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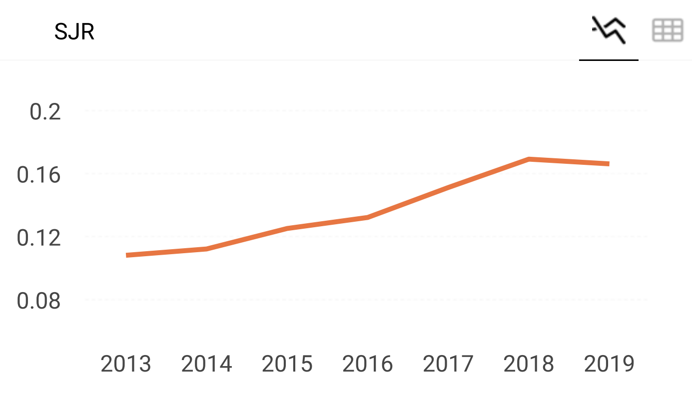

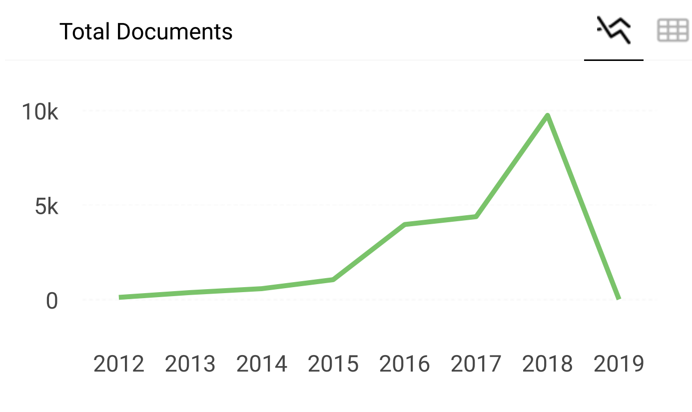

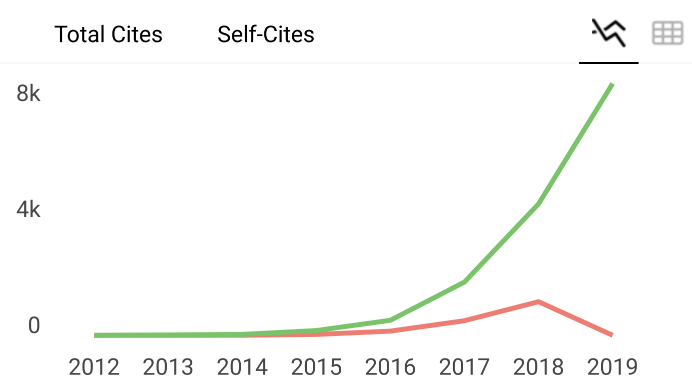

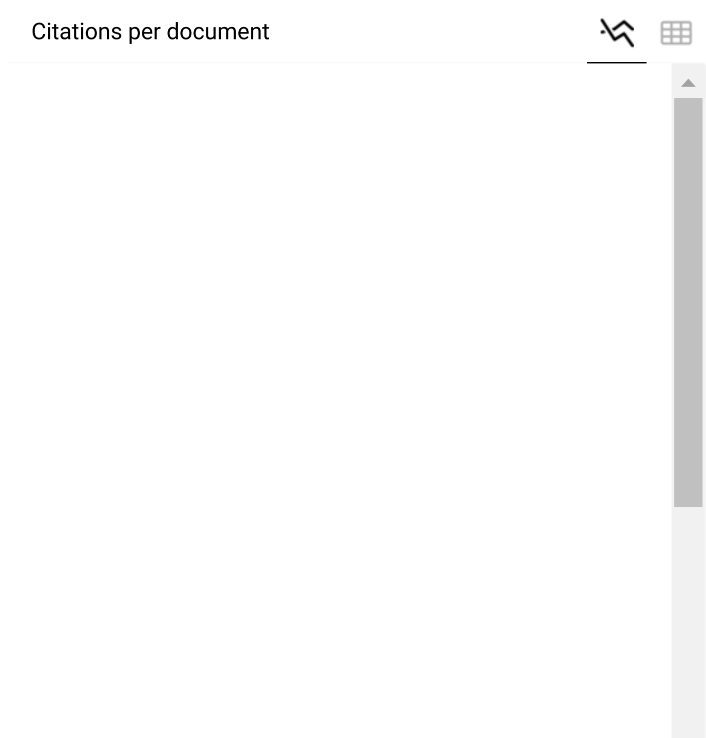

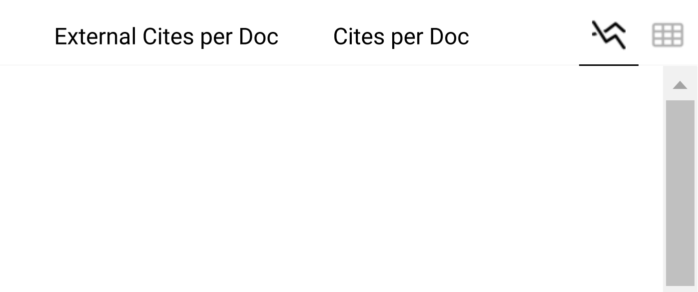

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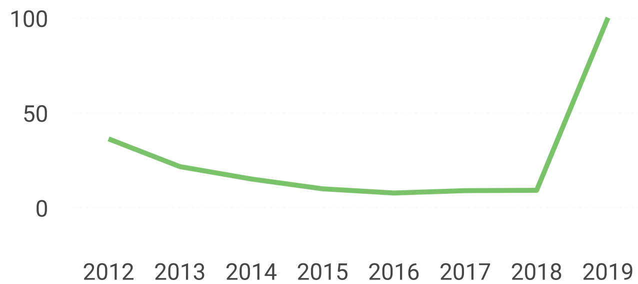

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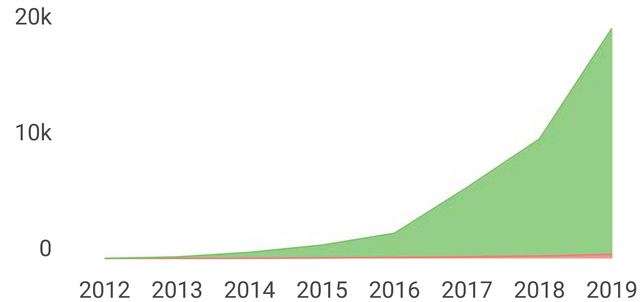

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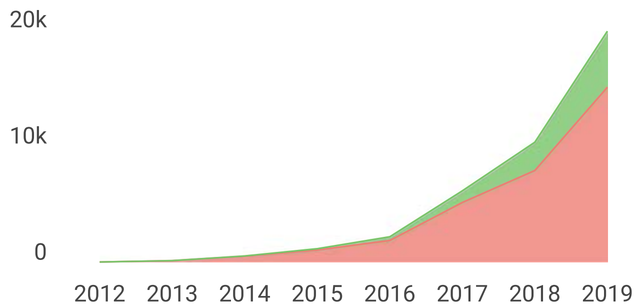

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Creep damage assessment of a 50 MW steam turbine shaft

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turbine shaft that has exceeded the designed lifetime (30 years). The inspection of turbine is a mandatory for safety and continued reliable operation. The shaft was made of nickel-chromium-molybdenum alloy steel. The turbine operated in the range temperature of 500-600 oC, and creep was considered to be a major damage mechanism. The remaining life assessment of the turbine shaft was also conducted using replication technique. The replica samples were taken from 125 position distributed along the turbine shaft. The microstructural analysa of replicas showed that creep had occurred, which was indicated by the cavities formation at the grain boundaries. After evaluation and assessment, it can be concluded that the turbine shaft still can be used however it needs to be re-inspected within 6 months.

Long-term stabilization of creep-resistant 9Cr steel by boron for high efficient, low emission power plant at 650 °C

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Creep damage assessment of a 50 MW steam turbine shaft

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[2] Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Indonesia

Abstract. This paper reported the evaluation of a 50 MW steam turbine shaft that has exceeded the designed lifetime (30 years). The inspection of turbine is a mandatory for safety and continued reliable operation. The shaft was made of nickel-chromium-molybdenum alloy steel. The turbine operated in the range temperature of 500-600 ^{o}C, and creep was considered to be a major damage mechanism. The remaining life assessment of the turbine shaft was also conducted using replication technique. The replica samples were taken from 125 position distributed along the turbine shaft. The microstructural analysa of replicas showed that creep had occurred, which was indicated by the cavities formation at the grain boundaries. After evaluation and assessment, it can be concluded that the turbine shaft still can be used however it needs to be re-inspected within 6 months.

1 Introduction

The reliability and life time of a steam turbine shaft that are exposed to elevated temperature will be reduced by some mechanisms, such as excessive creep deformation, bursting under pressure, cracking [1], fatigue, corrosion and material aging [2]. Those degradation mechanisms take place slowly and vary for each turbine material. The most common degradation mechanism occurs for engineering components operating at high temperature is creep [3-5]. Creep is time dependent and in consequence permanent plastic deformation at high temperature and at a stress lower than the high temperature yield stress [6,7]. There are some methods to assess the remaining life of the components due to creep damage. Previous researchers [6,8] had reviewed some non-destructive techniques for creep damage detection such as replication, ultrasonic, hardness test, eddy current, strain measurement, etc. and replication, which is based on microstructural changes is still a good technique. The curve creep where the creep strain as a function of time and in regard with microstructural changes can be seen in Fig.1.

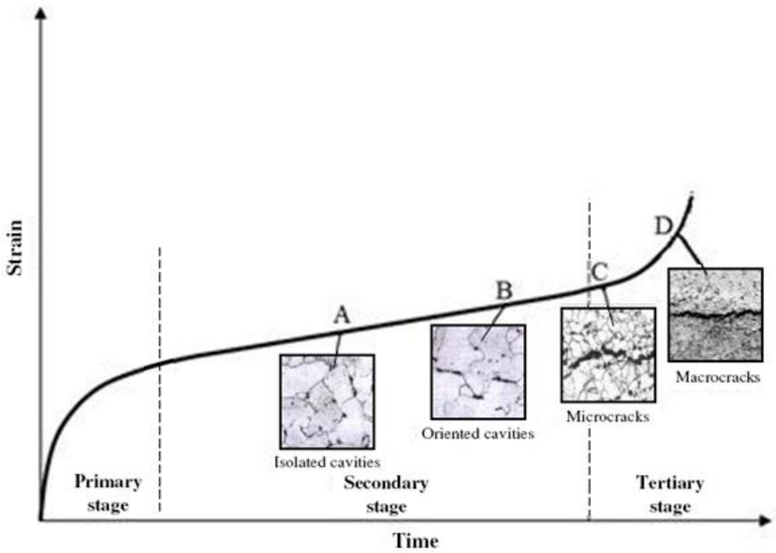

Figure 1. Microstructural evolution in creep [6]. For the letters, please see the text.

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The microstructural changes of creep are indicated by the formation of cavities at the grain boundaries. The classification of microstructural changes is divided into 5 categories [9], e.g.: Undamaged (t/t_r= 0.27) , isolated cavities (stage A, t/t_r= 0.46), oriented cavities (stage B, t/t_r=0.65), microcracks (stage C, t/t_r=0.84) and macrocracks (stage D, t/t_r= 1), where t_r is the service life expended and t is the rupture life. The remaining life (t_{rem}) is calculated using the Eq. 1 below [10] :

$$t_{rem} = t\left[\frac{t_r}{t} - 1\right] \quad (1)$$

By using Eq. 1, then the remaining life of each stage is 2.7t (undamaged), 1.17t (stage A), 0.54t (stage C), 0.19t (stage D). The safety factor of 3 is used in this study [11] and therefore the remaining life for undamaged, stage A, B, C and D is 0.4t, 0.18t, and 0.06 respectively. Note that, the remaining life assessment using replication technique will result the safe re-inspection intervals [9,10]. The re-inspection interval for each stage is presented in Table 1.

Table 1. Re-inpection intervals [8].

Damage classification	Inspection interval (Years)
Undamaged	5
Isolated cavities (stage A)	3
Oriented cavities (stage B)	1,5
Microcracks (stage C)	0,5
Macrocracks (stage D)	Repair immediately

Using replication technique and adapting the data in the table 1, the remaining life of a 50 MW steam turbine shaft operating at 570 ^oC and has been in service for 30 years was assessed. The result will be used as the basis of whether the turbine can be operated safely and need to be re-inspected within a certain period or rejected. The inspected steam turbine shaft is shown in Fig. 2.

Figure 2. Inspected steam turbine shaft.

2 Methodology

The type of inspected steam turbine was single cylinder horizontal single flow multistage condensing steam turbine. It had been used in Indonesia for more than 30 years. The chemical composition of inspected turbine shaft was measured using Positive Material identification method (PMI). For data verification and steel's softening characteristics, the hardness test was performed using in-situ portable hardness Mitech MH 320 with a load of 200 grams. The shaft has 17 stages of turbine, which is shown by D-1 until D-17 in Fig.2. The shaft turbine was inspected without its blades in all stages. The inspection methods, which were used to detect the discontinuities on the turbine shaft were dye penetrant, Eddy current and ultrasonic. Dye penetrant was utilized to detect the surface discontinuities. A NDE eddy current flaw detector was carried out to find out the fine cracks, especially in the blade groove areas. Omniscan phased array ultrasonic was conducted to detect the internal defects. The replication technique for creep damage analysis was conducted by taking 125 samples, which was distributed along the turbine shaft (see Fig. 3).

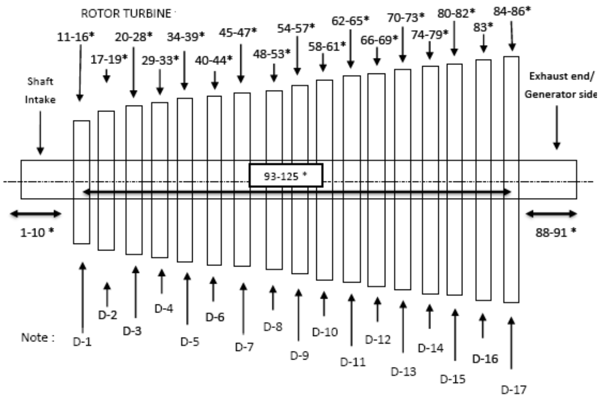

Figure 3. The location of replica taken from the steam turbine shaft (indicated by number).

The replica samples were prepared using standard conventional methods and the etchant used to reveal the grain boundaries was saturated picric acid plus few drops HCl. The replicas were then examined in a light optical microscope.

3 Results and Discussion

The chemical composition analysis of turbine shaft was 0.28 %C, 0.22 %Si, 0.39 %Mn, 0.43 %Cr, 0.51 %Mo, 2.89 %Ni and Fe-balance (in wt.%) that fulfilled the requirement standard of the ASTM standard of A470 class 4 (nickel chromium molybdenum alloy steel). The hardness value of the steel is in the range 211-275 HV, which is in good agreement with the hardness of steel ASTM A470 class 4 and no evidence found that the steel undergoes the softening. In general, the interpretation of dye penetrant inspection found pitting defects that were observed on some areas. Fig.4 shows the results of penetrant test on two locations of the inspected turbine shaft.

(a) Shaft intake

(b) disc of stage 8 (D-8)

Figure 4. Penetrant test results on inspected turbine shaft

Pitting occurred due to the effect of the corrosion environment in which during the process and the phase transition of working fluid took place from dry surface to wet region. Furthermore, the turbine shaft has been operated for 30 years. The pitting condition was then clarified by Eddy current and UT phased array. The eddy current surface test results show that no fine cracks were detected on all areas.

Scanning on overall surfaces of the turbine shaft using UT phased arrays results no reflector of defects appeared in the monitor. Hence, it can be concluded that the pitting was observed by dye penetrant test occurred only on the surface and no evidence the pitting propagated towards inside the turbine shaft as well as internal defect. The microstructural analysa of 125 replica samples gave strong evidence that creep had occurred in the steel. Two optical images of replica taken from different areas are shown in Figs. 5and 6.

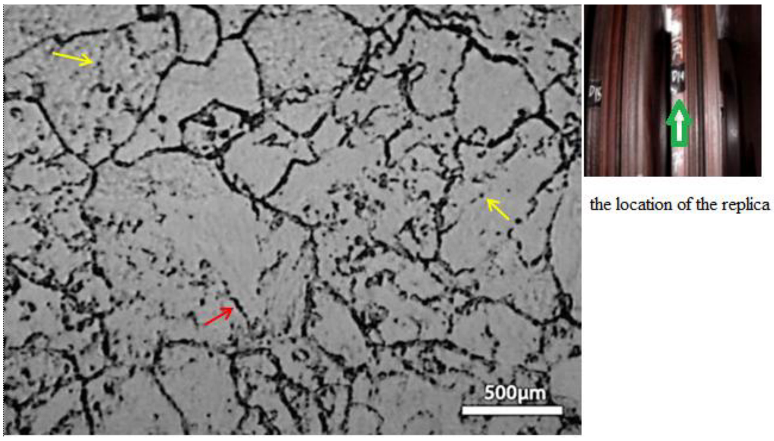

Figure 5. An optical image of replica (left) taken from 14th stages showing isolated (yellow arrows) and oriented cavities (red arrows) and location of replica was taken (right, indicated by green arrow).

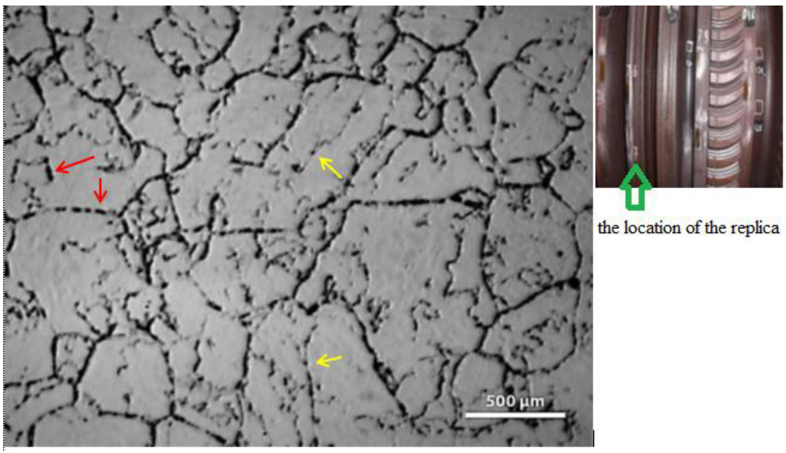

Figure 6. Replica image (left) taken from 14th stage showing isolated (yellow arrows) and oriented cavities (red arrows) and and location of replica was taken (right, indicated by green arrow).

Figs 5 and 6 show that a change in the microstructure occurred by forming isolated and oriented cavities at the grain boundaries. The presence of those cavities gives significant evidence that the turbine shaft had creep damage. The cavities start linking up to develop microcracks. From microstructural analysis of 125 replicas, 90 % of them show that the isolated and oriented cavities were presence and 10 % of replicas reveal that microcracks had already formed. From this point of view, the remaining life of turbine shaft was assessed adapting the data in Table 1. Although only 5 % of the replicas analyses exhibit the microcracks however it is important and used as a basis in determining the stage of damage, namely stage C. Hence, it is clearly that the inspected shaft turbine needs to be re-inspected in 6 months.

4 Conclusions

From the aforementioned results, the conclusion can be drawn as follows:

a. Based on chemical composition analysis and hardness test, the material of turbine shaft was made of nickel-chromium-molybdenum alloy steel and satisfies the standard of ASTM A470 class 4.

b. Pitting defects were observed on the surface of some inspected areas using dye penetrant test. However Eddy current and UT phased array tests reveal that no defects were observed, which indicate that the pitting did not propagate towards inside the turbine shaft.

c. Microstructural analysis of replicas taken from 125 areas distributed along the turbine shaft exhibit that the creep damage had occurred, which was shown by formation of isolated and oriented cavities dominantly and microcracks.

d. The remaining life of turbine shaft was assessed using replication technique and the results show that the shaft needs to be re-inspected in 6 months.

e. The shaft turbine was fit for continued reliable operation and needs to be re-inspected in 6 months.

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