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Weldability and Service Conditions of Steels in Thermal Power Plant Applications

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Abstract— **In this study, the usage purposes of the steel grades used in Thermal Power Plant applications were compiled. The welding conditions between the steels are specified. The service conditions and quantities of low carbon and Cr-Mo alloy steels used in thermal power plants are explained. Additional metal groups, preheat and inter-pass temperatures, non-destructive examinations and post-weld heat treatment conditions are explained in the welding of the Cr-Mo alloy steels used. The availability of pre-heat conditions before welding was examined according to the relevant standards. The selection conditions of the additional metals, welding positions and welding conditions of the welders were examined. The weldability of steels of similar or dissimilar quality is discussed. Information about post-weld stress relieving heat treatment has been compiled from the relevant standards and the conditions for which quality steel will be used have been analyzed. As a result, in this study, all the welding-related stages of the steels used in Thermal Power Plants were examined.**

Keywords— **Thermal Power Plant, Cr-Mo Steel, Weldability, Filler Metal, PWHT.**

I. INTRODUCTION

With the increasing need for energy in the modern era, the establishment of thermal power plants and nuclear power plants in the petro-chemical sector has become widespread all over the world. The production of steam boilers, heaters, reactors and pressure-exposed boilers operating under high temperature and high-pressure conditions is important. The materials used in these stages should be creep resistant steels with high mechanical properties. With the service conditions reaching 600°C levels, the use of high temperature resistant steels has become mandatory. Cr-Mo steels with these properties have an important place with their high thermal conductivity and high creep resistance, as well as high corrosion resistance. In addition, high thermal efficiency minimizes energy loss and does not cause environmental pollution thanks to low CO_2 emission [1-3].

Cr-Mo steels are materials resistant to high temperature (650°C) and high pressure (300 bar). For this reason, they are frequently preferred in thermal power plants, nuclear power plants and refineries that produce energy [4-6]. The usage areas of steels in a thermal power plant combustion chamber and general view are given in Figure 1 [7].

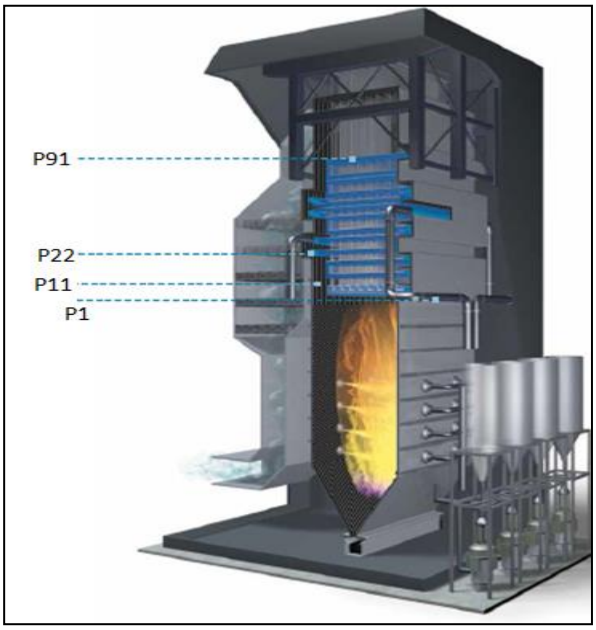

Fig. 1 A thermal power plant combustion chamber and the steels used

II. STEEL DETAILS

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In this study, first of all, subjects other than structural steel, which is used in every sector as basic steel, are discussed. In terms of service conditions, Cr-Mo steels with increased temperature parameters have been studied more in the study. We can list Cr-Mo steels according to service conditions as follows [8].

1. 16Mo3(P1) Service Temp. 100°C-200°C range
2. 13CrMo4-5(P11) Service Temp. 400°C-535°C range
3. 10CrMo9-10(P22) Service Temp. 535°C-560°C range
4. XCrMoVNb9-1(P91) Service Temp. 560°C-580°C range
5. XCrWMoVNb9-2 (P92) Service Temp. above 580°C

At a stage that explains the selection of steel alloys according to the place of use, should be given Figure 2 [9]. According to the temperature difference, the usage thickness detail can be compiled in this way.

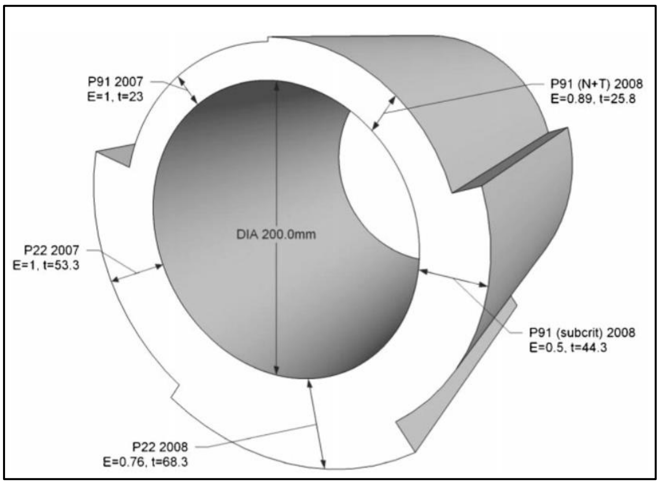

Fig. 2 Detail of usage thickness of Cr-Mo steels according to temperature difference

The thickness difference is observed in the direction allowed by the piping. However, in this case, temperature and pressure values can come into play. Finally, considering the cost variable, the most appropriate thickness / quality situation can be selected [5, 10].

The chemical contents of these Cr-Mo steels used according to the standard data are given in Table 1 [11-13]. In addition, the basic mechanical properties are listed in Table 2 [11, 13].

TABLE I
CHEMICAL COMPOSITION FOR CR-MO STEEL

	P1	P11	P22	P91	P92
C≤	0.10-0.20	0.05-0.15	0.05-0.15	0.08-0.12	0.07-0.13
Mn	0.30-0.80	0.30-0.61	0.30-0.60	0.30-0.60	0.30-0.60
P≤	0.025	0.025	0.025	0.020	0.020
S≤	0.025	0.025	0.025	0.010	0.010
Si≤	0.10-0.50	0.50-1.00	0.50	0.20-0.50	0.50
Cr	-	1.00-1.50	1.90-2.60	8.00-9.50	8.50-9.50
Mo	0.44-0.65	0.44-0.65	0.87-1.13	0.85-1.05	0.30-0.60
Fe	balance	balance	balance	balance	balance

Note 1: Other elements for P91 %: V 0.18-0.25; N 0.030-0.070; Ni ≤ 0.40; Al ≤ 0.04 ; Nb 0.06-0.10

Note 2: Other elements for P92 % : V 0.15-0.25; N 0.030-0.070; Ni ≤ 0.40; Al ≤ 0.04 ; Nb 0.04-0.09; W 1.5-2.00 ; B 0.001-0.006

III. WELDABILITY, NDT AND PWHT

Welding process in terms of rapid heating and cooling events affecting the steel locally; it can be defined as a thermal shock effect on steel or a series of similar effects. The ability of the steel against this situation is called the "welding capability degree" (WCD) [1, 2, 6].

TABLE II
MECHANIC DETAILS FOR CR-MO STEEL

Steel	Yield MPa	Tensile MPa	% Elongation	Impact Energy J, (+20C)
P1	220-275	440-590	>22	>35
P11	>205	>415	>22	>35
P22	>220	>415	>22	>35
P91	>415	>585	>20	>35
P92	>440	>620	>20	>35

The WCD level of these steels is inversely proportional to the Ceq value. According to the Ceq formula, the WCD level is low for a high value steel. Therefore, as the Ceq value increases, the details about the follow-up of the welding process increase. Each stage should be recorded, and welding should be done within the relevant conditions. The Ceq formula published by the IIW Society within the framework of these conditions is given below (Eq.1). This formula can be applied to P1, P11 and P22 quality steels calculated with this formula. However, it will not be correct to use this formula for P91 and P92 quality steels containing elements not found in the formula. At this stage, the most comprehensive formula published by "The Japanese Welding Engineering Society" is more useful (Eq. 2) [3, 14].

$$CE = \%C + \frac{\%Mn}{6} + \left(\frac{\%Cr + \%Mo + \%V}{5}\right) + \left(\frac{\%Cu + \%Ni}{15}\right) \quad \text{Eq.1}$$

$$Pcm = \%C + \frac{\%Si}{30} + \frac{\%Mn + \%Cu + \%Cr}{20} + \frac{\%Ni}{60} + \frac{\%Mo}{15} + \frac{\%V}{10} + 5B \quad \text{Eq.2}$$

At this stage, when the materials with a high Ceq difference are welded to each other, if the difference is >1, it is a must to use buffer material. This is due to the effect of sudden hardness change. This buffer material should have a Ceq value at the intermediate value of the two materials and should be used with a length of at least 150 mm. In this case, another question will be "Which additional wire and welding conditions are valid for steels with Ceq difference <1 when welding different steels during welding". As an answer, it can be said "Additional metal and welding conditions of steel with a high C_{eq} value are valid". In industrial applications, this situation is a subject of great attention and constant discussion [1, 6, 8, 15].

Welds are made by experienced welders certified according to the standard, after adequate listening and living needs are met. It is very important to control the welder outside the standard, and additional inspections should be applied if necessary. For example, situations such as a welder's daily sleep time or a welder working 3 days' night shifts can be added, which is a very common practice. In addition, when welding a different material, the welder is trained on the fluidity (viscosity) state of the weld metal of that material and the pre-heat conditions. All welders take the necessary parameters and weld through the "Welding Processing Specification" (WPS). It is constantly checked whether it uses variables other than these parameters. If a welder uses parameters other than WPS and repeated faults, the "welder certificate" is revoked by the quality team [16, 17].

The weld mouth detail is the first thing to be examined. Weld mouth prepared according to WPS and technical drawing details should be protected until the welding time. Because the corrosion protective oil film layer on the pipe is no longer present in this region. Protection can be done with a paper tape or protective spray oil. However, residues from the protective layer / adhesive must be cleaned with an alcohol-based solvent before welding starts. Because this type of polymer-based structures can burn during welding and cause "pore" error [1, 6].

Electrode and filler metal wires should be kept in the rooms under control in terms of humidity and temperature, followed by the quality team. In case of exit from this protection room, if "shock heat treatment" is required for the electrode, this is done in a controlled manner in the heat treatment furnaces in this room and recorded. The welder takes enough electrodes before starting the welding and has to match the electrode and the material to be welded in which weld zone he will weld. Then, the electrodes are carried out of this room by mobile heaters, which are also temperature-controlled, and the welding is started by recording them. The purpose of this is that the high moisture content causes the H_2 residue to be high in the weld metal. In this case, it will cause a hot crack failure and the weld will not pass any Non-Destructive Testing (NDT) tests. The electrodes must be used within the "life and service cycle" given in Figure 3 [1, 10, 18].

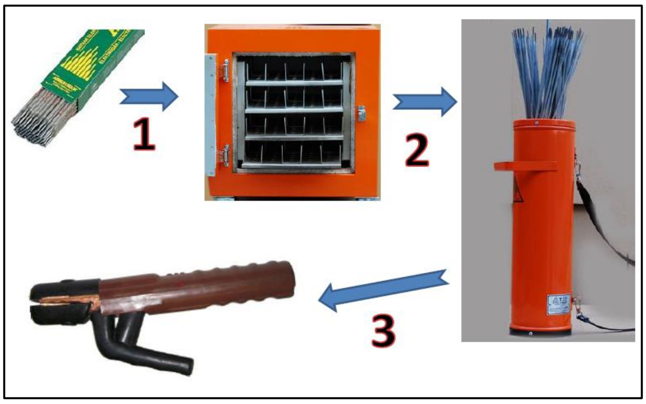

Fig. 3 The process of electrode life

Partial distortions may occur in the welds with a large wall thickness and diameter before the start of the weld. In this case, the root distance between the welds becomes narrower/wider. Therefore, a metal support piece with a similar alloy to the material and a "support cork" should be used before welding. Thus, the root spacing will remain constant. This support cork must be in a similar alloy with the base material and must be recorded [6].

During welding, the transition temperature between passes should be controlled according to WPS conditions. For multi-run welds, if possible, a break should be made when one full round of seam is finished. During the break, the weld should be protected with heat blankets to prevent sudden cooling. At the start of welding after the break, the starting cavity should be created with a grinding equipment. It is most appropriate to start after temperature control. If necessary, a suitable preheat can be given to the WPS again [17, 18].

After the weld has cooled sufficiently, the start of the control tests should be within 24 hours at the latest. The reason of this; It is to prevent unexpected stresses or micro cracks from growing and causing irreversible errors in the weld. The test is carried out according to the NDT method required for welding. Penetrant and Magnetic Tests are used to determine the defects reaching the surface. Radiographic and Ultrasonic Tests are used to detect volumetric errors. These tests are carried out by experts who are certified within the framework of EN 473 and equivalent standards [19]. After the control of these faults, the welds outside the acceptance conditions are recorded in the repair list to be re-welded for repair. At this stage, the error rate of each welder is very important. The welder with an increased error rate may be sent for a skill test or be recertified. As a result of these, a warning and suspension may be given to the welder whose error rate does not decrease, and if necessary, his certificate is revoked. Contrary to these, experienced welders who do not make any mistakes are determined and these faultless welders make pipe welds where the pressure and temperature value will be the highest under service conditions. In addition, these welders are called "Master-Welder”, these welders do repaired welding, and the weld is prevented from repairing again. For welding, the repair process can be repeated 3 times. This is partly specified in the related standards ASME Section III-IX and EN 12952-5 [18, 20]. Although it is allowed in the standards, exposure of a material to high heat input during welding 3 times will continuously expand the heat affected zone (HAZ) and deform the structure. Therefore, if the repair process continues to be repeated in the repaired weld metal, the material should be changed and in this case, it is stated in the relevant standards [3, 19, 20].

IV. Conclusions

Steels used in similar industrial systems in thermal power plants are indispensable elements. In addition, it is necessary to apply all the requirements with all the details during the welding of the steels. A process where all parameters such as welder, welding, steel, heat treatment, NDT, quality personnel, electrode, etc. are controlled must be controlled in all industrial systems. In this study, all parameters were mentioned, and experience gain interpretations were made.

Note: This study was presented as a poster at the "2nd International Iron and Steel Symposium (IISS'15)" symposium. It has been expanded and updated as a journal article with an academic view.

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