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Metallographic Aspects Investigation of Penstock Materials in Hydroelectric Power Plants and Penstock Maintenance Methods

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Abstract

Hydroelectric power plants are renewable energy sources and have little impact on the environment. Therefore, it is one of the most preferred energy sources in the world. In parallel with this situation, it is very important that the hydroelectric power plants are maintained, their failures are prevented or permanently removed. One of the most important parts of hydroelectric power plants is penstock pipes. Along with the snail part of the power plant, the penstock supplies the pressurized water to the turbine wheel for energy production. In the power plants that have been producing energy for many years, the maintenance and material properties of penstock are very important. In this study, one of the most important equipment of hydroelectric power plants, pressurized water pipes (penstock) and chemical components have been examined in macro and micro structure and their maintenance is investigated. In the metallographic study on the samples taken from two different regions of the penstock pipe; the perlitic structure, which has a homogeneous distribution into the ferritic structure forming the matrix, is determined and supported by analyzes. This study will help to ensure that all hydroelectric power plants operate smoothly in terms of penstock.

Keywords: Renewable energy, Hydroelectric Power Plants, Penstock, Metallographic Survey

1. INTRODUCTION

Hydroelectric power plants are the most important renewable energy source of the world's electricity supply due to their low environmental impact, low operating and maintenance costs. Hydroelectricity is one of the sustainable clean energy sources and suitable for environmental legislation such as Kyoto Protocol. Hydroelectric power plants do not produce greenhouse gas emissions, because they do not use fuel and do not pollute the air. They contribute to global warming prevention activities. Around 16% of the world's electricity production is provided by hydroelectric power [1].

The amount of energy to be produced from the water source in hydroelectric power plants depends on the net head and the flow rate of the water. According to these two main parameters, the type of turbine to be used is determined. Turbine types are classified in two main categories as impulse turbines and reaction turbines [2]. Impulse turbines include pelton and reaction turbines include Francis, Kaplan turbines[3]. In all turbine types, the pipes that convey the pressurized

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water for energy production are called as penstock. Therefore, manufacturing and calculation of penstock is very important. The risk of any explosion and perforation can cause enormous cost damage to hydroelectric power plant facilities. There are many studies on penstock pipes in the literature [4] [5] [6] [7]. Lucas et al. have conducted fatigue analysis in penstock because of variable water velocities in pumped power plants [8]. Kumar and Singal have solved the problem of material selection of penstock for small hydroelectric power plants by using Multiple Attribute Decision Making (MADM) method [9]. Kawamura et al. have studied metallographic and physical materials of the penstock of hydroelectric power plants that have been producing energy for many years [10]. Leon and Zhu have performed a dimensional analysis to determine the optimum penstock diameter and optimum flow in impulse and reaction turbines [11]. By calculating the optimum diameter of the penstock used in small-scale hydroelectric power plants, Alexander and Giddens have analyzed the cost of the penstock pipe diameter according to cost [12]. Bulloch and Callagy have conducted corrosion, fatigue and crack analysis in the penstock of a 25 MW hydroelectric power plant [13].

2. MATERIAL AND METHOD

In hydroelectric power plants, the pressure pipes between the dam lake or the loading pool and the turbines are called as penstock. Penstock pipes are manufactured by bending steel sheets and welding them together. The steel sheets must be ductile. St 37, St 42 and St 52 steel sheets are used in the manufacture of penstock pipes. The yield boundaries of these plates vary between 21-36 (kp/mm^2) and the breakage boundaries vary between 22-27%. The materials used for the penstock pipes manufacture must have the ability to withstand the pulling, bending, cracking stresses, and the inner surfaces of the penstock, which are manufactured, must be covered with a protective coating against corrosion and they must be smooth. In addition, the joints of penstock pipes should be assembled with gaskets against water tightness and must have a structure that tolerates stresses that may occur during temperature changes. Depending on the topography of the plant or in hydroelectric power plants having high hydraulic head, the length of the penstock can be very long. This significantly affects the initial investment cost of the plant. For this reason, optimum diameter calculation is very important in penstock pipes. In high hydraulic head power plants, it is necessary to calculate the wall thicknesses and connection parts of the penstock according to high static and dynamic stresses [14]. Figure 1 shows the penstock of a hydroelectric power plant.

Figure 1. Penstock pipes

The maintenance of the penstock pipes used for many years under pressure and the examination of the material structures are of great importance in terms of the prevention of any possible damage in the dams. The maintenance levels of the penstock pipes are given below.

- Visible areas of penstock pipes should be visually inspected once a week.
- Long penstock pipes are sealed by sealing material at certain distances. The reason for this is the expansion of the penstock due to the temperature difference caused by the seasons. Due to any maintenance in the turbine,

pressurized water in penstock is discharged. Empty penstock pipes seals get dry under the sun. Therefore, it is necessary to keep water continuously in the seals of empty penstock pipes.

- The wall thickness of the penstock pipes increases as a result of the pressure from the dam body to the turbine snail. Penstock thickness must be measured by ultrasonic method once a year. Measured values should be recorded by creating an archive and the values measured every year should be compared with the previous year.
- Internal and external parts of penstock pipes should be sanded and painted with epoxy paint in certain periods depending on corrosion.

2.1. Metallographic Survey

As a result of the metallographic studies on the samples taken from two different points of the penstock it is observed that in the optical images given in Figure 2, the main structure (matrix) is formed by ferrite (yellow regions) and disconnected black areas in the structure are perlite. Images taken at different magnifications enabled the detection of grain boundaries as a result of etching. The perlite contained in the ferritic structure positively affects many properties of ferrite, which contains very low carbon content (0.008%). Chemical and mechanical properties of the material;
C: 0,22 P: 0,04 Mn: 0,6 Al: 0,02 Tensile strength: 490-630 Mpa, Yielding point: 335 Mpa

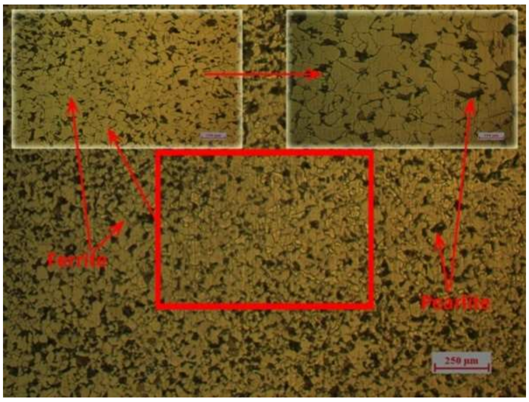


Figure 2. Optical images of the sample one at different magnifications.

When we examine the SEM images at different magnifications in Figure 3, it is evident that the ferritic structure forming the matrix is the black regions. The styliform white areas are composed of perlite, a two-phase structure with coverglass gathering the iron and cementite phases.

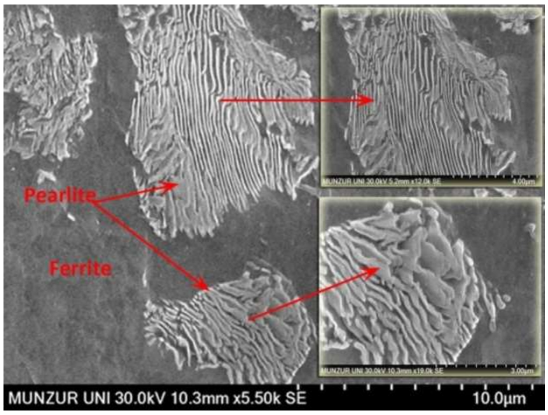
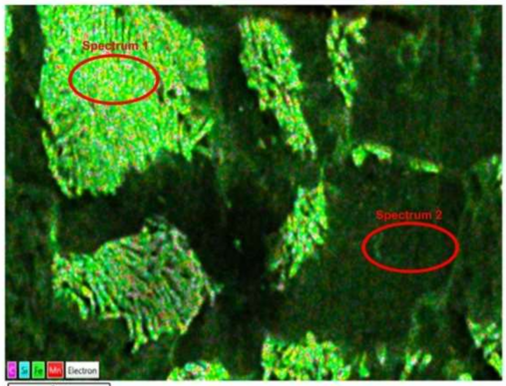


Figure 3. SEM images of the sample one at different magnifications.

In Figure 4, regional and point EDS analyzes are given. In the analysis we have obtained from the overall structure, it is seen that the matrix is composed of 96.18% Fe as a result of the different coloring we made for each element, while the portions of other elements are very small. When we examine the spectrum peaks, C, Mg and Si compounds are composed of Fe and Mn.



Element	General Spectrum	Spectrum 1	Spectrum 2
Fe	96.18	95.41	97.57
Mn	2.60	2.73	1.48
Si	1.03	1.41	0.78
C	0.19	0.45	0.17

Figure 4. Demonstration of regional and spot EDS analysis of the sample one.

When we examined the metallographic images of the sample from the second region as it can be observed in Figure 5 at different optical magnifications, perritic structure is in the ferritic structure disorganizedly (Yellow regions Ferrite, Black regions Perrite)

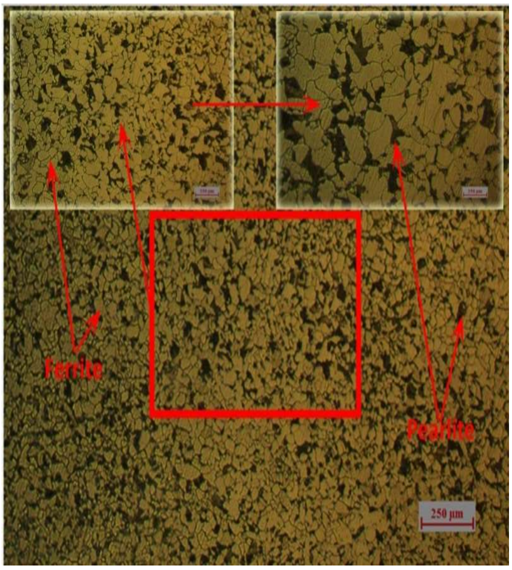


Figure 5. SEM images of the sample two at different magnifications.

When we examine the SEM images shown in Figure 6, it is seen that this hypoeutectoid structure consisting of ferritic and perlitic structure, as seen in the sample one, consists of a few cementite phases.

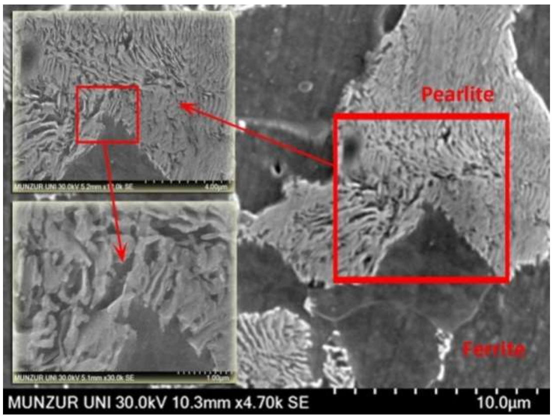


Figure 6. Optical images of sample two at different magnifications.

In the image we examined in Figure 7, regional and point EDS analyzes are given. The structure, which contains over 95% Fe, consists of ferrite in dark areas and Perlite in light green areas. In the peaks obtained from EDS analyzes, it contains a second compound formed by C, Mn and Si as well as the compound consisting of Fe and Mn.

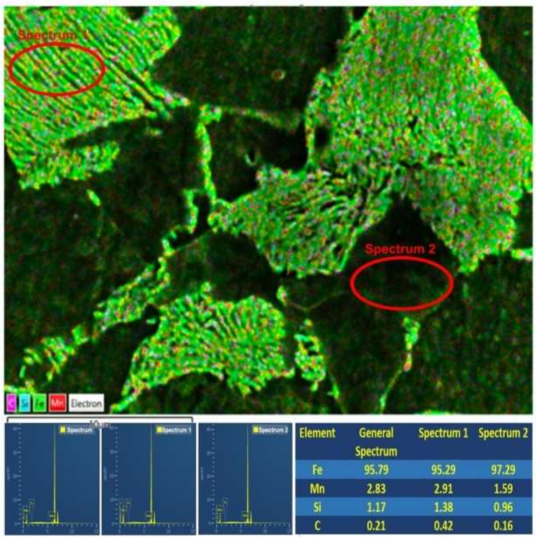


Figure 7. Demonstration of regional and point EDS analysis of sample two.

3. CONCLUSION

Penstock pipes are one of the most important parts of hydroelectric power plants. According to the net head of the dam their pressure varies between 5 and 25 bar. This pressure can cause huge loss of life and property in any penstock pipe burst. Hydroelectric power plants, which are the most important renewable energy source of the countries and which generate huge economic income, may not produce electricity for years due to failures and penstock pipe accidents. Therefore, they cause huge financial losses for countries. The results obtained in this study are given below,

1)The maintenance process of penstock pipes in hydroelectric power plants is investigated.

2)A sample is taken from the penstock of a hydroelectric power plant and analyzed from two different points and examined metallographically.

3)As a result of the investigations, it is evident that the general structure is ferrite, and the coverglass formed by the combination of iron and cementite phases creates perlitic structure.

4)It is found that a small amount of Mn, Si, C and low carbon steel are present in the material containing more than 95% Fe.

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