FIRE CRACK FAILURE OF A DUCTILE CAST IRON ROLL

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ABSTRACT

This paper reports the failure analysis of fire crack of a ductile iron roll in a hot rolling mill in Medan, Indonesia. The roll failed prematurely after only 3,500 tons of service instead of the normal service life of about 65,000-70,000 tons. Standard procedures for failure analysis were employed in the investigation. It was found that the failure of the roll was due to excessive heat. Then it led to causing numerous fire cracks being created very high stress resulting from inadequate water cooling of the roll. Heat cracks around the fracture surface were clearly visible. It was, therefore, concluded that the root cause of the failure is inadequate designs of the roll and associated equipment. Alternative designs are suggested to prevent or minimize similar failures in the future, and to avoid the losses resulting from such failures.

KEYWORDS: Ductile Iron Roll, Hot Steel Rolling, Fire Crack, Roll Failure

1. Introduction

Ductile cast iron rolls are extensively used in steel rolling mills particularly for hot rolling operations. A combination of desirable characteristics including high strength, good ductility, and good thermal shock resistance makes ductile iron a preferred material for rolls. Additional characteristics such as corrosion and wear resistance can also be improved by appropriate alloying additions and treatments. Failures of rolls not only result in replacement cost, but also in process downtime as well as other undesirable consequences. This could have a drastic effect on productivity and, more importantly, late delivery. In the case being investigated, for example, the downtime was 40 hours, 1,200 tons of steel equivalent, was lost before the failed roll could be replaced.

The causes of premature failures of rolls are numerous. They can be improper operations, faulty roll designs, manufacturing defects, and faulty materials or metallurgical factors. Operating factors which include the choice of rolling parameters such as rolling load, rolling speed, temperature of steel bars and the experience of the operators can play a key role in roll failures [1]. Many roll failures in hot rolling steel re-bars mills were found to be due to overload resulting from dynamic impact and fire cracks [2]. Fire cracks range in appearance from small (1 mm) tight longitudinal cracks to large cracks of various patterns (crazing, dry river bed). Thermal shock (spelling, resulting from rapid heating and cooling of the roller body surface) is a more severe form of fire cracking and occurs in an instantaneous manner [3]. The severity of the cracks is dependent up on the contact time and the rate of cooling. The easiest way to avoid thermal breakage is to minimize thermal gradients, which can be achieved by good rolling / cooling strategies and proper handling of rolls [4]. An analysis of failures of rolls with grooves on a 3-high-roughing mill stand for hot rolling is presented, found that 3 out of 4 are failed by rotation bending load with high stress concentration and one in four are failed by dynamic impact [5]. Cooling of working surfaces of rolls by high pressure water and spray nozzle was found to improve the resistance to cracking of rolls some 1.5-2 times [6]. Ensure efficiency of the water-cooling system and verify if the volumes and pressures are correct. The inspect roll cool headers and nozzles for blockage and before rolls are inserted, turn cooling water on to check nozzle spray pattern [7]. A chemical composition of roll materials also influences the resistance to heat cracking. Additions of Ni and Cr were found to increase cracking resistance of rolls [8]. Human errors were also found to be main contributors leading to roll failures. Human errors can be of three general types (1) errors of knowledge (usually involve insufficient knowledge, education, training and experience), (2) errors of performance (lack of sufficient care or from negligence), and (3) errors of intent (very commonly involve greed) (9). The aim of this work was to investigate the cause of premature failure of a ductile cast iron roll in an Indonesian steel rolling mill so that the reoccurrence of similar failure can be avoided or minimized in the future.

2. Background

The failed roll was used at an intermediate rolling stand in a continuous hot rolling steel rebar mill in Medan, Indonesia. The roll failed after it was used for rolling approximately 3,500 tons of steel. Normally, the service life of this type of roll is much longer and can be used for rolling up to 65,000-70,000 tons of steel. The mill produced reinforced concrete steel re-bar sized 6 to 22 mm diameter with the reheating furnace capacity of 30 tons/hr. It was designed for rolling steel billets with cross-sectional areas of 45 X 45 mm^2 square and 82 X 35 mm^2 oval. The rolling temperature of this rolling stand was approximately 1,000 °C. Nominal dimensions (mm) of the failed roll and fracture point are shown in Figure 1. Chemical **c**ompositions of the roll material are shown in Table 1.

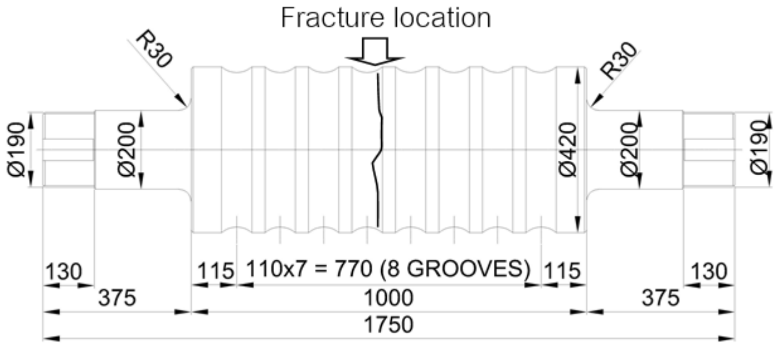

Figure 1 Nominal dimensions and fracture location of the failed roll

Table 1 Chemical compositions

Chemical Compositions (% by wt)					
C	Si	Mn	Ni	Cr	Mo
3.60	1.50	0.68	1.45	0.36	0.36

3. Investigation Procedures

The failure investigation was conducted as follows. The failed roll was inspected visually to get the overall picture of the fractures which include the locations, type of fracture, and the nature of cracks around fracture surfaces. Dye-penetrant technique (DPT) was employed to enhance visual inspection of the cracks. A specimen as shown in Figure 7 was cleaned ultrasonically in acetone. The specimen was examined using a JEOL-JSM 6380LV scanning electron microscope (SEM). A specimen for microstructural examination was prepared in accordance with ASTM E407 standard. Microstructure was examined using an optical microscope (LECO: IA32 Image Analysis System).

4. Results

4.1 Visual Examination

A general appearance of the failed roll is as shown in Figure 2. The failed roll was taken out from the rolling stand and examined visually. The fracture occurred at the 4th groove from drive side of the top roll. The fracture surfaces were slightly flat as shown in Figure 3. The presence of oxides (dark) at the periphery of the fracture surfaces, approximate 10 mm, is readily apparent, as shown in Figure 4. The fire cracks, on oval grooves, were observed on the top and the bottom rolls.

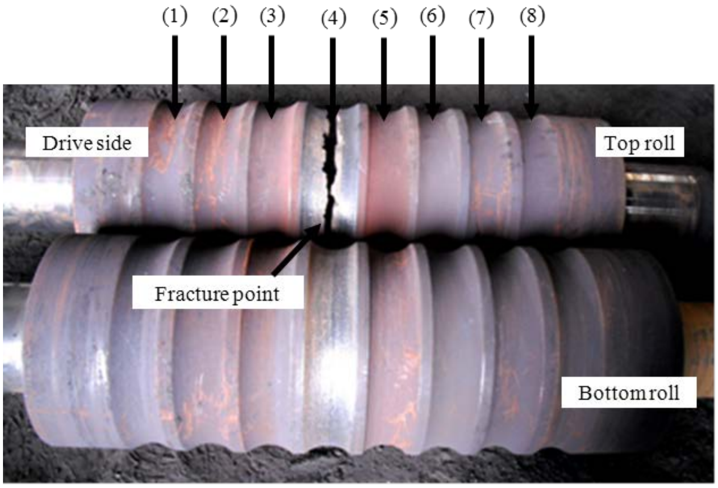

Figure 2 Roll design, oval groove distribution, and position of fracture point

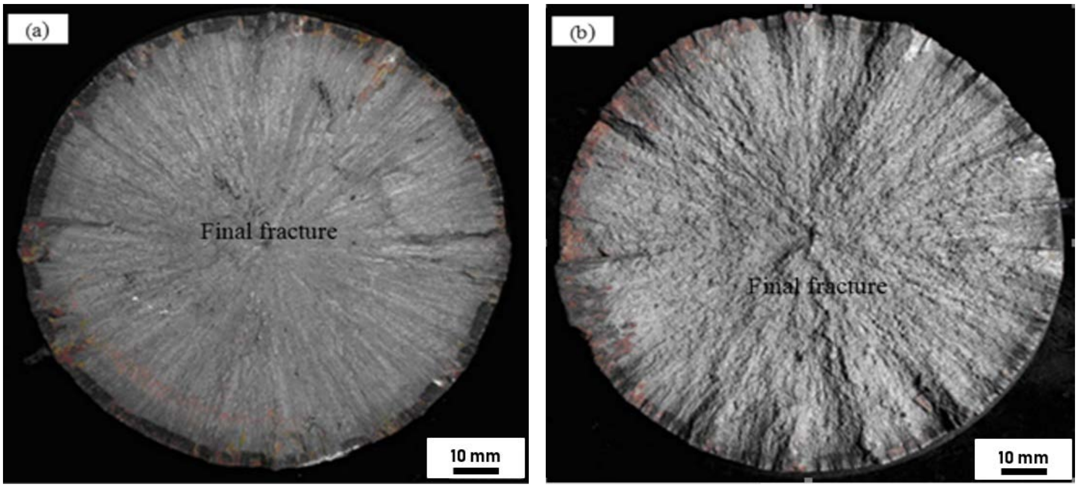

Figure 3 Fracture surfaces of the failed roll (a) drive side (b) top side

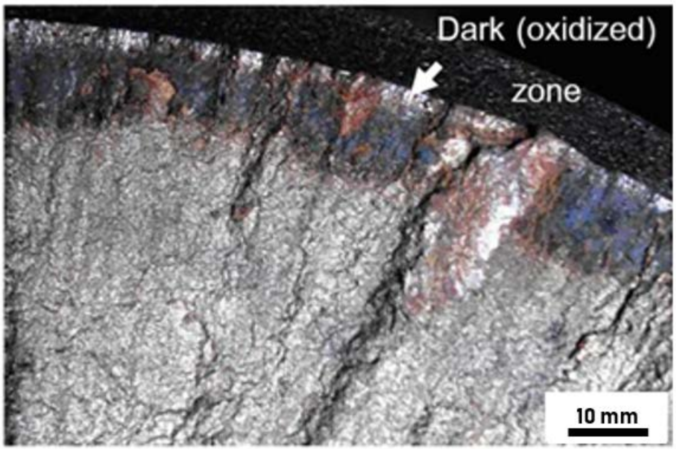

Figure 4 Magnified view of fracture surface

4.2 Dye-Penetration Test

The crack initiations occurred at the surface of oval groove as shown in Figure 5. Numerous fire cracks were observed in the vicinity of the fracture surfaces and surface of oval groove of bottom roll as shown in Figure 6. It can be initially indicated that the failure of the roll occurred due to the fire cracks which subsequently formed a larger crack leading to final failure. From the observation of the groove surface of the rolls, both the top and the bottom rolls occurred the network of fire cracks on the surface of the oval groove as shown in Figure 6, which is indicated both rolls water cooling from supply not enough.

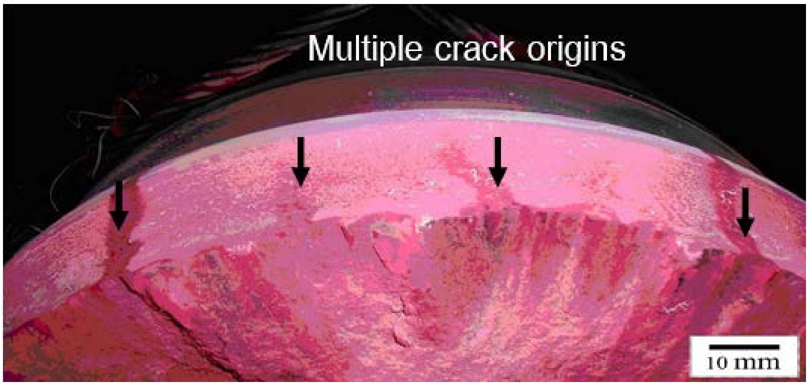

Figure 5 Fracture surface of the crack origins

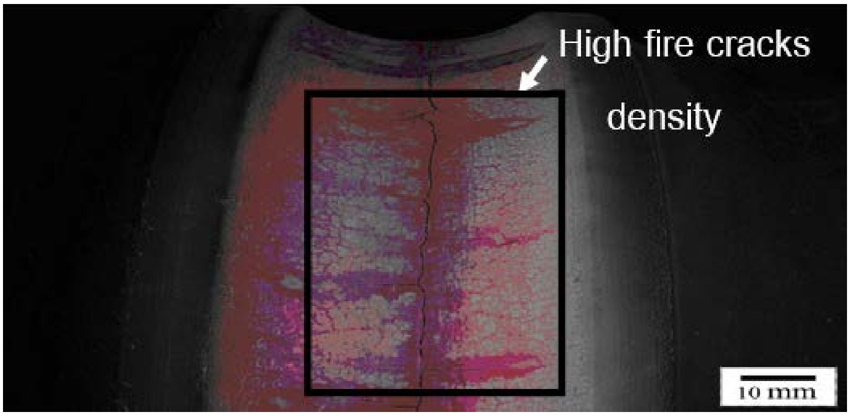

Figure 6 High fire cracks density on oval groove of the bottom roll

4.3 Fractography

The specimen of fracture surface of the failed roll, which is shown in Figure 7 was examined by SEM in order to look more closely at the nature of the fracture. The cracks and oxides were also found in the fracture surface which can be seen in Figure 8. The crack started at the periphery of the oval groove of the roll and then it moved inward to the center of the roll. The oxides, which cover the crack originated surface, was observed. It can be seen that the fracture surface in Figure 8 shows the decohesion surface is rather flat, as shown in Figure 9. Moreover, although the fracture surface is essentially brittle. Figure 9 is, however, primarily brittle (cleavage) and show manifestations of cracking and cleavage steps.

Figure 7 Specimen for SEM examined

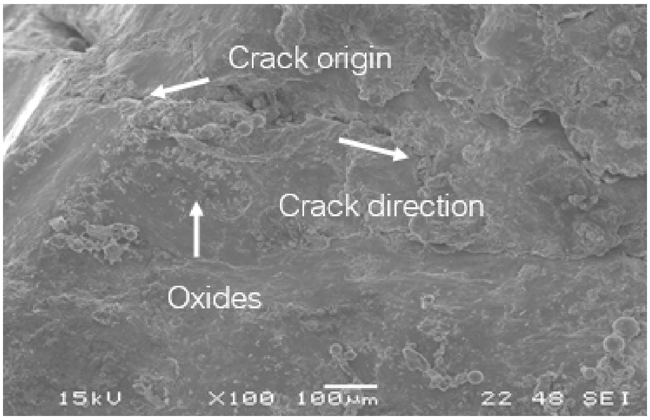

Figure 8 Fractography showing view of the crack origin and oxides

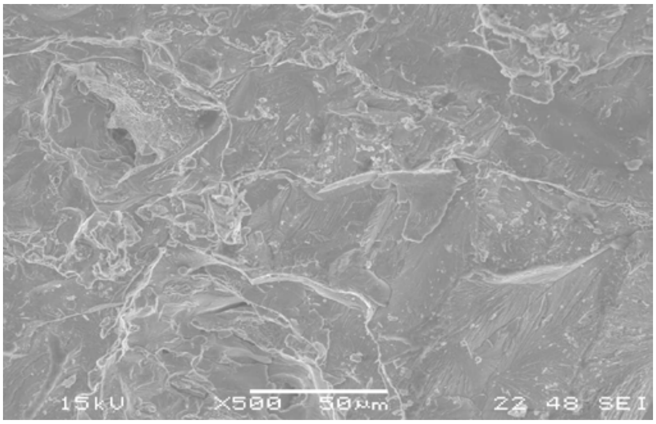

Figure 9 Morphology of brittle features and small ductile zone

4.4 Microstructure examination

The microstructure consists of nodular graphite and eutectic carbide in pearlite matrix as shown in Figure 10a, typical for ductile cast iron rolls [10]. Multiple cracks were also found on outer shell of roll as can be seen in Figure 10b. These cracks appeared as started at the periphery of the outer shell of the roll and moved inward to the center. Higher magnification micrograph of one of these cracks and crack depth approximately 5.2 mm is shown in Figure 10c.

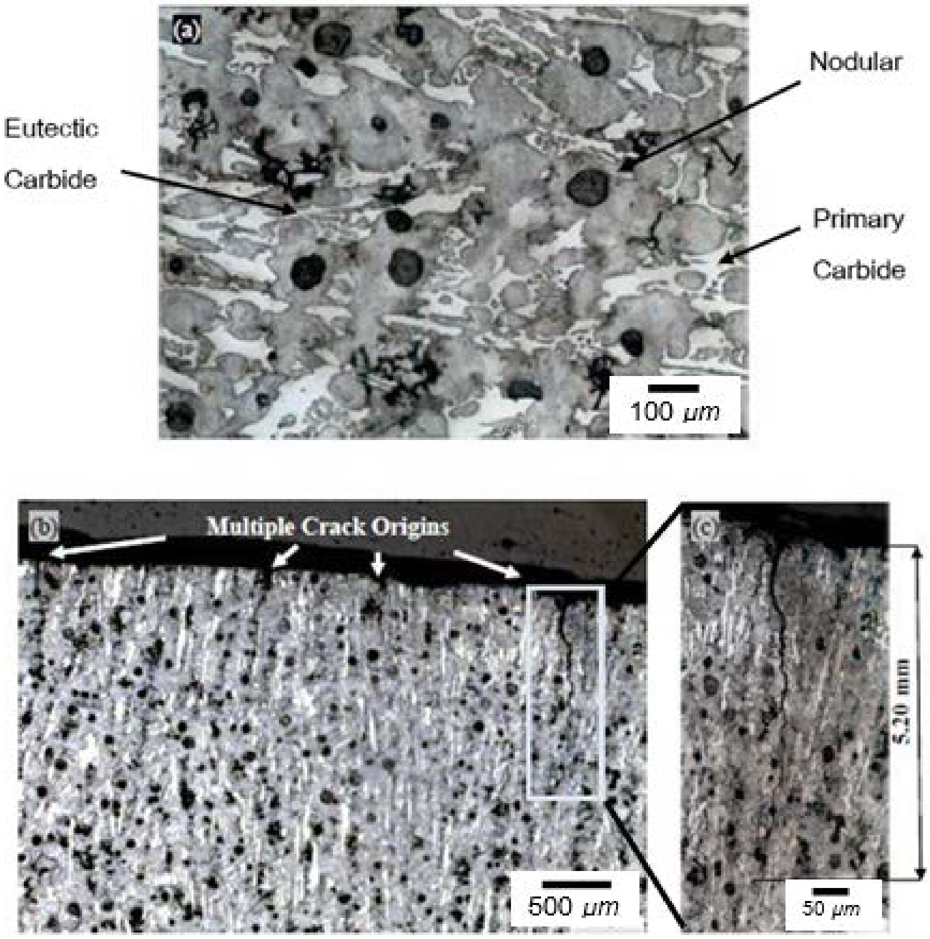

Figure 10 Microstructure of the failed roll: a) nodular graphite in structure, b) microstructure with multiple cracks, and c) higher magnification morphology of a crack depth (Etched with 2% nital)

4.5 Roll cooling system

The cooling system for the rolls in this particulars mill will be shown in Figure 11. Cooling water was pumped through a steel piping and plastic hose. The control system of water for cooling individual rolls was accomplished by gate valves. Header water piping for roll cooling was installed only at the top of top roll, which means the exit side did not have the water piping. Such design of the cooling system is rather fragile because there was not any warning where things started to go wrong.

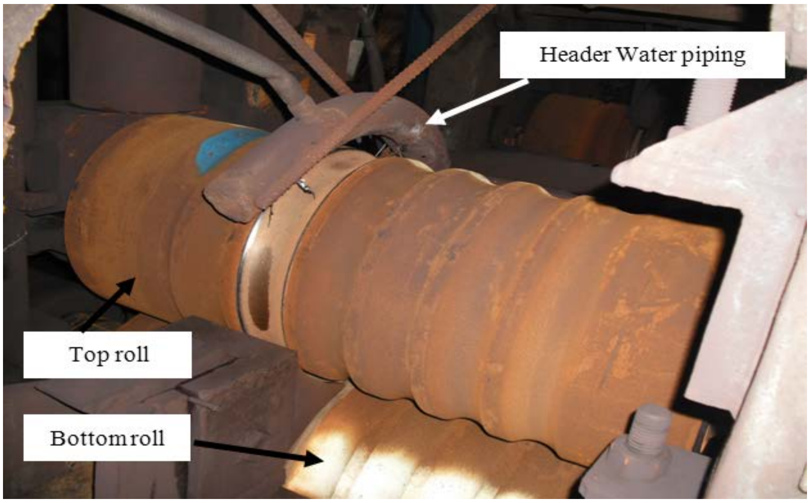

Figure 11 Existing roll cooling system

5. Discussion

Fire cracks occurred on the oval groove of the failed roll because excessive heating due to a small area of the oval groove surface is directly contact the hot steel bars. In this case, the oval groove surfaces do not cool down. Maximum temperature of the oval groove too high (500-650 °C), the average roll body temperature and the temperature difference increase steadily. In addition, temperature gradients can develop within the roll. The temperature gradients can cause large stresses to build up in the surface layer, exceed hot yield strength of the roll material, and lead to the formation of a network of heat cracks, often referred to as fire cracks. Fracture surface was oxides (dark) cover approximate 10 mm from outer shell of the roll as shown in Figure 3 and Figure 4 because of excessive heat that acted at the oval groove surface. After that, it started cracks and continuously inward to the center of the failed roll. However, the failed roll during cyclic stress whilst, the failed roll was operating. For this reason, the cracks on the tensile stress spread out. While the crack surfaces were directly expanded, the failed roll was heated by hot bars when it was operated. The crack surfaces were oxidized between water and iron. Hence, the crack surfaces became dark because oxides cover the cracks.

Resulting from the investigations above, it can be concluded that the failure of the roll was due to excessive heating at the oval groove of the failed roll. Such excessive heating led to thermal stress being created at the surface of the groove causing numerous small fire cracks. The cracks that acted as stress concentrators resulting very high stress at the groove of the roll. The fire cracks that acted as the origins of a larger crack growing inwards to the center of the roll leading, eventually, to final fracture. The cause of excessive heating was inadequate cooling of the roll. Such occurrence was, in turn, the result of inadequate design of the roll cooling system. The design of the roll cooling system was also to blame.

6. Conclusions and Recommendation

1) The roll failed by brittle fracture. The crack originated at the surface of the oval groove of the roll, where numerous fire cracks occurred, were formed earlier.

2) The consequence of the inadequate cooling of the roll is excessive heating which result in the fire cracks forming.

3) Inadequacy in roll water cooling result partly from inadequate design of the roll cooling system.

4) It can be recommended that a robust roll cooling should be redesigned to replace the current one. Header water piping must be moved close to the exit bars where can be guaranteed that the maximum possible temperature will never be critical. Furthermore, the devices, which control water flow rate as same between top and bottom roll, must be added. When such parameters are out of the set values, the system should warn the operator. The recommended design is as shown in Figure 12.

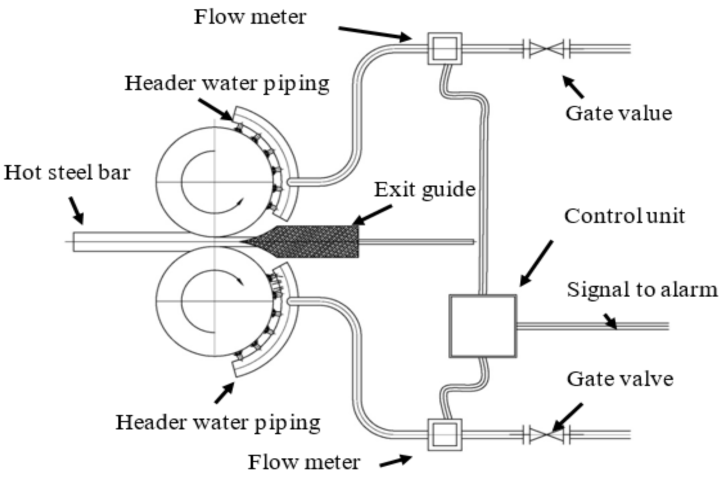

Figure 12 Roll cooling system with sensor devices

Acknowledgement

The authors would like to thank Mr. Octo Julius who is factory manager in the PT. Putra Baja Deli, Medan Indonesia for his help in the history of the failed roll and allowing the publication of this information.

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