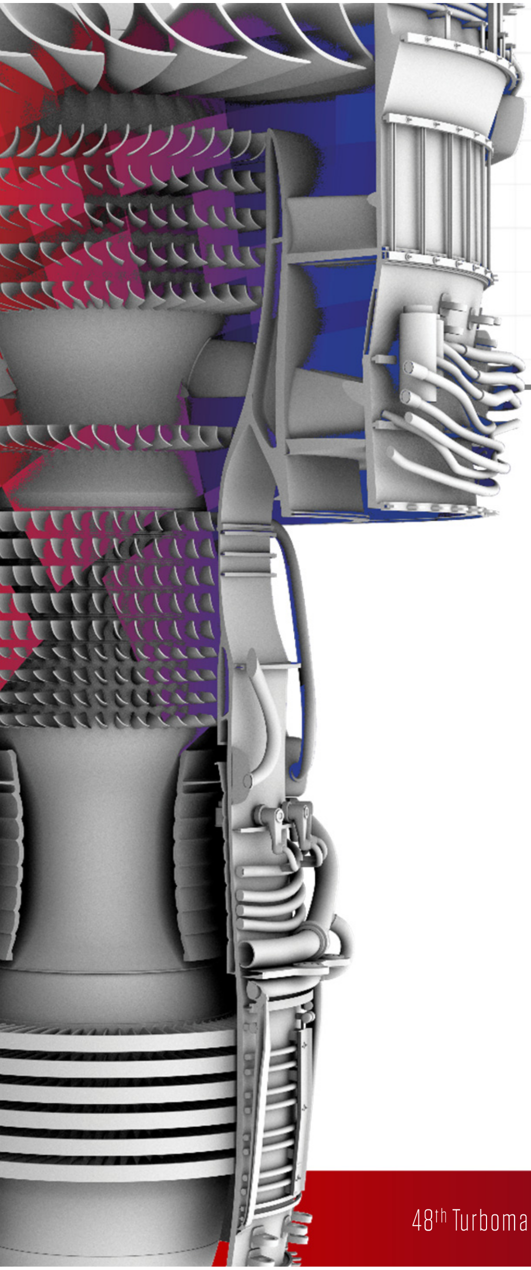

TURBOMACHINERY & PUMP SYMPOSIA

Blade failure analysis for steam turbines used for driving centrifugal compressors

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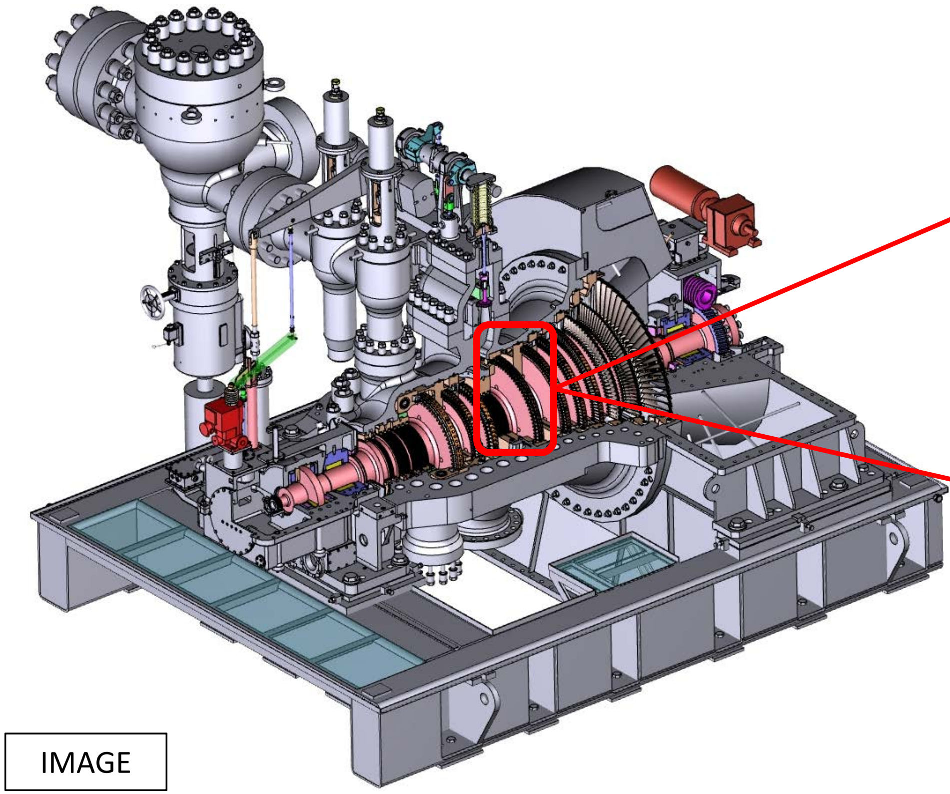
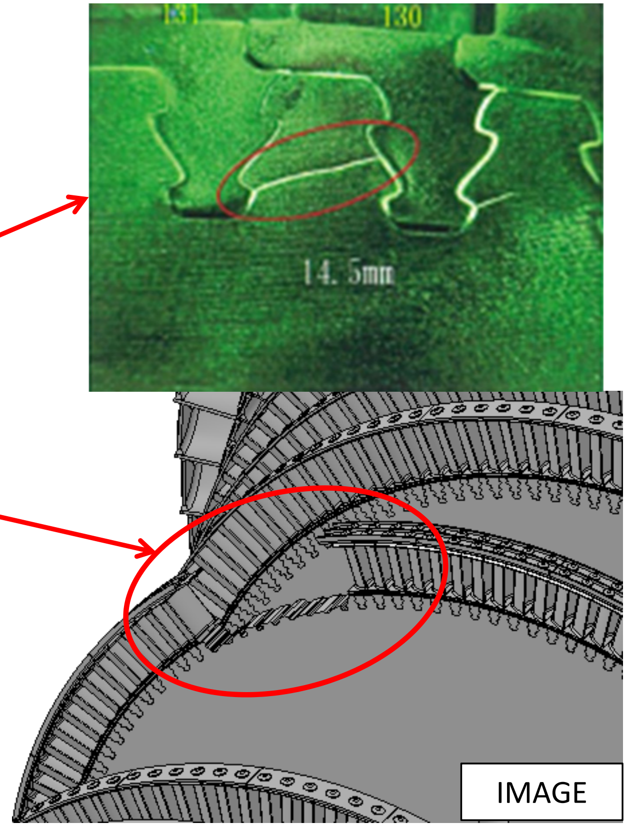
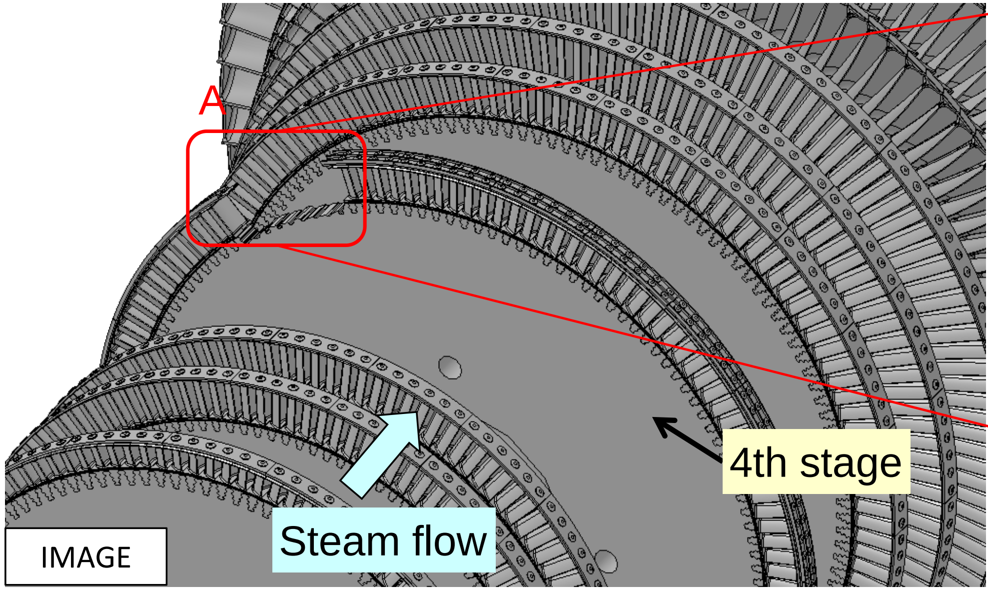


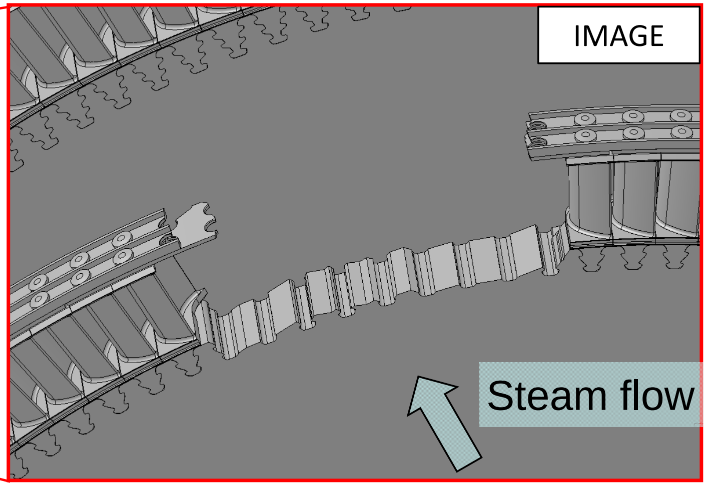


In 2016, the compressor drive steam turbine was tripped by high radial vibration.
After that, turbine casing was opened for internal parts check.

1. Background



Rotor condition



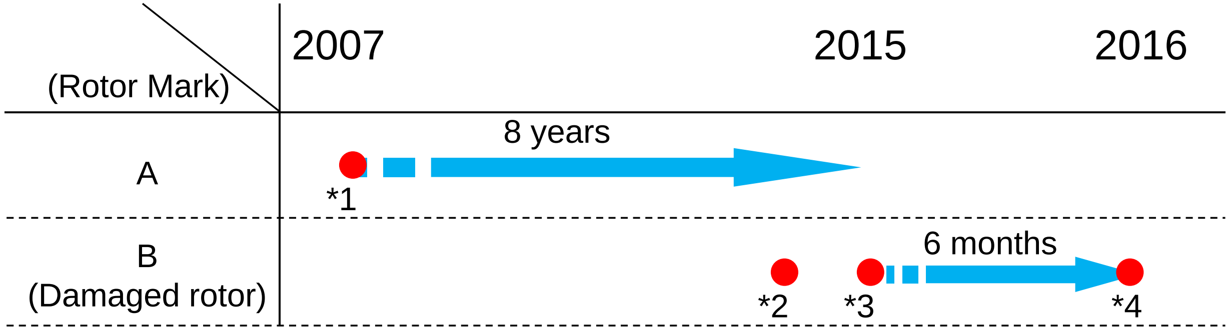
4th stage disk condition (Magnification A)

4th stage disk condition (After cut)

- 4th stage disk failure was found
  - 9 blades broke away and disc failure occurred at serration part of the groove.
  - 8 blade roots of disk side situated next to failed blades were cracked

2. Rotor history of this turbine

The history of both rotors are shown in table below.



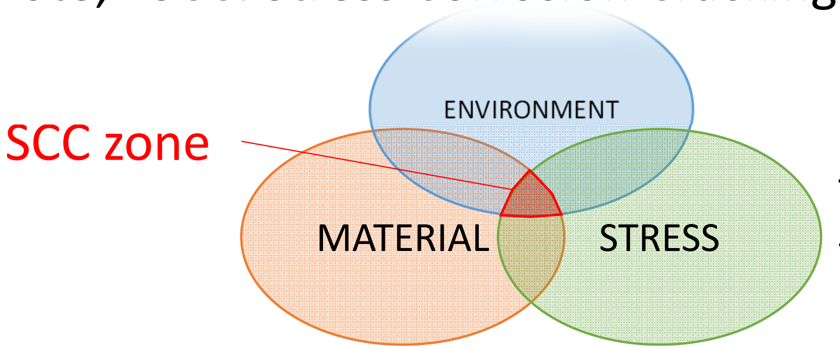
Rotor A: Original rotor
Rotor B: Revamped rotor (Damaged)

*1 Plant started with rotor A in 2007 and 8 years of normal operation was completed.
*2 Rotor B was modified for revamped turbine to increase the plant capacity.
Only HP stages design was changed but 4^{th} stage (LP stage) was not changed.
*3 Rotor was replaced from rotor A to rotor B.
*4 After 6 months of operation, Turbine tripped due to high vibration. High vibration occurred due to the failure of 4^{th} stage blade and related disk area.

3. Fault Tree Analysis for root cause of failure

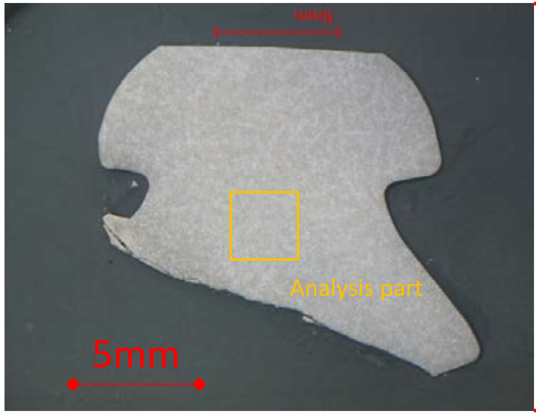
PHENOMENON	ANALYSIS OF FAILURE PHENOMENON		HOW TO VERIFY	RESULT OF VERIFICATION	Conclusion
4th stage disk failure	Corrosive environment	Insufficient quality of steam	Chemical analysis for scale on rotor disk surface	Large sodium (Na) contamination was detected on fractured surface and sampled scale.	Possible
			Observation of fractured surface	Intergranular surface, corrosion pits, and sub cracks were observed. The crack is *SCC due to corrosive environment.	Possible
	Excessive stress			Checked	Not Possible
	Insufficient design of disk strength			Checked	Not Possible
	Inferior material			Checked	Not Possible

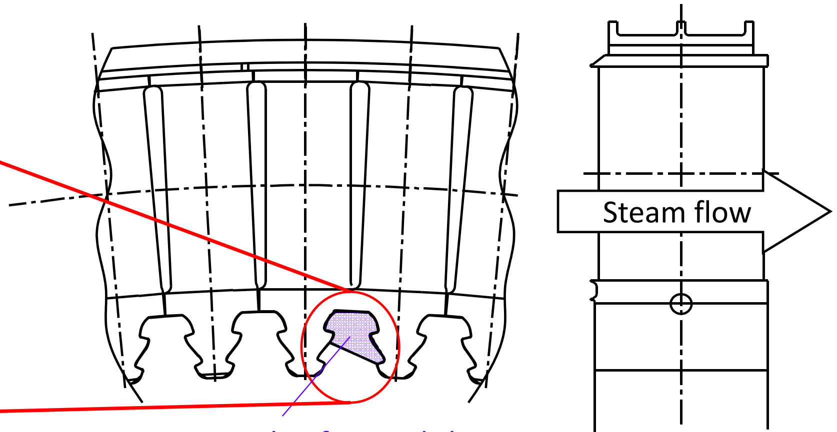
Note; *SCC: Stress Corrosion Cracking



SCC will occur when these three factors occur at the same time. (Stress, Material, Environment) Therefore, these three factors should be investigated to conclude that this failure is caused by SCC.

4. Material Factor – Investigation for base metal





4th stage blade & disc

Disc material ; Low-alloy steel

Chemical composition [%]

	C	Si	Mn	P	S	Ni	Cr	Mo	V
SAMPLE (Base metal)	0.29	0.21	0.64	0.007	0.001	1.2	1.29	0.42	0.70
Material spec	0.25-0.33	0.15-0.35	0.35-0.65	≦0.015	≦0.015	1.00-1.50	1.00-1.50	0.40-0.60	0.05-0.15

Conclusion

- Abnormality was not observed after chemical composition check.
- Mechanical properties are satisfied by material specification.
- Result : Proper material selection was carried out and there was no problem with the design.

5. Stress Factor – Checking of groove wall stress

- In order to evaluate the stress on failed stage disc, groove wall stress was calculated.

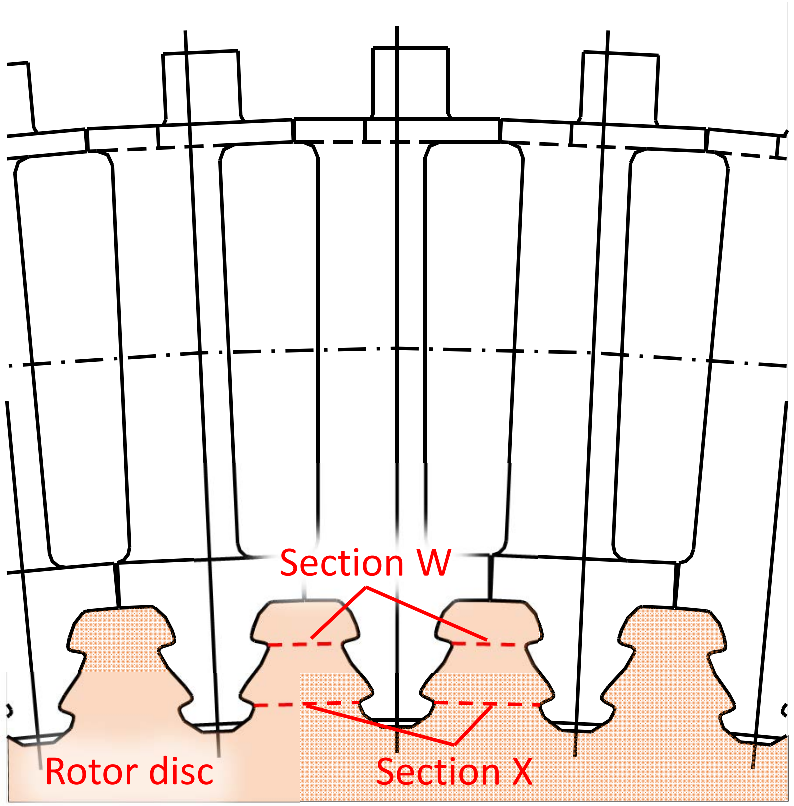


Table. Result of groove wall stress of 4th stage disc.

Stage No.	Part of groove	Calculated Stress [kgf/mm^2]	Allowable Stress [kgf/mm^2]	Safety Factor
4th stage	Section W	4.9	28.2	5.8
	Section X	7.0	28.2	4.0

Calculation condition :

- Rotating speed : 3840rpm (Maximum speed)

Conclusion

➢ Groove wall stress for 4th stage has enough safety margin as compared to the allowable stress.

6. Environmental Factor

- According to material factor and stress factor analysis, no abnormality was found.
  Therefore, following items were carried out to investigate environmental factor:

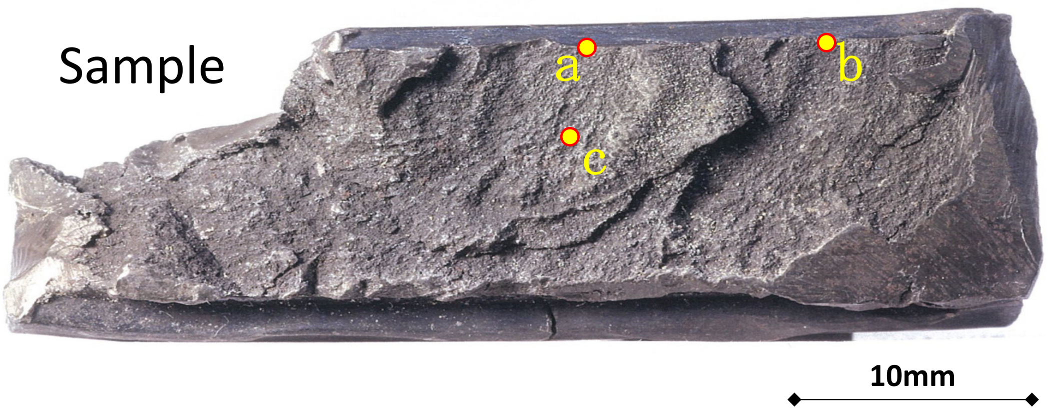
➢ Investigation of fractured surface.

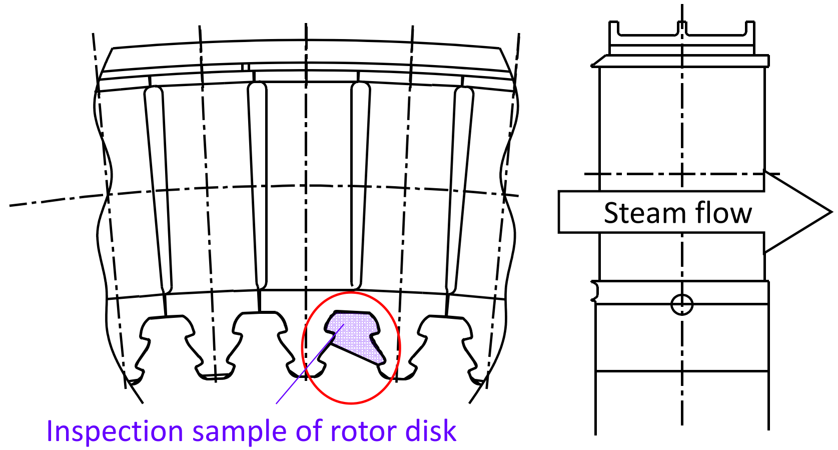
➢ Operation data review.

➢ Analysis of severe cracking area.

6. Environmental Factor – Investigation of fractured surface.

Sample





Disc material ; Low-alloy steel (Ni-Cr-Mo-V)

4th stage blade & disc

Elements [%]

	Si	P	S	Cr	Mn	Ni	C	Na	K	Cl
Part a	2.7	0.9	0.9	0.8	0.6	0.7	12.0	6.7	0.4	0.2
Part b	0.8	1.2	1.2	1.5	0.8	1.2	11.9	4.1	0.3	0.2
Part c	0.8	0.8	0.3	1.4	0.6	0.7	2.7	1.7	0.1	-
Material spec	0.15~0.35	≦0.015	≦0.015	1.00~1.50	0.35~0.65	1.00~1.50	0.25~0.33	-	-	-

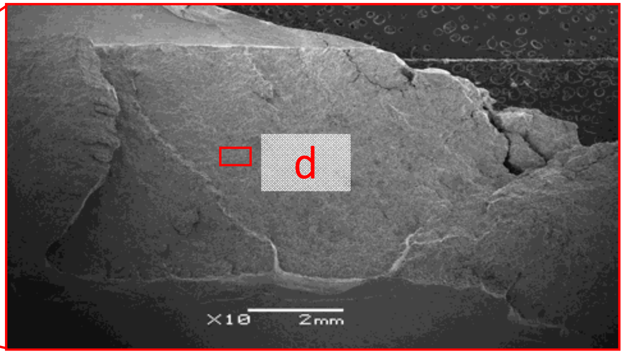
Findings:

- Na, Cl, K were detected from fractured surface except from base material.
- Corrosive material such as Na, Cl were detected on fractured surface.

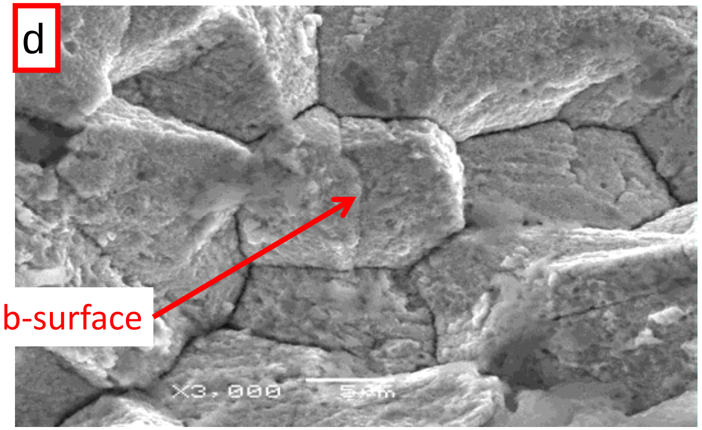
6. Environmental Factor – Investigation of fractured surface.

Fractured surface (1/2)

Overview of sample



Magnified



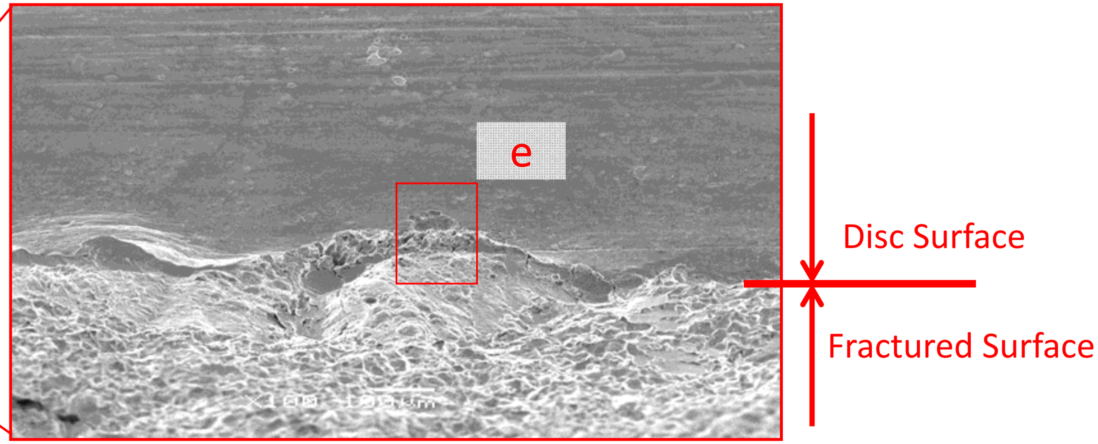
Finding

- The intergranular sub-surfaces were observed on fractured surface, which is a typical characteristic of SCC.

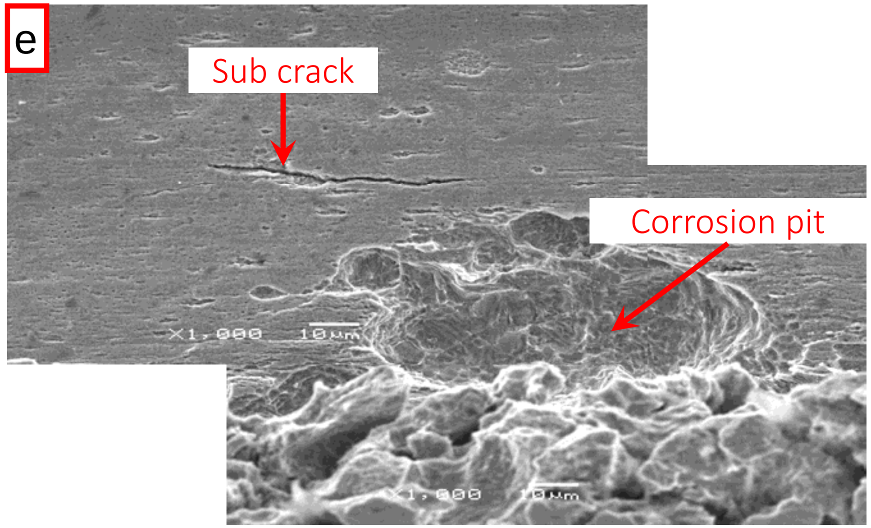
6. Environmental Factor – Investigation of fractured surface.

Fractured surface (2/2)

Overview of sample



Magnified



Finding

- Some corrosion pits and sub-cracks were found on disc surface near the crack.

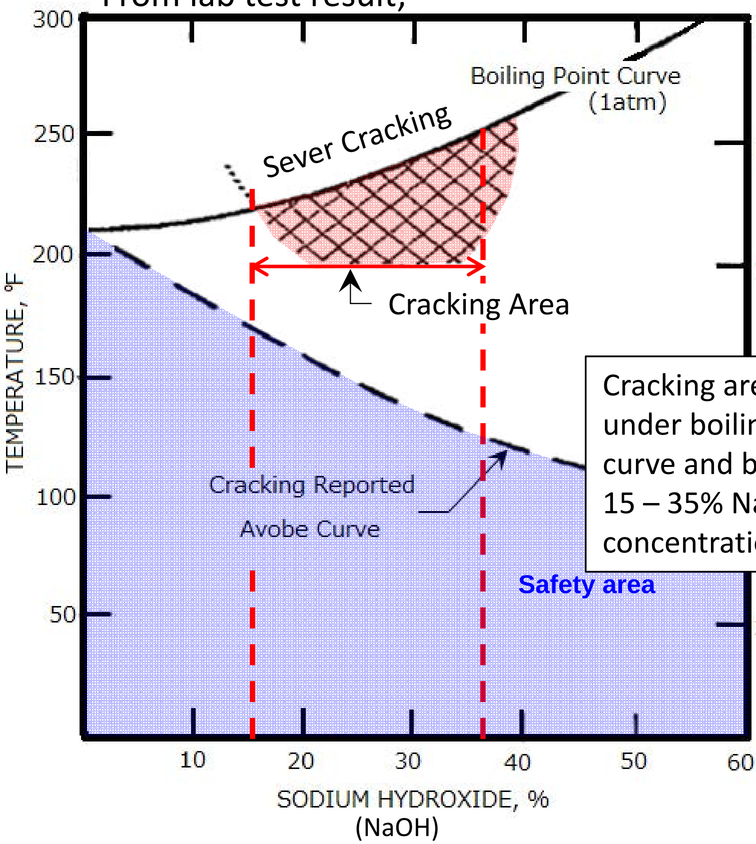
6. Environmental Factor – Operation data review.

- In order to evaluate the environmental effect on failed stage, operation data was reviewed.
  - According to operating data of damaged rotor, distinct overshoots of pH value in inlet steam were found. This implies that some corrosive material was mixed into inlet steam.
  - No other abnormal condition was found.
    (Ex. Speed, steam pressure, temperature and flow rate)

6. Environmental Factor – Analysis of severe cracking area.

- Following analysis explains the reason behind the particular failure of 4th stage

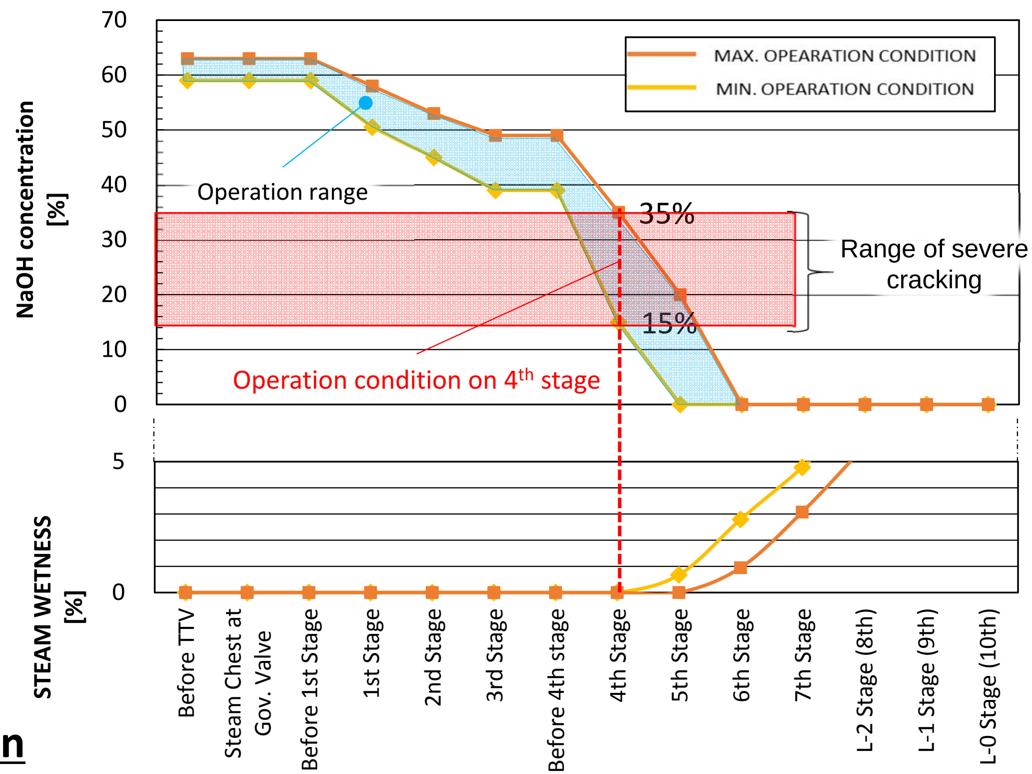
From lab test result;



Cracking area is just under boiling point curve and between 15 – 35% NaOH concentration.

Ref. J. K. Nelson, PPG Industries, inc., Materials of Construction for Alkalies and Hypochlorites, Process Industries Corrosion., pp.297- pp.310

Operating condition;



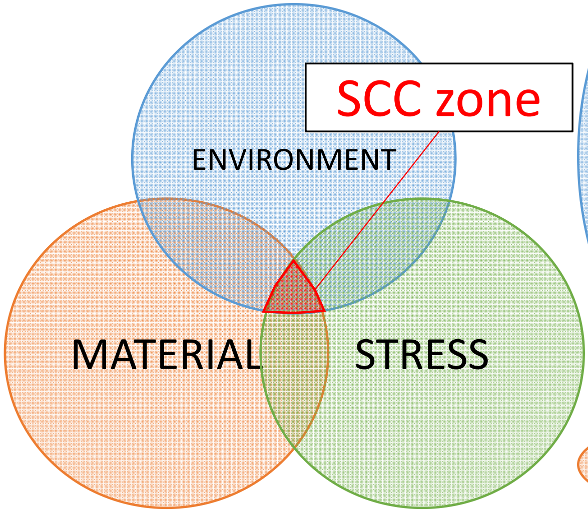
Conclusion

- This analysis shows that the concentration of NaOH solution in 4th stage blade was 15-35%. This concentration falls in severe cracking area and this result corresponds with actual failure location in turbine.

6. Environmental Factor

- As a result of investigation for environmental factors, following items were confirmed:
  - Large corrosive element (Na) was found on fractured surface.
  - The intergranular sub-surfaces were observed on fractured surface.
  - Some corrosion pits and sub-cracks were found on disc surface near the crack.
  - Distinct overshoots of pH value in inlet steam were found.
  - Concentration of NaOH solution in 4^{th} stage was 15-35%. This concentration falls in severe cracking area and this result corresponds with actual failure location in turbine.

7. Summary



ENVIRONMENT

- Some corrosive material was mixed into inlet steam
- NaOH concentration of 4th stage was discovered to be about 15-35% (severe cracking area).
- This concentration falls under the severe cracking area.
- Corrosive material and corrosion pit were observed on fractured surface.

MATERIAL

- No abnormality was found on disc material.

STRESS

- No abnormality was found on groove wall stress.

<u>Conclusion</u>

Some corrosive material was mixed into inlet steam.
However, SCC occurred only for 4th stage disc. This is because NaOH concentration of 4th stage fell under the severe cracking area.

8. Lessons learned

- According to this experience, following items were proposed about steam environment.

Factors	OEM	User
ENVIRONMENT	・Online monitoring system of user's steam inlet condition and operation data should be developed.	
	・Discussion about user's steam condition should be carried out before manufacturing the machine at OEM.	
	-	・If there is any possibility of some corrosive material getting mixed into steam or steam water, user should inform this to OEM. *1)

Note*) Steam purity limits are shown as following for reference:

STEAM PURITY-LIMITS

	Continuous	Start-Up
Conductivity- Micromhos/cm at 25℃		
Drum	0.3	1.0
Once through	0.2	0.5
SiO, ppb, max	20	50
Fe, ppb, max	20	50
Cu, ppb, max	3	10
Na + K, ppb, max		
Up to 800 psi [5516kPa (gauge)]	20	20
801 to 1450 psi [5517 to 9998kPa(gauge)]	10	10
1451 to 2400 psi [9999 to 16548(gauge)]	5	5
Over 2400 psi [over 16548kPa(gauge)]	3	3

Ref. NEMA SM 23. 1991.Item.9.7