TURBINE MATERIALS FOR GEOTHERMAL POWER GENERATION

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1. Introduction

Geothermal power generation have been gradually increased for past twenty years and will be steadily promoted as the alternative electric source of fossil power generation. Recently, many large turbine units over 100 MW have been constructed, in addition to small turbine units. The reliability of power plants becomes more important with the increase in the unit capacity. The schematic drawing of typical 130 MW class turbine unit is shown in Fig.1. Since the high availability of geothermal power plants depends strongly on the high reliability of turbine components such as rotor, blades and other structural components, many efforts on material and design modification have been continuously made.

Major concerns on materials to improve reliability of plants are the best selection of high resistant materials and protection methods to the corrosion-related problems caused by geothermal steam containing harmful elements such as clorine, hydrogen sulfide and carbon dioxide, as well as an improvement of material quality.

Since the geothermal steam chemistry is significantly varied in different geothermal power stations, it it extremely important to evaluate the corrosion behaviour of materials such as general corrosion, stress corrosion cracking and corrosion fatigue strength in the field tests using actual geothermal steam. We have carreid out many field tests in domestic and foreign countries for many years. The data base accumulated have been utilized to make further improvement of plant reliability.

In this paper, the material development and optimization for geothermal steam turbine components are reported, based on fundamental field corrosion test data.

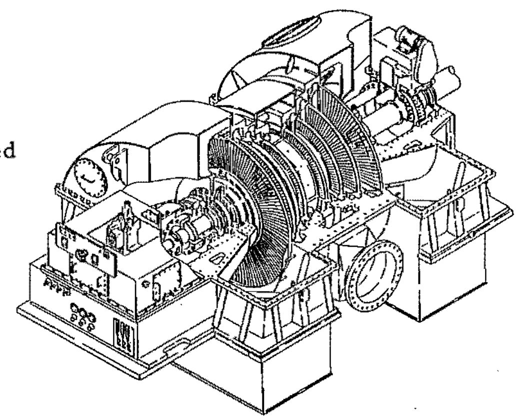

Fig.1 Typical 130 MW class geothermal turbine unit (a half of two casings)

2. Geothermal Turbine Rotor Materials

Turbine rotor is one of the most critical components in steam turbines because of the largest part rotating at high speeds of 3000 or 3600 rpm. Therefore, a good balance between strength and toughness and high quality throughout large rotor forgings is basically required for rotor material. In addition, a good resistance of rotor material to corrosion and stress corrosion cracking is more important in geothermal turbines. A low alloy CrMoV steel has been successfully used for geothermal turbine rotors over twenty years, which has a good corrosion resistance inherently. From the demand for more reliable rotor with increasing the plant capacity, a high toughness and clean CrMoV rotor material has been developed for geothermal use.

The foundamental material properties are strongly dependent on chemical composition, heat treatments and processing on manufacturing rotor forgings. Then, the alloying elements and impurities in CrMoV steel were controlled to achieve a good combination of strength and toughness. Concerning heat treatment conditions, quenching temperature and quenching method were optimized for large forgings. As results of lower quenching temperature and faster quenching rate than in conventional CrMoV rotors, higher toughness and finer microstructure could be attained. Fig.2 shows the improvement of toughness due to the modification of heat treatment and chemical composition in CrMoV steel. Here, the Fracture appearance transition temperature, called as FATT, and notch impact absorbed energy in charpy impact tests are summarized, which are the main parameters indicating the toughness of materials. FATT can be improved by heat treatment optimization mentioned above and further improved by an adition of chemical composition modification. Corresponding to improve FATT, notch impact absorbed energy is remarkably increased.

Moreover, strict control of raw materials and modern steel making technologies such as ladle refining process and vacuum carbon deoxidization are adopted for modified geothermal rotor to decrease impurities, sulfur and phosphorus, and their segregation.

As results of all modifications mentioned above, a marked improvement of toughness can be achieved in modified CrMoV geothermal rotor as shown in Fig.2, where the impact properties of several actual rotors are summarized by shaded squares.

Modified CrMoV geothermal rotor steel is also comfirmed to have a good stress corrosion cracking resistance. Table 1 indicates the results of field stress corrosion cracking tests under acceralated high stress condition in various geothermal power plant sites, using some kinds of turbine rotor materials and surface treatments. Whereas the tendency of materials to stress corrosion cracking is quite different from site to site even on same material due to the variation in geothermal steam chemistry, modified rotor material with high cleanliness and fine microstructure has the lowest susceptibility to SCC among materials tested.

Such a better resistance to SCC can contribute to a high reliability of geothermal rotor ,together with improved toughness.

To suppress stress corrosion cracking, it is also found that surface treatments such as shot peening and Al-coating are quite effective even for long-time exposure, as listed in Table 1. Such surface trearments have been applied to some rotors of geothermal plants and confirmed its effectiveness.

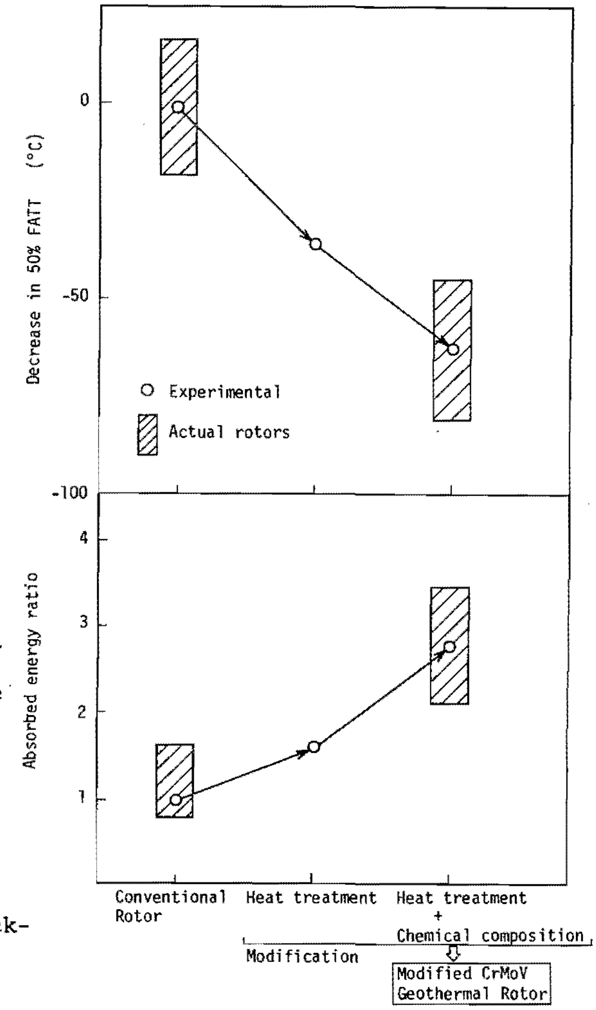

Fig.2 Improvement of toughness in CrMoV rotor steel

Table 1 Field SCC test results of rotor materials and surface treatments

Geothermal site (test period)	Mod. CrMoV geothermal rotor	CrMoV conventional rotor	NiCrMoV fossil rotor	Shot peened CrMoV	Al-coated CrMoV
Site A (1.5 years)	NC	NC	NC	-	-
Site B (1 year)	NC	NC	C	NC	NC
Site C (1 year)	NC	C	C	-	-
Site D (2.5 years)	C	C	C	NC	NC

Note; stress:over yield strength
NC:not cracked
C:cracked

3. Blade Materials

For turbine blades, 12 Cr steels having a high corrosion resistance have been widely used. Field corrosion fatigue tests of 12 Cr blade steels were conducted at several domestic and foreign geothermal power stations. Test results are summarized in Fig.3. Field corrosion fatigue data are largely spreaded owing to different steam chemistry in test sites. Moreover, corrosion fatigue strength has not apparent endurance limit and gradually dereases with increasing test cycles, although a definite endurance limit exists in air test. This tendency of geothermal corrosion fatigue strength is similar to those of other corrosion fatigue behaviours tested in sea water or other corrosive environments.

Therefore, it is important to take these points into cosideration for blade design of geothermal turbines.

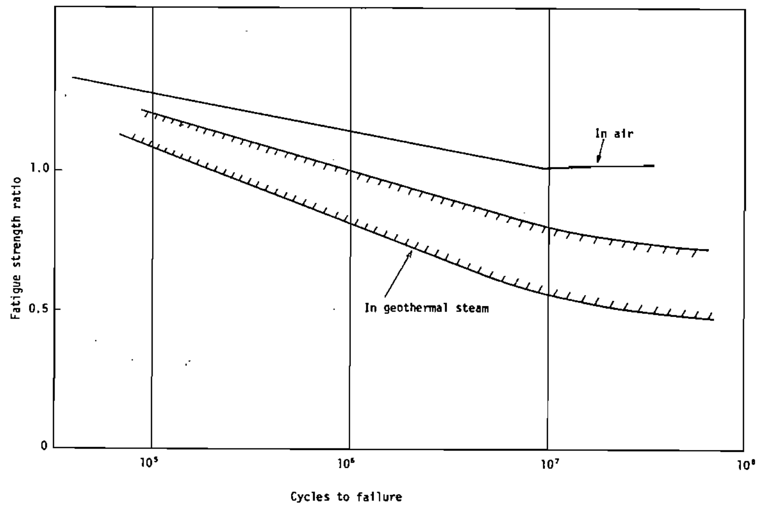

Fig.3 Field corrosion fatigue test results of 12 Cr blade steel in various geothermal power stations

4. Structural Components

As for important structural components including condenser, coolers and pipings, suitable materials are selected for each component, based on long-time field corrosion tests. Fig.4 shows the field corrosion test results carried out in steam and condensate at several geothermal power stations. The corrosion rates of stainless steels and titanium were very low at every test locations, whereas those of carbon steel, low alloy steel and copper alloys were very high and varied extensively depending on test location. Thus, austenitic stainless steels are applied to trays in condenser, turbine internal pipings and so on where severe corrosion may occur. Condenser inner walls are made up of epoxy-lining or stainless-clad carbon steel to protect from heavy corrosion.

Titanium tubing are also used for oil cooler instead of copper alloy tubing used in fossil turbines since copper alloys are easily corroded in hydrogen-surfide containing environment as shown in Fig.4.

In the case of carbon steel piping, thickness margine for corrosion are took into design consideration or epoxy-lining is adopted at relatively low temperature use.

In aerated steam environment which may occur in gas extraction line from condenser and turbine grand steam line, the mixture of geothermal steam, non-condensable gas and air can cause extremely heavy corrosion with increasing temperature. From the field tests, it was found that even stainless steels may be subjected to severe corrosion and stress corrosion cracking in such environment. Thus, extra-low carbon ferritic stainless steel and corrosion resistant FRP can be utilized in such lines. From the design aspects, common austenitic stainless steels can be used successfully by lowering the temperature of gas extraction line.

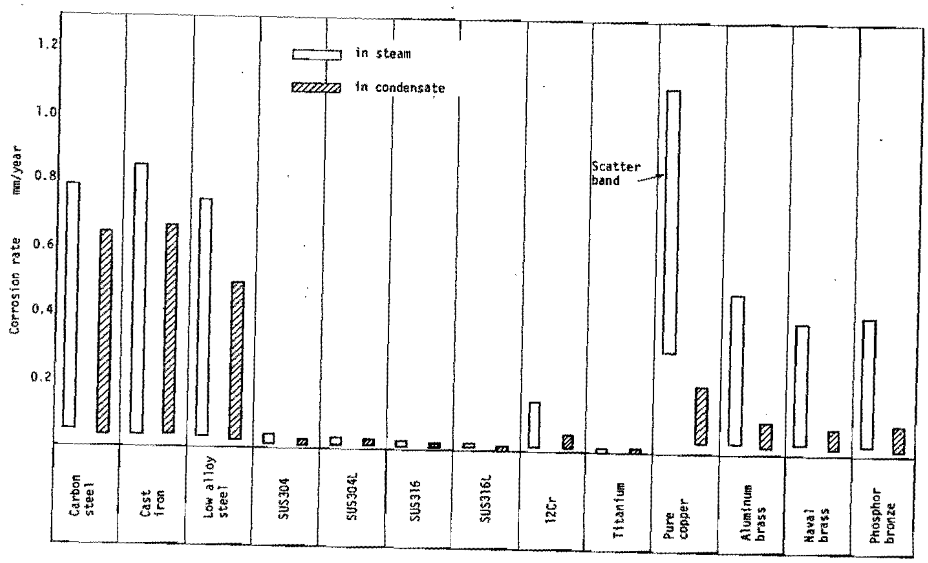

Fig.4 Field corrosion test results of various materials

5. Summary

As mentioned above, the development and best selection of turbine materials have been promoted from the viewpoint of high resistance to general corrosion, stress corrosion cracking or high corrosion fatigue strength, based on field corrosion test data. The measurs from material aspects have contributed to the significant improvement on the reliability of geothermal power plants, combining with design considerations including lowering the stress levels and structural modifications.

Field corrosion tests for material evaluation are still going on and foundmental data base will be accumulated in order to achieve higher reliability of geothermal power plants.