Life Assessment by Metallurgical Examination in Aged Power Turbine Rotor

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ABSTRACT Material damages of aged power turbine rotor are shown as variation of microstructure due to material degradation, and these quantified variations are measured through image processing; thus, it is possible to conduct damage assessment with high reliability when compared with microstructure of virgin material [1-5]. In addition, the metallurgical degradation assessment of steam turbine rotor was a method to observe the change of macroscopic microstructure. But for reliable assessment, quantitative measurements of more microscopic variation on carbides are needed [6].

Therefore, this thesis conducted a quantitative analysis of carbides movement due to heat, and evaluated the life by developing damage assessment program through organizing mathematical damage model between carbides movement and the life of turbine rotor.

INTRODUCTION A microstructure analysis on steam turbine rotor, with various operation time, and accelerated degradation specimen was conducted by using SEM and TEM to examine the relationship between damage of steam turbine rotor and carbides in microstructure. As a result, the relationship between the life of steam turbine rotor and variation of morphology, size, and spacing of carbides were found. These variations of carbides were analyzed by using image processing to organize a mathematical damage model of the relationship between the life of turbine rotor and quantified variation values. Life assessment through the spacing between carbide particles is possible because the growth of metastable carbide is expressed by a function depending on operating temperature and aging time.

As for the life assessment due to the size of carbides particles, the carbide particles grew bigger due to aging time; thus, it is possible to express life assessment due to size of carbides particles and aging through a function. In addition, turbine rotor material CrMo steel transforms from needle Type M_3C carbides to globular type $M_{23}C_6$ carbides[7]. For quantitative assessment of the phenomenon, the relationship between life and shape function was found and life assessment was conducted. Thus, life assessment program was developed by using the relationship between life of turbine rotor and variation of morphology, size, and spacing of carbides.

Life assessment was held through microstructure after stripping extractive replicas from the same position as the steam turbine of unit 1 in domestic “P” fossil power plant(operating hours : 175,000, number of start up or shut down : 2,190), which is being operated today.

LIFE ASSESSMENT PROGRAM USING CARBIDE APPROACH In order to investigate the relationship between stream turbine rotor and carbides within microstructures, micro structural analysis was conducted on discarded steam turbine rotor and accelerated degradation test piece using an optical microscope and Scanning Electron Microscope(SEM). As for the result, it was investigated that life consumption of steam turbine is correlated with distance between carbides, carbide's size and alteration of carbide's structure. Such rate of carbide alteration is measured quantitatively using image analysis system and the relationship between rotor's life span and the measured values was structured with mathematical model. Therefore the following carbide evaluation program was developed as can be seen in Fig. 1 and Fig. 2. In order to acquire optimal image of carbide through SEM, carbide information was quantified using various filters, threshold, and optimal image process methods.

Also, this program utilizes measured valued of hardness therefore includes steam rotor life evaluation module. Steam turbine rotor's high stress areas experience softening due to long-term operation that causes creep and fatigue damage therefore have lower hardness values compared to that of low stress areas. Such differences of hardness values have direct relationship with Larson-Miller parameter and hardness is correlated with distribution of carbides. This hardness module is life evaluation program that uses database which contains 10 years of accumulated data of domestic(A, B) steam turbine rotor's measured hardness values and micro-structures as can be seen in Fig. 3.

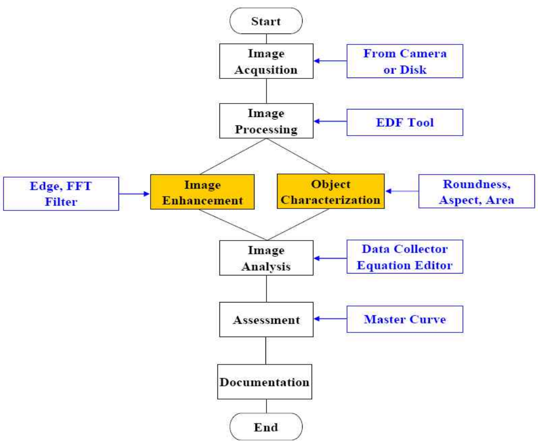


Fig. 1 Configuration of carbide approach program system

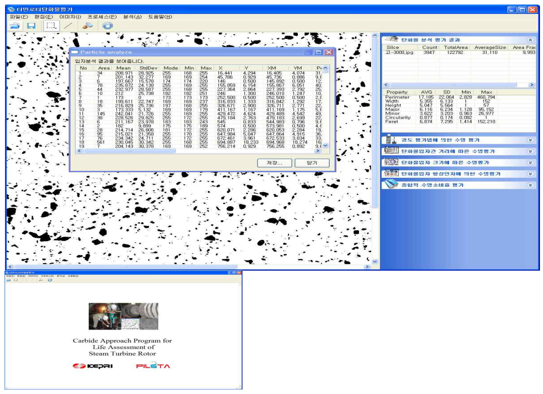


Fig. 2 Life calculating process for steam turbine rotor using microstructure carbide approach

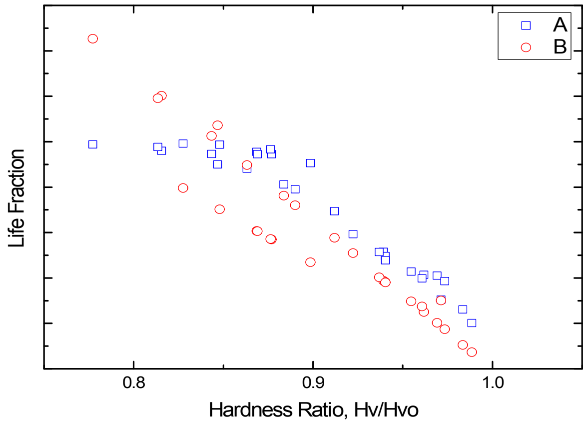


Fig. 3 Relationship between life fraction & hardness ratio

☞ Life evaluation using distances between carbides(interspacing method)

If the material goes through degradation process, the distance between carbides increases. The growth of metastable carbide can be described in equation (1) of temperature and time; it defines constant through degradated carbide analysis and proves the correlation between life and distance between carbides as can be seen in Fig. 4.

$$\frac{d\lambda^3}{dt} = C_0 \exp(\beta T) \qquad (1)$$

λ : Interparticle spacing at t

λ_0 : Interparticle spacing at t =0

C_0, β : Constant

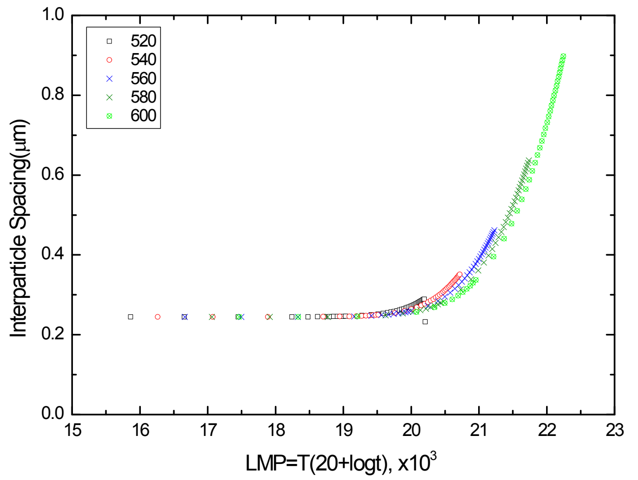


Fig. 4 Relationship between interspacing of carbides & LMP

☞ Life evaluation using the size of carbide (size method)

The growth of carbide on time basis can be described through carbide particle growth equation (2) using carbide coarsening model.

$$r = kt^{1/2} \qquad (2)$$

k is constant, t is operation time

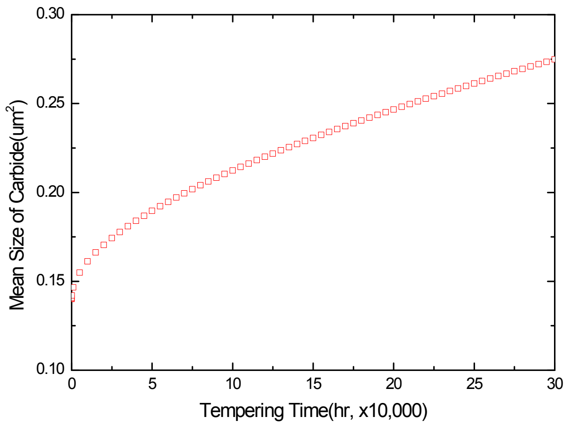


Fig. 5 Relationship between size of carbides & tempering time

But, due to the existence of newly formed carbides during degradation process, such carbides must be neglected from the analysis. Through various analyses, carbide particles that are below standard size were omitted and relationship between degradation time and particle sizes were mathematically modeled.

☞ Life evaluation through carbide particle shape factor(shape method)

Steam turbine rotor transforms its needle type M3C to M23C6 through degradation process. During the process, interior energy of the material decreases and the entropy increases therefore the particle stransforms from complex to simple. In order to quantitatively analyze such physical phenomenon, the particle structure was defined through acquired image using image function(Eq. 3) and correlation was proved for equipment's life evaluation. x parameter represents carbide's elongation and distortion, and y represents carbide's complexity of particle's structure therefore it is a parameter that is related to circularity. Carbide's standard images and field acquired images from rotors were analyzed through image processing therefore defined x, y parameters according to the three main structures (Circle, Ellipse, Needle).

$$x = \pi D^2/(4A) \text{ : Degree of elongation}$$
$$y = P^2/(4A\pi) \text{ : Degree of intricacy} \qquad (3)$$

A is Area(μm^2), D is Major Length(μm), and P is Perimeter(μm)

Strength that requires all creep strength depends of the degree of strength corresponding to microscopically distributed carbide particles. Generally the distances between them were considered significant. If this is considered to be a concept that interferes carbide particle dislocation, as the distance increases the creep strength will decrease and this phenomenon enlarges according to applied stress. If solid expansion occurs in high temperature, carbide particle becomes coarse in order to decrease overall surface area. But particle's coarse process is achieved through increased particle distance with given volume fraction. This occurs because relatively large particle captures smaller particles where such process decreases the number of particles.

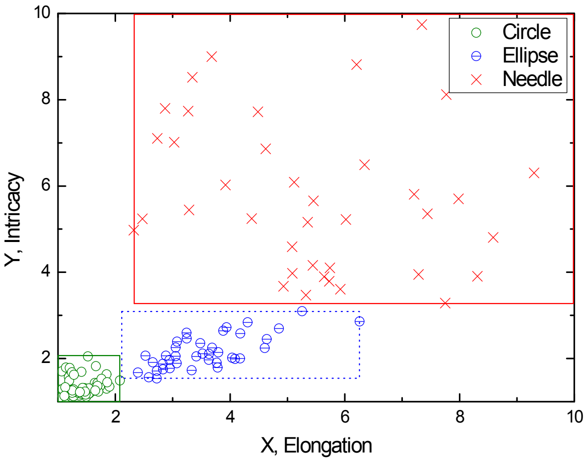


Fig. 6 Definition of carbide shape

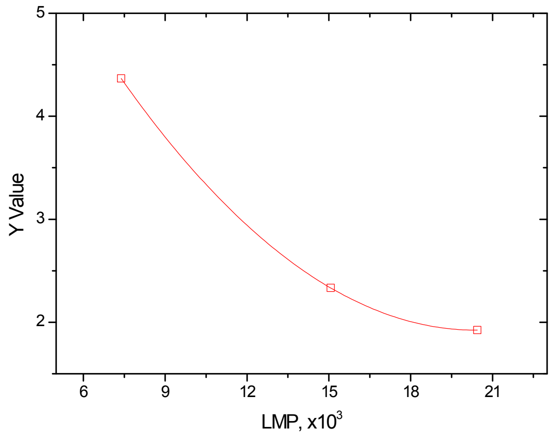


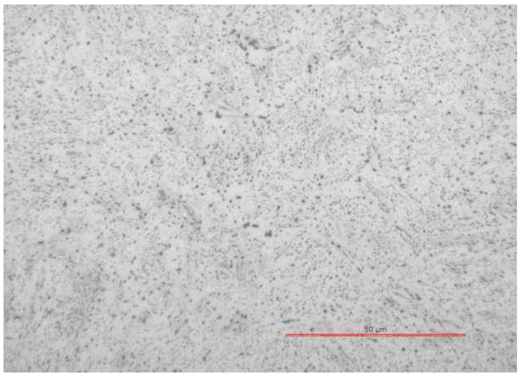
Fig. 7 Relationship between shape parameter & LMP

CASE STUDY Hardness was measured on operating 'P' thermal power plant's unit 1 high pressure turbine (Operating time : 175,000, Operation stop frequency : 2,190), and by using replica carbide information and micro structure were acquired. Life evaluation was conducted using developed carbide evaluation program.

Fig. 8 Steam turbine rotor of 'P' plant

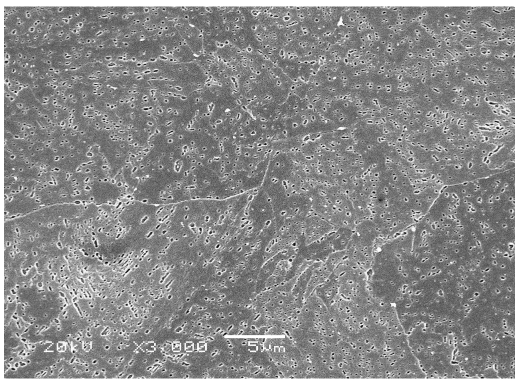
☞ **Microstructure by replication** Rotor forging steel is precipitation hardened tool steel where basic microstructure is tempered bainite. The coupling area of microstructure that is not affected by temperature and stress can be seen in Fig. 9(a), Fig. 10(a) where it is tempered bainite. The structure of the bainite is complete and there is no precipitated carbide on grain boundary. But HP 1 heat groove's microstructure shows dismantled bainite and intergranular and transgranular carbides are structured and coarse. (Refer to Fig. 9(b), Fig. 10(b)). But creep cavity is not observed currently.

(a) Coupling

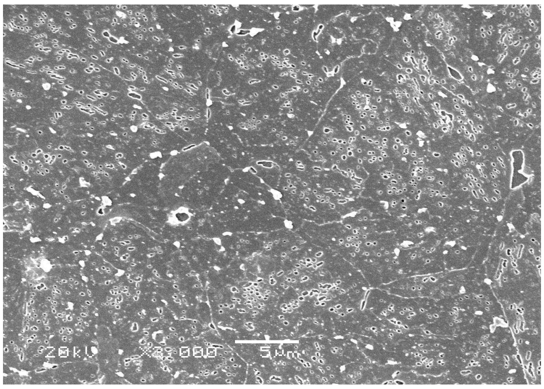


(b) Stage 1 of HP rotor

Fig. 9 Microstructure(Replica, OM, X1000)



(a) Coupling



(b) Stage 1 of HP rotor

Fig. 10 Microstructure (Replica, SEM, X3000)

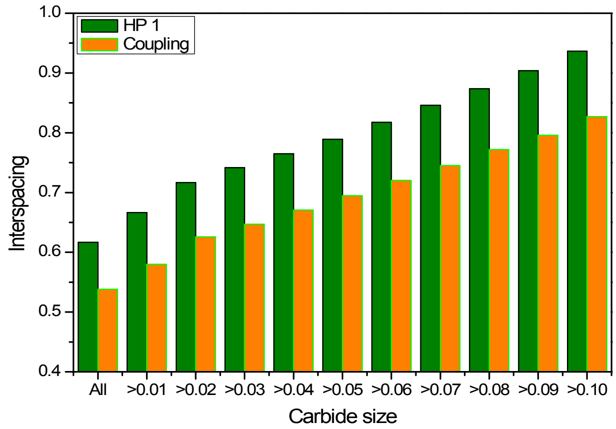


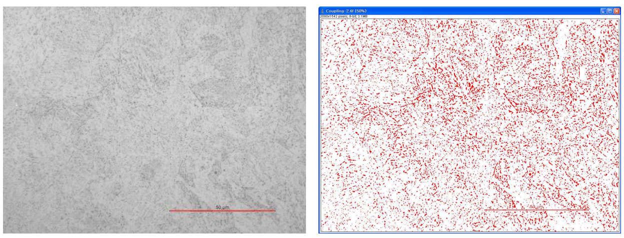
Fig. 12 Interspacing(μm) distribution of carbide by size(μm^2)

☞ **Results of interspacing method** The Fig. 11 at below shows image processing of microstructure image. Image was transformed to 8 bit and threshold was set to be lower 0 to upper 230, and noise was removed using despeckle function. Carbide size, shape, dispersion condition can be seen more descriptively compared to microstructure image.

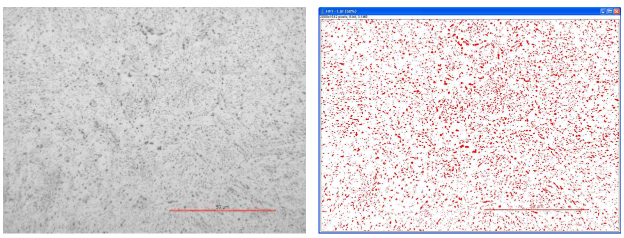
The average distance distribution corresponding to carbide size within standard area(142x92μm^2) can be seen at the graph below. It shows that the difference between distances is constant according to carbide size.

Coupling and HP level 1 carbide distance and life consumption rate evaluation result can be seen at below.

- Interspacing in coupling : 0.694μm
- Interspacing in HP 1 : 0.789μm
- Life consumption : 115.9%



(a)Coupling



(b)Stage 1 of HP rotor

Fig. 11 Image processing(Replica, OM, X1000)

☞ **Results of size method** The particle distribution according to above given standard area can be seen at the following graph. The particles are distributed evenly according to the size of the carbide. Coupling and HP level 1 carbide distance and life consumption rate evaluation result can be seen at below.

- Mean size in coupling : 0.140μm^2
- Mean size in HP 1 : 0.283μm^2
- Life consumption : 110.1%

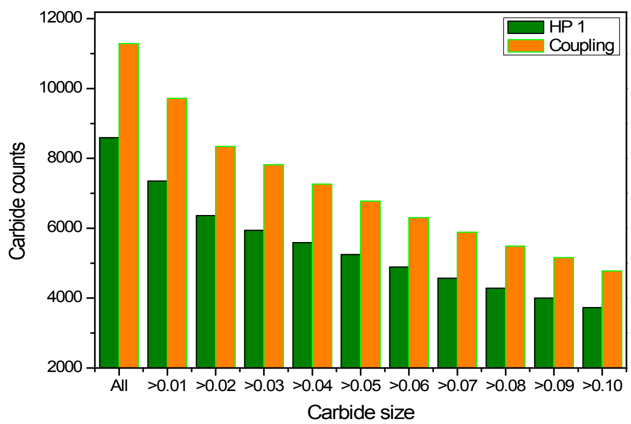


Fig. 13 Distribution of carbide by size(μm^2)

☞ **Results of shape method** Coupling and HP level 1's carbide shape parameter(Y) and life consumption rate can be seen at below.

- Shape parameter in coupling : 36.036
- Shape parameter in HP 1 : 1.026
- Life consumption : 85.6%

☞ **Hardness method** The value of hardness was acquired using portable Equotip hardness device (DynaMIC), Vickers hardness, and in order to increase the credibility of the measured value it was measure 30 times and the average value was used. Equipment was calibrated using standard block was provided by the manufacturer. Also in order to minimize the error and measure accurately on perpendicular direction, custom made device was used. HP level 1, 7, and coupling was measured in 4 directions which are 0,90,180,270°.

Measured hardness value and life consumption rate through the program can be seen at below.

- •HP 1 Hardness : 233.9HV
- •HP 7 Hardness : 261.5HV
- •Coupling Hardness : 266.5HV
- •Hardness difference : 32.6HV
- •Hardness ratio : 0.878
- •Life consumption : 97.6%

Fig. 14 Hardness measurement using device

☞ **Summary** The compared results of 'P' plant steam turbine rotor life evaluation using carbide evaluation program that uses 4 different methods can be seen at the table below. Life consumption rate was 78.4 ~ 125.4% in the 95% confidence interval and average was 102.3% which represent the life of the rotor has came to end.

Table 1 Results of life assessment by using the program

Method	Hardness	Carbide image analyzing			Remarks
		Inter spacing	Size	Shape	
LF(%)	97.4 ~ 97.8	106.4 ~ 125.4	98.7 ~ 121.5	78.4 ~ 92.8	Confidence Interval 95%
	97.6	115.9	110.1	85.6	Average

CONCLUSIONS

The conclusions of this study are summarized as follows.

(1) Information of carbides in microstructure was quantitatively analyzed through image processing and the relationship between life and variation of morphology, size, and spacing of carbides were found for quantitative life assessment of steam turbine rotor.

(2) Development of carbides assessment program, based on algorithm, of steam turbine rotor.

(3) For the verification of the program, it was applied to highly pressured turbine rotor of unit 1 in "P" fossil power plant; and it gave out satisfying results, which were similar to other assessment methods.

References

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