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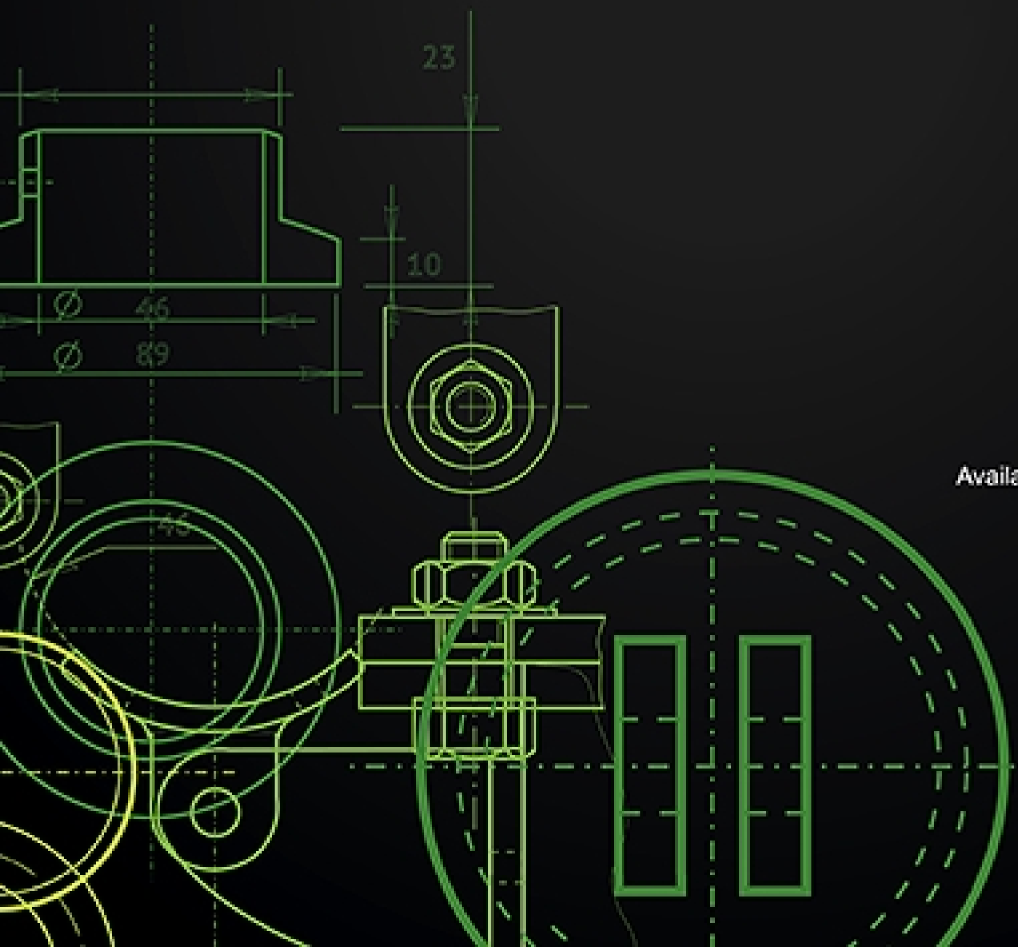

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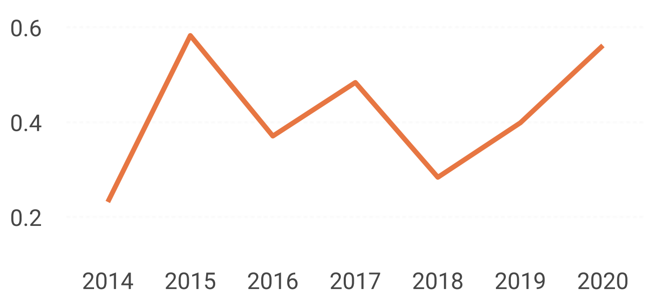

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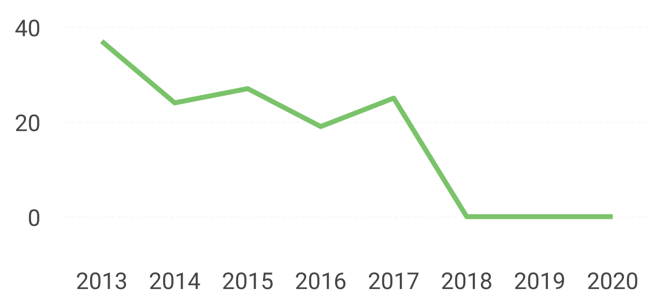

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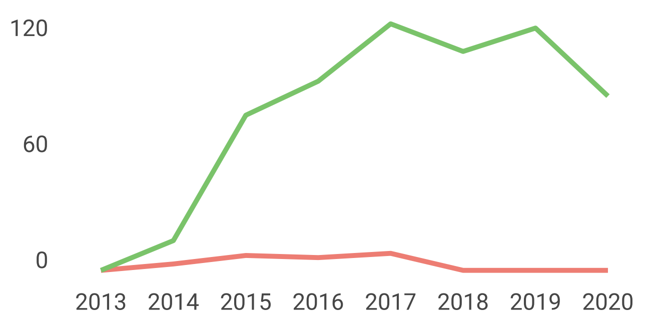

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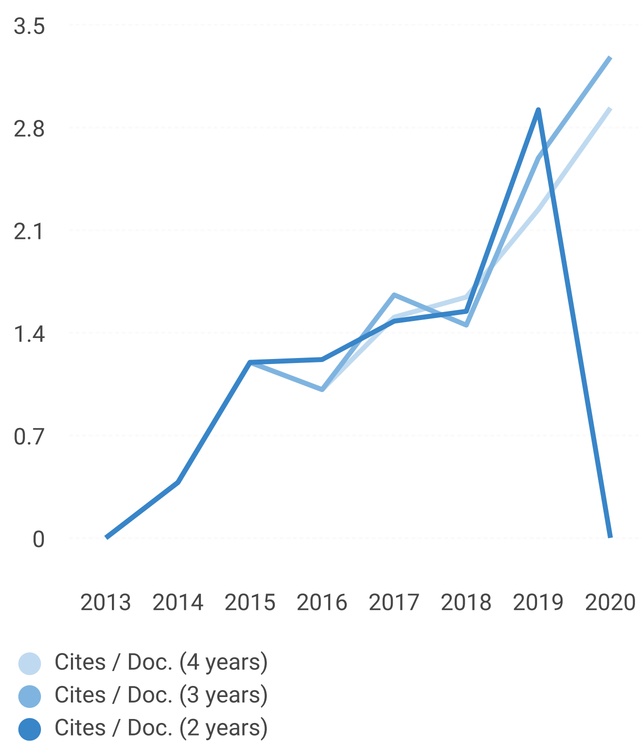

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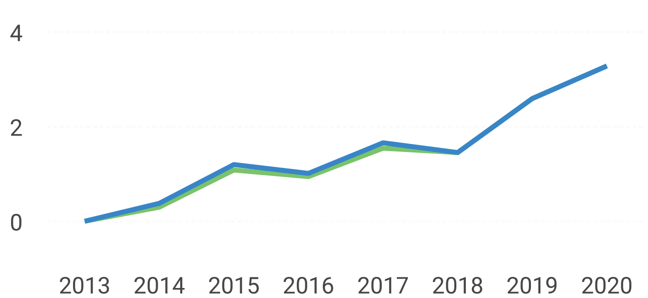

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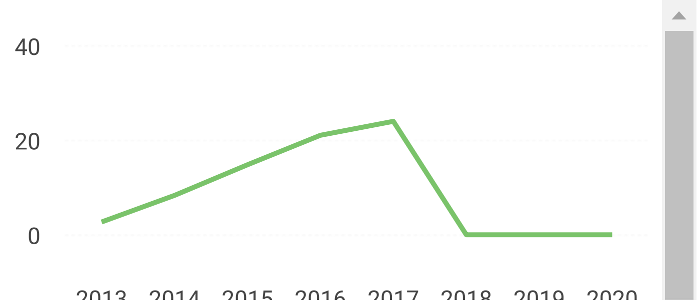

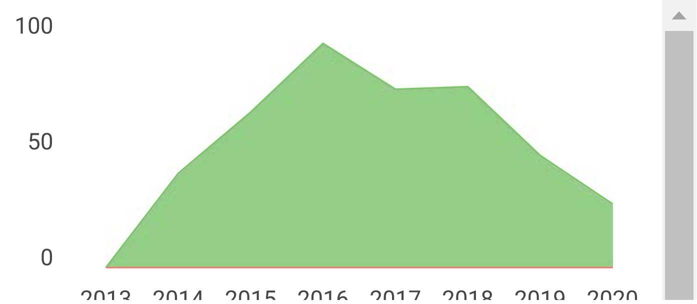

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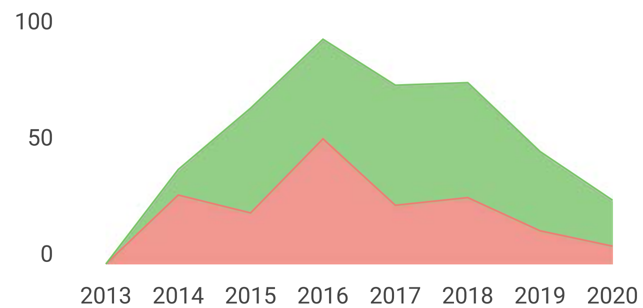

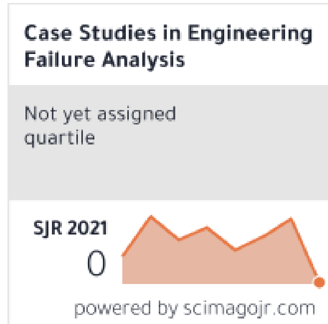

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Damage analysis of the forced draft fan blade in coal fired power plant

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ABSTRACT

The Forced Draft Fan (FDF) blade in a 300 MW coal fired power plant that experienced catastrophic failure has been investigated. There were two main locations of the blade damage, namely damage at the root of the blade and the other one is at the third of the blade height. The FDF blade has been run for 5 years and before its failure, the FDF experienced high vibration (14 mm/s). The forced draft fan is an axial flow fan horizontally in front of the boiler and the fan is single stage. Visual inspection, metallographic analysis, chemical composition and hardness test were carried out to find the cause of the failure. It is concluded that the material of the blade is cast Al-Si alloy (A356.0) that fits the requirements for FDF blade application, the failure of the third of the blade height is owing to the external particles collide to the leading edge of the blades causing erosion and notch. That notch acted as initial crack. The failure at the root blade was caused by broken fragments of the others damaged blades entered in between casing (stator) and the blade (rotor) so they obstructed the blade rotation.

1. Introduction

In coal fired power plants, forced draft fans (FDF) are usually used to supply combustion air into boiler [1]. The FDF has an important role to provide the effective combustion in various conditions and produce better heat transfer by circulating gases. In boiler, the combustion air flow consumption depends on the boiler load and is controlled by an oil-hydraulic impeller blade adjustment system. There are two types of FDF blade, e.g.; axial flow and centrifugal flow fan [2]. The FDF components can be damaged due to some degradation mechanism and cause to high cost maintenance activities. It has been reported that most common serious damage occurred in power plant fans are corrosion, erosion, vibration. Valyakal et al. [3] and Yan-qing et al. [4] found that the failure of a fan blade was due to vibration in the machine. Kazempour-Liacy, et al. [1] reported that the erosion and corrosion fatigue caused the failure of the FDF blade. This current study investigated a forced draft fan (FDF) blades, which experienced catastrophic failure in a 300 MW coal fired power plant resulting the whole system was shut down. The FDF has been operated for 5 years and before its failure, the FDF experienced high vibration (14 mm/s) whereas the maximum allowable vibration when the engine is operated at 7 mm/s. The forced draft fan is an axial flow type, installed horizontally in front of the boiler and consists of 14 blades. The fan is single stage and has a casting structure. The blades are adjusted during operation by the hydraulic impeller blade adjustment system and kept in position. The blades were installed to a centre spindle using screw and the direction of rotation of the fan is clockwise viewed upstream. The premature failure of these blades was unusual and need an exact failure analysis.

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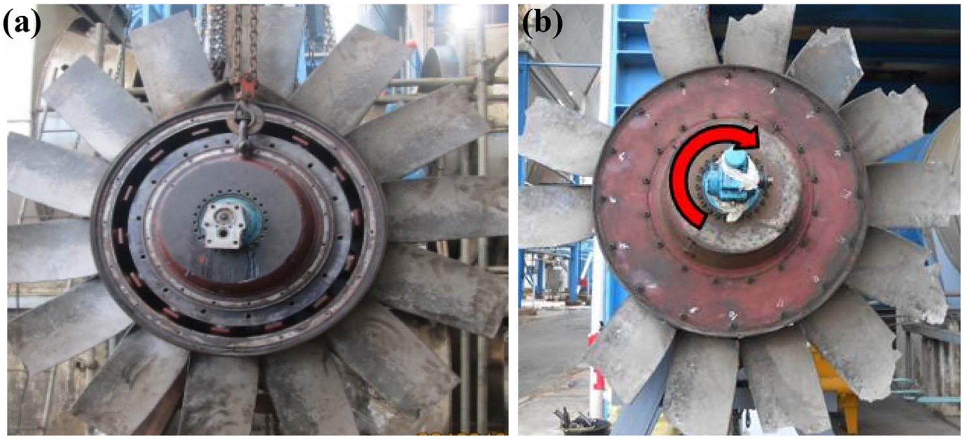

Fig. 1. Investigated FDF blades: (a) before failure and (b) after failure (red arrow indicates direction of rotation).

2. Methodology

To define the cause of the damage, some methods consist of non-destructive and destructive examinations were carried out. Fig. 1 shows the FDF blades before and after failure.

Visual inspection found that the coating of leading edge of the the blade had serious erosion damage, as can be seen in Fig. 2a and lots of debris had been collected behind the fan, including the heavily damaged blade itself. The debris of fractured blades was accumulated to support the analysis (see Fig. 2b). Fig. 2c shows the fractographs of damaged coating near to the leading edge of the blade. The coating of the blade has already lost and the base metal is clearly seen. Visual observation also found that there were two locations of damaged blade e.g., damage at the root of the blade and the other one is at the third of the blade height, as shown in Fig. 3.

Based on the visual inspection findings, the following methods were chosen to determine the cause of damage namely, metallographic analysis, chemical composition test and hardness test. Atomic absorption spectrometer was used to chemical composition analysis of the blade's material and the debris. Average hardness data was taken from 6 times measurement on the blade surface and was performed on Vickers Hardness Tester with load 200 grams and dwelling time 15 s. Scanning electron microscope (SEM) was used on JEOL 610-LA operated at 20 kV to find the fracture morphology and the EDS (Energy Dispersive Spectroscopy) was performed for local chemical analysis to study the deposit of the surface fractured blade. The coating of the blade was also studied using SEM-EDS. Microstructure sample was prepared using metallography standard and Keller's etchant was applied to reveal the microstructure. Fig. 4a and b show the locations of sample taken from the two investigated blades for metalographic analysis, chemical composition test and hardness test. The samples were cut using electro discharge machine.

3. Results and discussion

3.1. Material verification of the damaged blade

Chemical composition analysis of the investigated blade confirmed that the blade was made of aluminum alloy, which consists of 6.5% Si, 0.16% Fe, 0.8% Cu, 0.2% Mn, 0.3% Mg, 1.2% Zn (in %wt) and Al is balance. The chemical composition analysis of the debris was also in a good agreement with the materials of the damaged blade. The average hardness of the blade is 123.7 HV and the microstructure of damaged blade is shown in Fig. 5.

Fig. 5 shows the coarse microstructure consists of dendritic structure α-Al phase and associated segregation. The dendritic structures are surrounded by eutectic silicon and this is strong evidence that the blade was made by casting process. The cast alloys need to be well observed due to the defects formation during solidification process and the chemical composition of the alloys affect the mechanical properties [5]. There are some requirements for material to be used as FDF blade, e.g.: light weight, good wear resistance in high flow rate, good corrosion resistance and low maintenance. The application of aluminum cast alloy for the FDF blade is widely used in industry by considering that the characteristic of the aluminum alloys fulfill the requirements for the FDF [6]. Therefore, the use of Al-Si alloy for FDF blade in this coal fired plant met with the requirements. Refering to the results of the chemical composition, hardness and miscrostructure analysis of the blade, it can be concluded that the blade material is within the standardized cast Al-Si alloys (A356.0) and there was no indication of manufacturing defect, which contributed to the failure of the blade.

3.2. Coating material

Fig. 6a shows a back scattered SEM image taken from undamaged area of the primary and intermediate of the blade coating. The

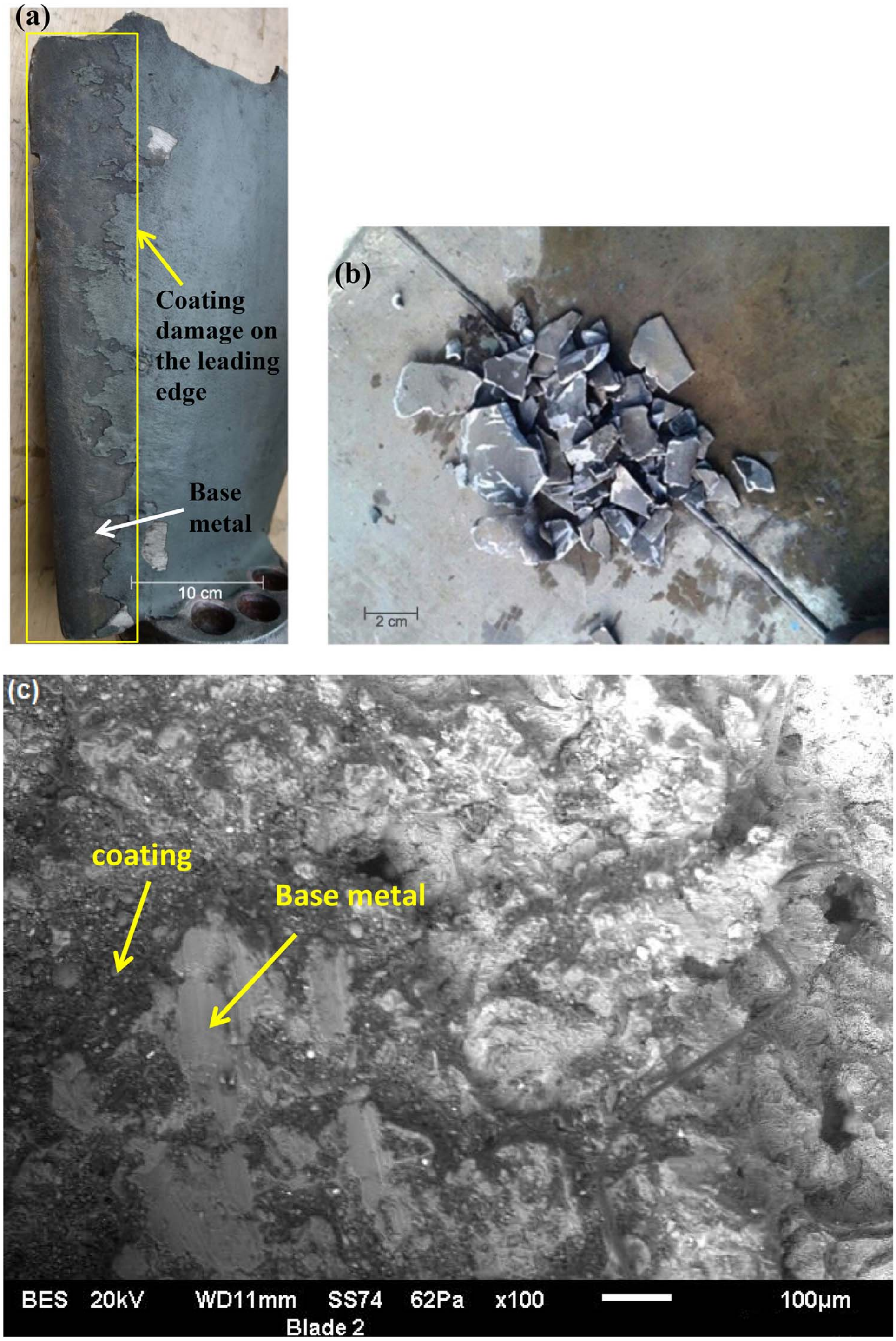

Fig. 2. (a) Coating damage on the blade leading edge (indicated by square); (b) the debris of fractured blades and (c) a secondary electron image of coating damage area.

characteristic feature of the blade coating is coarse with different phases, which is shown by the microstructure contrast. Some discontinuities were found between the substrate and coatings. The EDS spectra of the coating blade (Fig. 6b and c) indicate that the primary and intermediate coatings contain Iron (Fe) and Titanium (Ti), respectively. The primary coating is thicker than the intermediate coating. In this case, the primary coating plays an important role to increase the corrosion resistance of the blade and the intermediate coating was applied to improve the resistance to erosion. The SEM studies exhibit that the coating blade (coating materials and their thickness) are appropriate for the FDF blade.

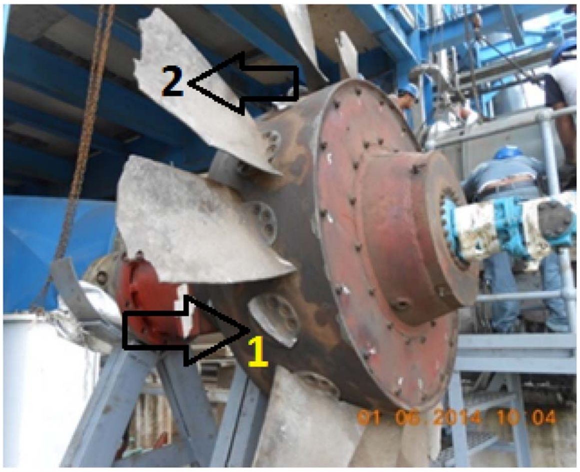

Fig. 3. Two locations of damaged blade: fracture at the root blade (shown by number 1) and fracture at the third of the blade height (shown by number 2).

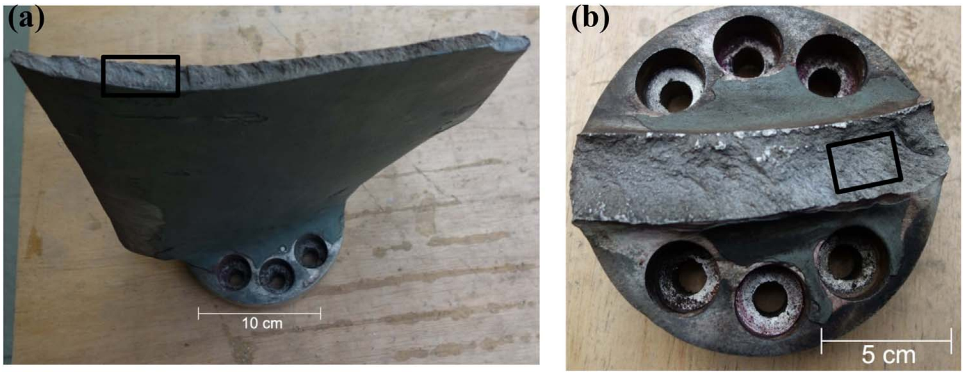

Fig. 4. The location of samples taken from the damaged blades (indicated by black square): (a) the third of the blade height and (b) at the root of the blade.

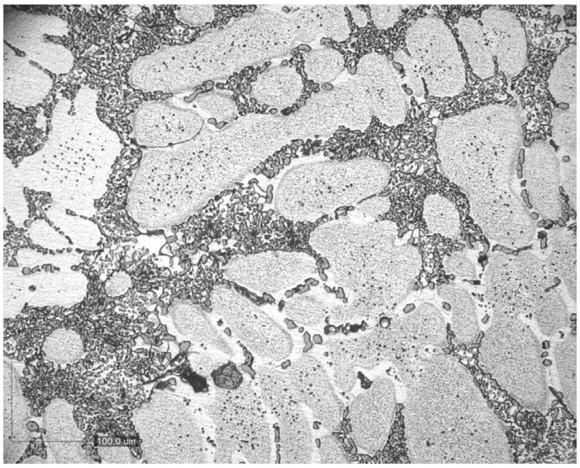

Fig. 5. An optical image of the investigated blade (hypoeutectic cast aluminum-silicon alloy).

3.3. Failure analysis of the blade

Fractography analysis using SEM was done on the surface of damaged blade and the result can be seen in Fig. 7

Fig. 7 shows that there are no beachmark and striations, which meant the failure of blade was not due to fatigue loading. The SEM image of damaged surface in Fig. 7 shows there are many porosities, which is typical of casting product and no evidence of prior plastic deformation. The brittle failure is supported by the debris of blade, which was broken down into pieces and no plastic deformation occurred (see Fig. 2b). SEM-EDS was performed on fractured surface of the damaged blade to study the deposit and the

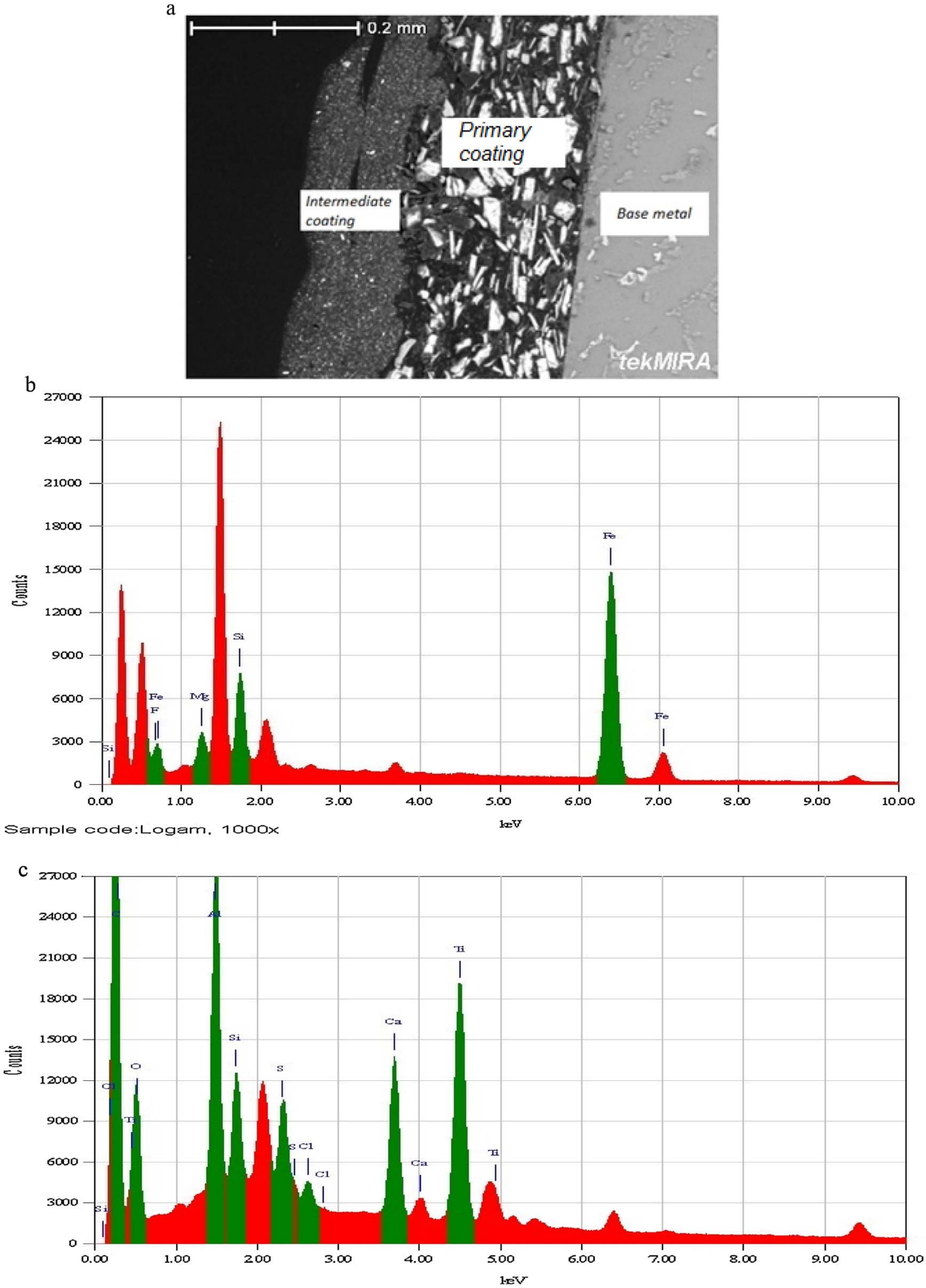

Fig. 6. a) A back scattered SEM image of the primary and intermediate microstructures of the coating blade. b) SEM-EDS spectra of the primary coating blade. c) SEM-EDS spectra of the intermediate coating blade.

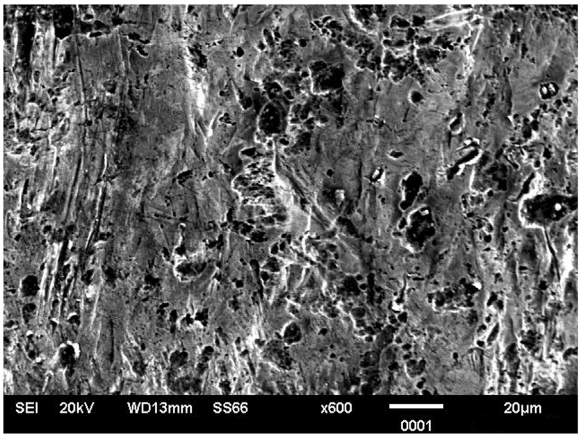

Fig. 7. A secondary electron image of fracture damaged blade.

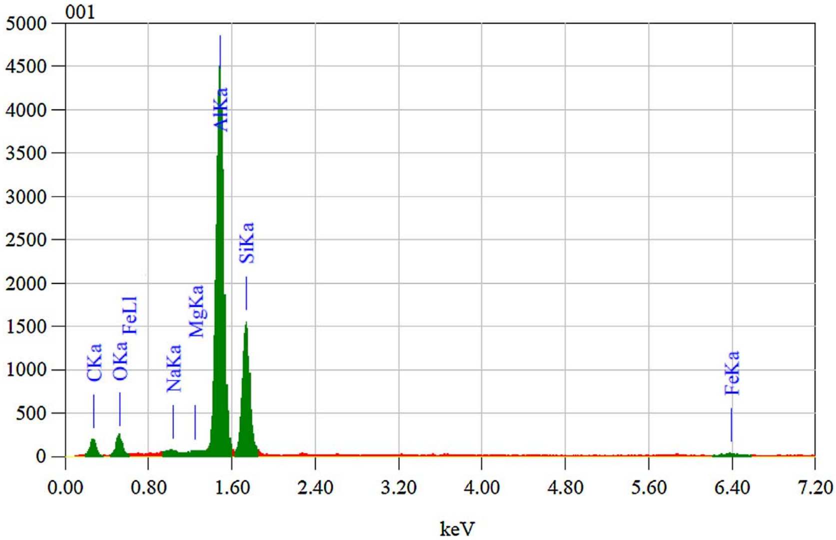

Fig. 8. SEM EDS qualitative analysis of coal fly ash on surface of damaged blade.

results can be seen in Fig. 8.

The SEM-EDS qualitative analysis of coal fly ash particles (Fig. 8) shows the presence of Carbon, Oxygen, Aluminum, and Silicon, and with low level elements of Sodium, Magnesium, and Iron. It means that coal fly ash particles were elementally composed of abrasive particles. The SEM-EDS result indicates that the damage at the third of the blade height was due to a possibility of entering external abrasive particles to hit the FDF blade. Collision of these external particles to the surface of the FDF blades caused erosion not only damage to the leading edge coating (see Fig. 2a) but also in the body of the blade. However the leading edge erosion occurred in all blades. This is due to the leading edge of the blade is the initial edge of the part of the blade that first contacts with the air [7]. Moreover the type of coal used in this power plant is high ash content low range coal (LRC), which produces large amounts of fly ash. Furthermore, the formation of fly ash is also the result as part of combustion process [8]. This is consistent with the findings on the surface of the blade with erosion and notch as can be seen in Fig. 9. The entering of fly ash that caused damage to the FDF blade was probably due to the filtration system did not work properly.

Erosion of FDF blade is characterized by the loss of blade material because of the mechanical action of particles in the air flow hiting or scratching on the blades surfaces. The influence of severe erosion brings about to extreme unbalance and high vibration. It has been reported that small particles with the size below about 10 microns do not have sufficient kinetic energy to cause blade erosion [9]. Thus in this failure of FDF blade was believed that the entering fly ash particle size was over 10 microns that less tends to stick on the blade surface, but they can cause erosion [8] and notch. Visual inspection found that there was notch that was formed near the leading edge of the damaged blade (see, Fig. 10) and experiencing crack propagation during the operation. This is not surprising, as mentioned before; the leading edge is the foremost part of the blade that first contacts with the air. That notch was probably the beginning of the heavy damaged of the FDF blades that were located at the third of the blade height blade. The notch acted as stress concentration and as well as the initial cracks. As the material of the blade is cast alloy that is brittle and very low toughness, the cast alloy of the blade can not withstand with the centrifugal forces caused by high rotation (1490 rpm) during the

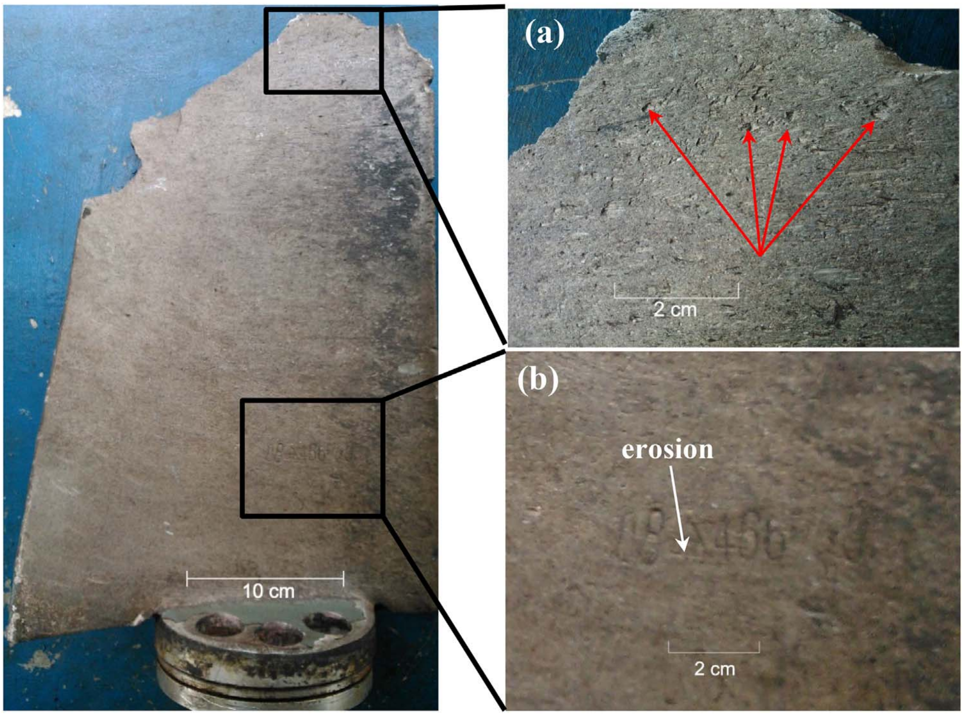

Fig. 9. Surface damage of the investigated blade: (a) notch (indicated by red arrows) and (b) erosion.

Fig. 10. Notch at the blade leading edge and proceed to crack propagation.

operation and led to rapid crack propagation occurs [4]. Hence, it is possible that any damages to one blade can cause multiple collisions to the other blades and as a result there were lots of debris.

The FDF blade was operated in clockwise at the rotation 1490 rpm and temperature 30 °C. The failure occurred at the root blade was actually caused by other blades' damaged on the body of those blades. The broken fragments of the blade entered in between casing (stator) and the blade (rotor) so they obstructed the blade rotation and causing a moment that resulted in a broken blade at the root.

4. Conclusions

As a result of investigation, it can be concluded as follows:

- The material of the blade is cast Al-Si alloy (A356.0) that meets the requirements for FDF blade application.
- The primary and the intermediate blade coating materials contain Iron (Fe) and Titanium (Ti), respectively and the coating materials are appropriate for the FDF blade.
- The surface damaged of the blade was due to the external particle and based on SEM-EDS result, the external particle is fly ash, which probably came from the usage of low range coal and as part of combustion process.
- The failure of the third of the blade height because the external particles collide to the leading edge of the blades causing erosion and notch and the notch acted as initial crack. As the material of the blade was brittle and experienced high rotation causing the blade led to rapid crack propagation.
- The failure of the root blade because of broken fragments of the others damaged blade entered in between casing (stator) and the blade (rotor) so they obstructed the blade rotation.

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