures in transit.

1 Introduction

The flywheel is a key component of internal combustion engines: its basic function is to keep the engine moving steadily by adjusting the distribution of energy over each cycle [1]. The failure of engine components is common [2-5], for example, it accounts for approximately 41% of automotive component failures [6]. Flywheels were often found (sometimes up to 5% of total production), during shakeout, surface cleaning and finishing, packing in a foundry, dynamic balance measuring and so on, to have been fractured in transit. The failed flywheel (fracture occurred during surface cleaning and finishing) was made from HT 250 with the following specified chemical composition (wt. %): 3.1-3.4 C, 1.8-2.1 Si, 0.6-0.9 Mn, ≤ 0.20 P, ≤ 0.13 S, 0.2-0.35 Cr, 0.25-0.35 Cu, and Fe, balance. The hardness of the flywheel casting near its central hole is required to be within the range HB 187 to HB 250. The failed flywheel was set aside for forensic analysis aimed at the prevention of recurrence of such a failure in transit.

2 Experimental procedures

The iron melts were carried out in 6 t intermediate frequency induction furnace. The main raw materials had pig iron, steel scrap and returned material with an addition rate of 35-45%: 15-25%: 35-45%. The superheated temperature was

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controlled at 1500±20℃ for below 2 hours. The tapping temperatures were in a range of 1450-1500℃. The inoculation treatment was an in-ladle method in front of the furnace. The FeSi75 inoculant was added into the molten iron in the ladle. The flywheel was produced using automatic air-impact green-sand mould production line with two castings per mould. The pouring temperatures were in a range of 1340-1380℃.
The chemical composition of the failed flywheel material was determined using CS-280 and GBS-307C analysers. The failure characteristics of the cracked zone were studied by visual inspection, with optical microscope and JSM-5610LV scanning electron microscope (SEM) and energy dispersive x-ray spectrometer (EDS). The microstructure was observed with optical microscope (OM). Hardness tests were performed with an HB 3000 Brinell hardness machine.
Brinell hardness tests were conducted with a steel ball of 10 mm diameter under an added mass of 3000 kg.

3 Failure analysis

3.1 Visual inspection

Fig. 1 shows a partial view of the failed flywheel as received from the foundry. The intact flywheel is shown for comparison in Fig. 2. It can be inferred from it that the crack initiated in the centre of the flywheel and propagated toward the fringe surface (Fig. 1). From the colour of the section in Fig. 1, we deduce that this crack should belong to cold crack, rather than hot crack.

Figure 1. The as-received section of failed flywheel.

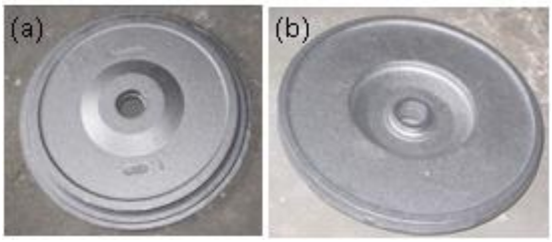


Figure 2. The intact flywheel.

3.2 Chemical composition

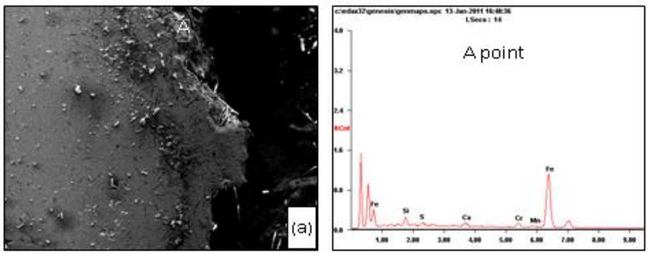
The chemical composition of the failed flywheel material is shown in Table 1. It can be seen that the composition of the material corresponds to the one specified.

Table 1. Chemical composition of the failed flywheel (wt %)

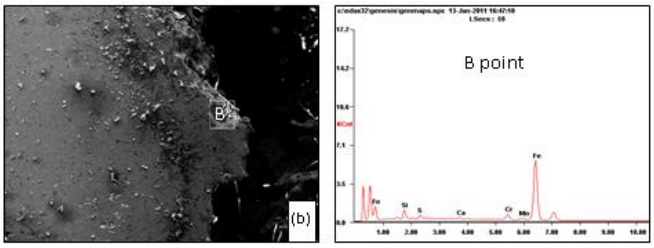
C	Si	Mn	P	S	Cr	Cu	Fe
3.21	2.01	0.72	0.038	0.085	0.31	0.28	Balance

3.3 SEM inspection of fractured section

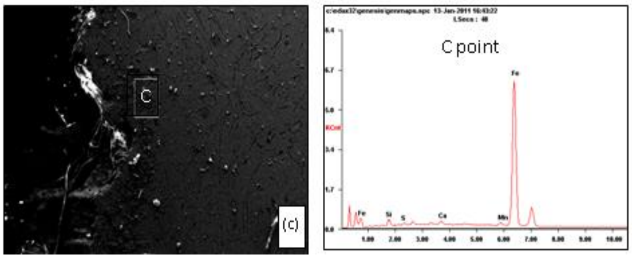
Fig. 3 shows EDS analysis of the fracture surface by SEM: the EDS result shown in Fig. 3 is also given in Table 2. It can be seen that regions A and B near the crack zone contain higher Si, S, and Ca, while the normal regions C and D remote from the crack have less Si, and no S or Ca. This indicates that some inclusions containing Si, S, and Ca may have been responsible for the fracture of the flywheel. During casting, potential origins for such inclusion formation were:



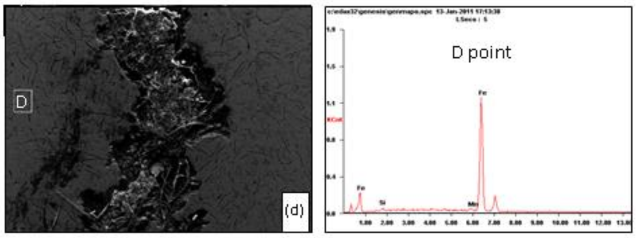
a)



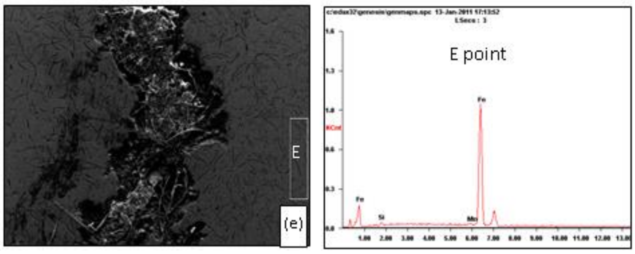
b)



c)



d)



e)

Figure 3. EDS analysis of the fracture surface (a-e).

Table 2. The EDS analyzed results shown in Fig. 3 (wt.%)

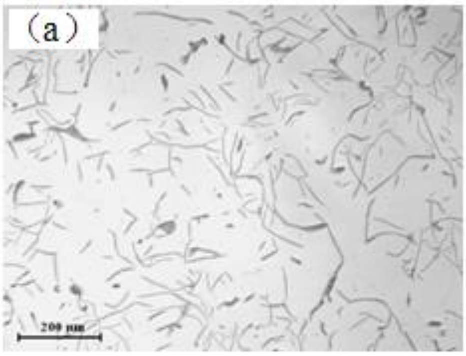
Position	Si	Mn	S	Cr	Ca	Fe
A	9.98	1.85	3.11	3.45	2.82	78.79
B	8.89	1.21	2.75	4.78	1.01	81.36
C	3.56	1.95	0.66		1.12	92.71
D	2.36	2.18				95.46
E	2.47	1.70				95.83

1) The molten iron oxidised when it was tapped from the 6 t intermediate frequency induction furnace while being poured into the sand mould for casting the flywheel.
2) During inoculation treatment, the temperature of the molten iron was lower than the specified range of 1450 to 1500°C: this could result in incomplete melting of the inoculants. A 75SiCaFe alloy with the addition rate of 0.2-0.5 wt.% was used as the inoculants during production of this particular flywheel.
3) The inclusion occurred at the former stage and afterwards was not cleaned-up.
4) The slag-blocking measures in the pouring system were not properly designed for pouring the molten iron into the flywheel mould.

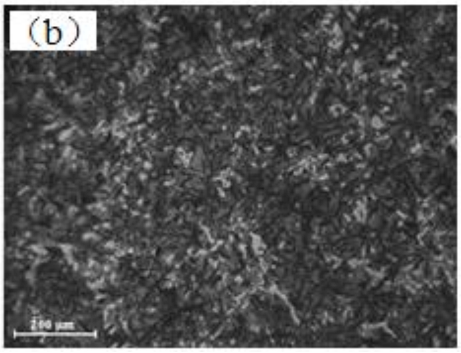
It can be inferred from the results of Fig. 3 and Table 2 that the aforementioned causes of inclusion formation may be the second, and/or third, and/or fourth, rather than the first (*i.e*. due to the absence of oxygen).

3.4 Microstructural observation and hardness inspection

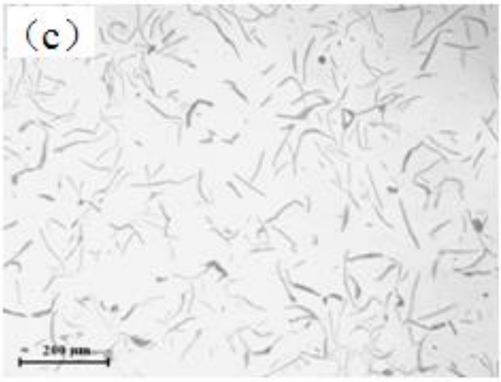
The sample for metallographic investigation was taken from the cracked zone of the fractured flywheel. Microstructural observations and hardness inspection both near-crack and far-field were conducted. The results are shown in Fig. 4 and Table 3, and evaluated according to the properties of this flywheel. The lower hardness correlated well with the presence of higher ferrite content in the near-crack zone.



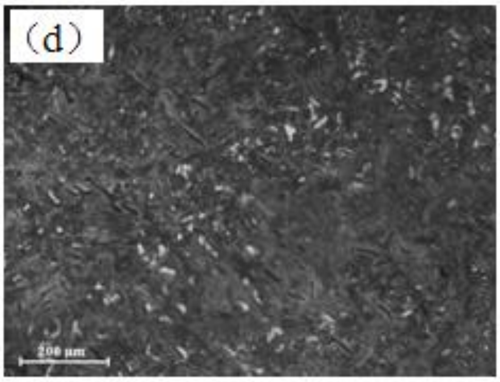
a) graphite near the crack zone



b) matrix near the crack zone



c) graphite of the normal zone



d) matrix of the normal zone

Figure 4. Microstructure observation of the failed flywheel (a-d)

Table 3. The results of the microstructure observation and hardness inspection

Position examined	Graphite		Matrix		Hardness (HB)
	Morphology	Length	Morphology	Amount of pearlite	
C zone (near crack)	A	3-4 grade	pearlite	95%	179, 177, 181, 179, 183
D zone (normal zone)	A	4-5 grade	pearlite	98%	202, 207, 197, 207, 197
the specified	A type（B+D+E ≤ 20%）, C type isn't allowed	4-7 grade	pearlite	≥95%	187-250

4 Problem solving

The aforementioned results indicate that the cause of flywheel fracture is due to more inclusions containing higher Si, S, and Ca. The composition of the material corresponds to the specified composition range, but the graphite plate length in the vicinity of the crack is longer than the one specified, and the hardness is lower than the lower limit allowed by the standard. As a result, some improved measures are to be adopted to prevent flywheel fracture:

1) During inoculation treatment, the tapped temperature of the molten iron controlled was within the specified range of 1450 to 1500°C, thus ensuring the complete melting of the inoculant.
2) Before pouring molten iron into the casting mould, the coating agent and inclusions such as slag on its surface should be completely eliminated.
3) A ceramic filter was not used in this pouring system to block slag and so on from entering the mould for casting the flywheel while the molten

iron was being poured, however, a proposed filter design is shown in Figures 5 and 6.

Figure 5. The upper sand mould.

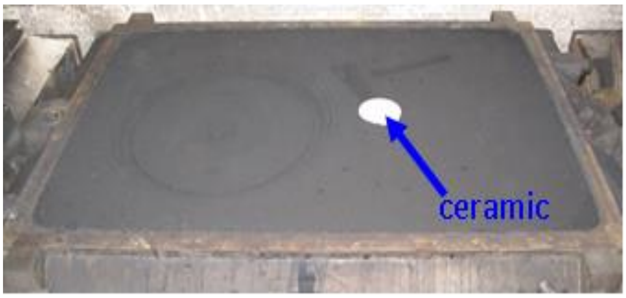


Figure 6. The lower sand mould.

5 Conclusions

1) The main reason for the fracture failure of his flywheel was that some inclusions containing higher Si, S, and Ca were present in the fractured zones.
2) The graphite plate length in the vicinity of the crack was longer than that allowed by its specification: its hardness was lower than the lower limit allowed by the standard.
3) The possibility of inclusion formation is analysed, and some preventative measures are proposed. As a result, in future such flywheel fractures could be effectively prevented.

Acknowledgements

This research is financially supported by the National Natural Science Foundation of China (51275156).

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