WELDING OF 9-12% CR STEELS FOR HIGH TEMPERATURE PRESSURE PART OF POWER PLANTS

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Alloy Steels exhibiting superior creep rupture strength and excellent resistance to thermal fatigue have been developed for use in recent years. These steels have been included in the list of materials by the ASTM, the ASME codes apart from other International codes like the DIN 17175. These steels also are selected, today, for their higher strength to weight ratios compared to the conventional Low Alloy Cr-Mo Steels hitherto employed for high temperature service.

The modified 9Cr - 1Mo (P91) steel is one such steel developed in USA for fast breed reactor components operating at 600°C. This steel has superior creep strength as compared to the Type 309 stainless steel in this temperature range. At temperature ranges in the vicinity of 540°C, the martensitic stainless steel X20 CrMoV 12 1 (X20) possesses better creep strength than the steel mentioned above. The P91 and X20 steels with their superior creep strength ably fill the wide gap observed in creep strength between the low alloy steels and highly alloyed austenitic stainless steels.

Modified 9Cr-1Mo steels contain controlled addition of Nb and V. This addition sufficiently increases creep strength. This steel gained ASTM approval in 1983 for elevated temperature application with the specification as ASTM A335 P91 (P91) for piping. Table-1 gives the chemical composition of the steel. The X20 CrMoV 12 1 steel has been used widely especially in Germany. It has been in use in Power Plants since 1960's, and the chemical composition is given in Table-1. This paper discusses the salient features of ASTM A335 P91 and X20 CrMoV 12 1 steel, with emphasis on their welding characteristics.

Transformation Behaviour and Microstructure

The Time Temperature Transformation diagram and Continuous Cooling Temperature of P91 and X20 steels are given in Fig.1 and Fig. 2. The CCT diagrams of P91 and X20 are quite similar. After normalising at 1050°C precipitation of chromium carbide occurs in X20 CrMoV 12 1 at the temperature of 700°C to 900°C and the Martensitic start temperature (Ms) is about 300°C. On accelerated cooling, fully martensitic structure is obtained for larger wall thickness. Compared to X20 Cr Mo V121, the Ms

TABLE 1
CHEMICAL COMPOSITION OF ASTM A335 P91 AND X20 CrMoV121

Elements	P91 Composition / Wt. %		X20 Composition / Wt.%	
	As Per Specification	As Analysed	As per Specification	As Analysed
C	0.80 - 0.12	0.10	0.17 - 0.23	0.21
Si	0.20 - 0.50	0.40	0.5 max.	0.26
Mn	0.30 - 0.60	0.44	1.0 max.	0.64
P	0.020	<0.01	0.03 max.	0.018
S	0.010	<0.01	0.02 max.	—
Cr	8.0 - 9.5	8.0	10.0 - 12.5	11.1
Ni	0.40	<0.10	0.03 - 0.8	0.7
Mo	0.85 - 1.05	0.96	0.8 - 1.2	0.8
V	0.13 - 0.25	0.20	0.25 - 0.35	0.25

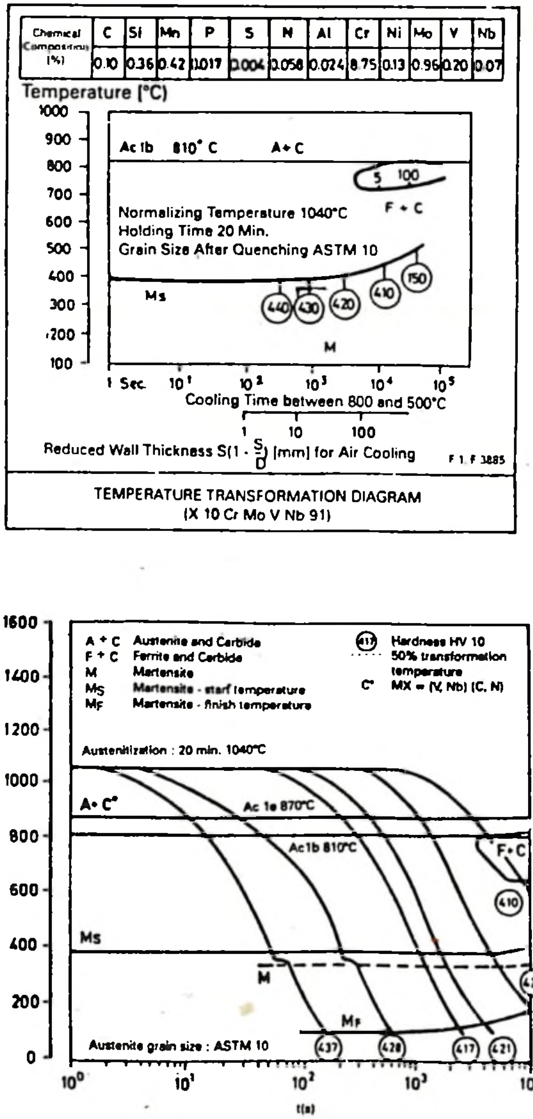

Fig.1 Continuous Cooling Transformation Diagram for the 9% Cr Steel.

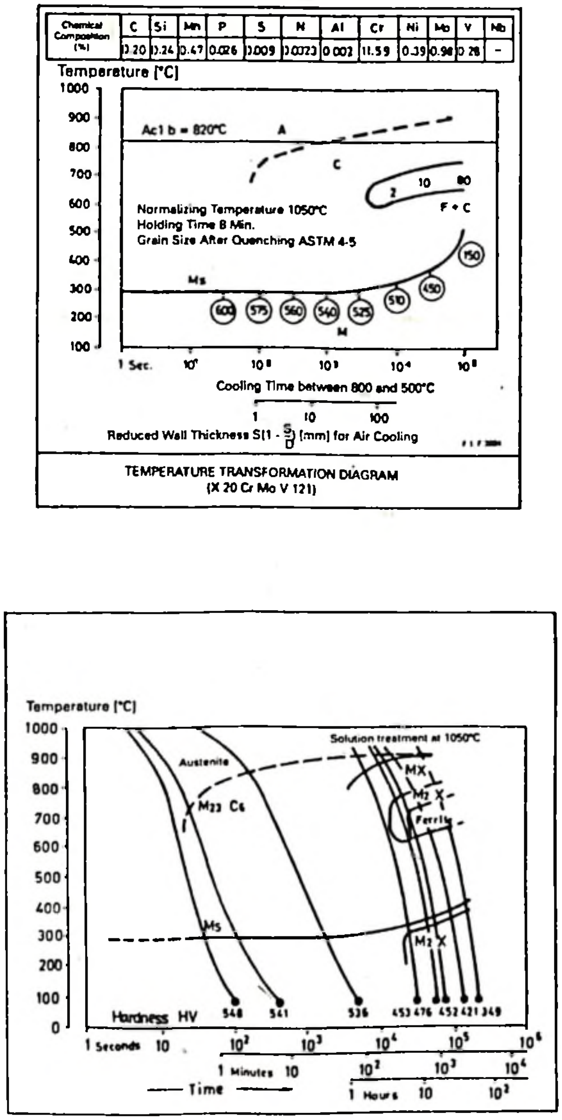

Fig.2 Continuous Cooling Transformation Diagram for X20 Cr Steel Mo V12 1

temperature of P91 steel is higher by 100°C. The martensitic hardness for P91 is comparatively lower, by 150 HV, than that observed for X20. These effects are due to different levels of carbon content in the steels. The lower hardness value is advantageous for workability. Besides, the cold cracking tendency is remarkably reduced and cooling to RT is rendered possible. Both the steels show high dislocation density in the sub-grain structure and coherent MX precipitates. The fine sub-grain structure with high dislocation density is the key factor for high creep strength. This dislocation density decreases during service at high temperature due to recovery processes. Typical microstructure of the steels are shown in Fig. 3 and Fig. 4.

Physical and Mechanical Properties

One of the important properties of material to be used in Power Plants are thermal expansion and thermal conductivity. Table 2 gives the physical properties of both the steels and these properties are not dependent on the microstructure but on the lattice structure. As can be seen from the Table 2, the X20 and

P91 have comparable physical properties and these are quite superior to the highly alloyed austenitic stainless steels. The room temperature tensile and impact properties of P91 and X20 steels are given in Table-3. The P91 steel shows better impact properties than X20. Fig. 5 shows the elevated temperature strength for the alloys P91 and X20. It is quite evident that P91, at temperature range 550°C to 600°C is superior to X20.

Welding Characteristics of ASTM A335 P91 and X20 CrMoV12 1 Steels

Welding of ASTM A335 P91 Steel

The modified 9Cr-1Mo steels are readily weldable provided recommended welding conditions and heat treatments are followed. As the steel's microstructure after Normalising & Training is of martensite, Hydrogen induced Cracking (HIC) is a potential risk. Pre-heating in the temperature range 200-250°C is generally followed to avoid HIC. The electrodes are to be baked prior to welding. SMAW and GTAW welding process are easily employed for welding of P91. SAW process can also be used for P91 steel and the pre-heat used is about 230-250°C. The interpass temperature during welding should not exceed 350°C max. and the flux should be adequately baked to keep the hydrogen at low levels. Table-4 gives the typical composition of SMA and SAW weld metal deposits. A Post Weld Heat Treatment of 740°C ±15°C is administered to the weld which will improve the toughness and also remove any risk to stress corrosion cracking.

Welding of X20 CrMoV 12 1

The X20 CrMoV 12 1 steel under normal rates of cooling after welding is strongly martensitic. With high carbon levels specified for creep properties, the steel developes extremely high hardness in HAZ of the weld and this zone is highly susceptible to hydrogen induced cracking. Welding processes with low potential for hydrogen are to be

TABLE 2
PHYSICAL PROPERTIES OF ASTM A335 P91 AND X20 Cr Mo V 12 1 STEELS

Temp °C	P91 Thermal conductivity W / m.K	P91 Co-efficient Linear Expansion 10^{-6}m/m/°K	X 20 Thermal conductivity W / m.K	X 20 Co-efficient Linear Expansion 10^{-6} m/m/K
20	26	—	24	—
50	26	10.6	24	—
100	27	10.9	24	10.8
200	28	11.3	25	11.2
300	28	11.7	25	11.6
400	29	12.0	26	11.9
500	30	12.3	26	12.1
600	30	12.6	26	12.3

TABLE 3
ROOM TEMP. MECHANICAL PROPERTIES ASTM A335 P91 AND X30CrMoV121 STEELS

Steel	UTS (N/mm^2)	YS (N/mm^2)	%E LO=5.65√SO Long.	%E Trans.	Impact Energy J.(Min) Long.	Impact Energy Trans.
P91	585-850	415	17	14	68	41
X20	690-840	490	17	14	48	34

TABLE 4
TYPICAL COMPOSITION OF WELD METALS

Element	Chemical Composition Wt.% Manual Metal Arc Weld Metal	Chemical Composition Wt.% Submerged Arc Weld Metal
C	0.098	0.088
Si	0.34	0.50
Mn	0.54	0.35
P	0.013	0.012
S	0.007	0.006
Cr	8.93	8.79
Ni	0.90	0.81
Mo	1.00	0.93
V	0.20	0.10
Nb	0.044	0.041
N	0.035	0.045
Al	0.002	0.009

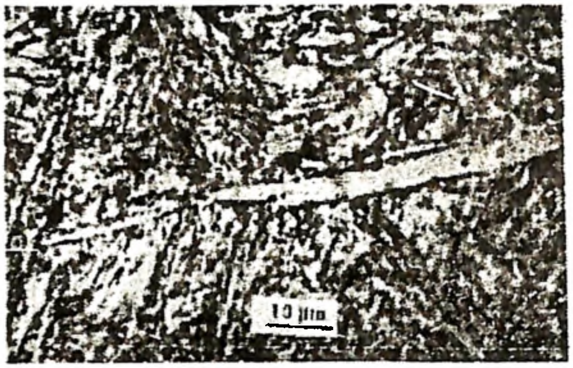

Fig.3: Tempered Martensite structure - P91

Fig.4: Needle like Martensite seen - X20 Cr Mo V12 1

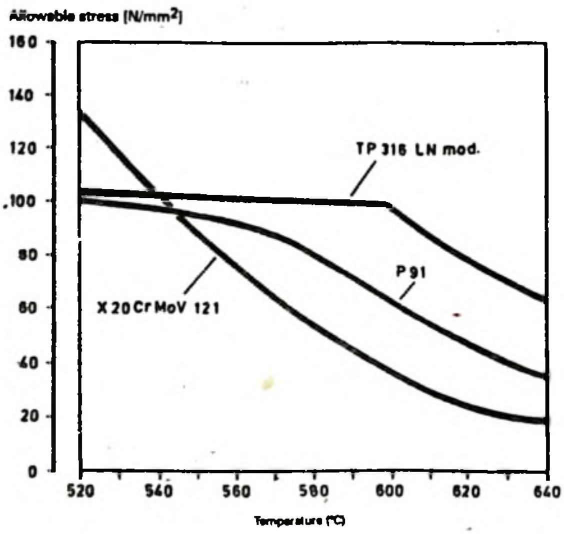

Fig.5: Allowable Stresses for steels TP 316 LN mod., P 91 and X20 Cr MoV 12 1

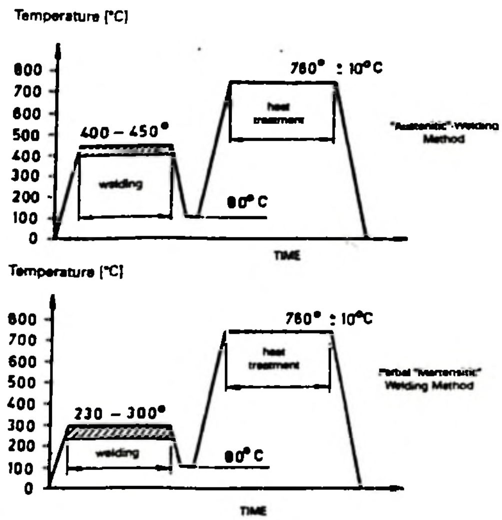

Fig.6: Temperature Regimes for Austenitic and Martensitic welding and PWHT

employed, to avoid the risk of cold cracking.

Welding of X20 CrMoV 12 1 can be done in two regimes ie. "Austenitic welding" or "Martensitic welding". The welding regimes are defined by the working temperature adopted while welding. A preheat above the Martensitic start (Ms) will be of austenitic type while those below Ms is Martensitic welding. The control of temperature is quite vital for obtaining sound welds with requisite properties. Fig.6 shows the schematic for the austenitic and martensitic type of welding. Extensive work has been carried out in these areas.

After completion of welding, the X20 CrMov 12 1 weldment should be cooled to 80°C to facilitate transformation of austenite into martensite. Sufficient time should be given for completion of the above

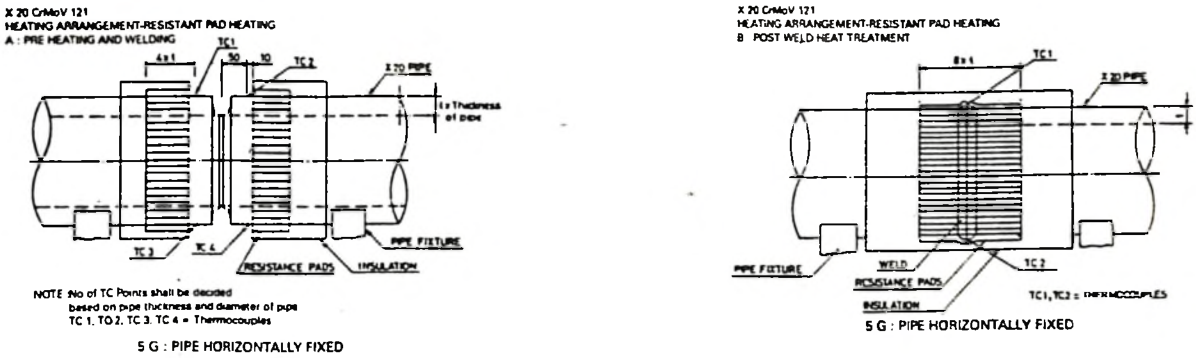

Fig.7: Heating arrangement for pre-heating and PWHT using resistant pads position horizontally fixed.

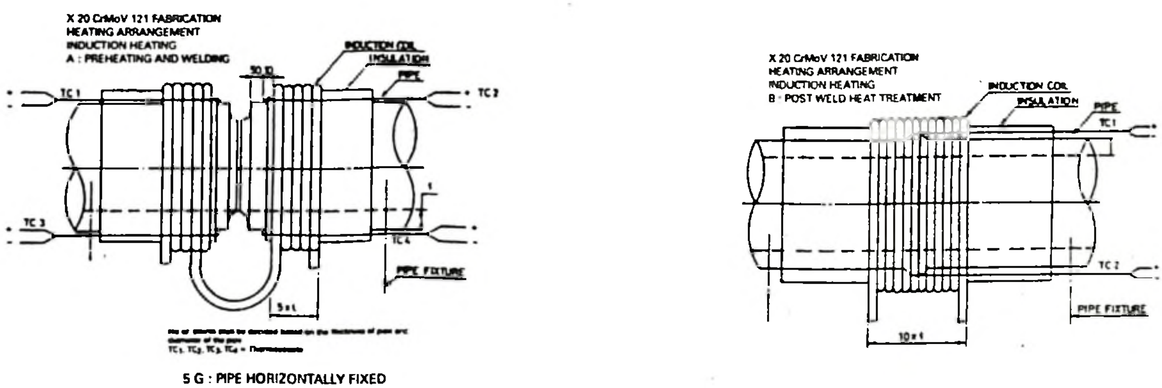

Fig.8 : Heating arrangement for pre-heating and PWHT using Induction coil position horizontally fixed.

Fig.9 : Resistance pad arrangement for vertical fixed position.

transformation and this aspect is quite important for the weldment and any shortcoming in this temperature range will drastically affect the weld properties.

Immediately after completion of transformation to martensite, the weldment, without cooling to RT, is given a PWHT at 760 deg C plus or minus 10°C. By this PWHT tempered martensite is formed which gives the weldment sufficient toughness and the stresses are relieved. In addition to the above the risk to stress corrosion cracking is also reduced.

The above disadvantage can be overcome by adopting martensitic welding, as the pre-heat is below Ms, the austentie is transformed to martensite during welding process. This brittle martensite is converted into tempered martensite by the subsequent layer deposit. This will lead to higher toughness in the part of the weld metal deposited. As a result, lower structural transformation stress will occur during intermediate cooling, as there is already a certain amount of tempered martensite present, compared with austenitic welding. The reduction of structural transformation stresses is due to the reduction in the residual austenitic content as compared with austenitic welding. Hence, the risk of cracking is reduced. Thus, intermediate cooling at temperature below 80°C is possible if martensitic welding is employed. Martensitic welding seems to be relatively advantageous in comparison to austenitic welding for any fabrication industry. Fig 6 shows the weld and heat treatment cycle of "Austenitic" and "Martensitic" welding .

To obtain defect-free welds in the root pass while welding of X20 some industries use low alloy steel filler. The root welding is completed with GTAW passes with filler wire with a composition of 2.25 Cr - 1Mo, ie. AWS-ER90X, while others use matching composition. The filling passes are done using SMAW process. The advantage of using 2.25Cr. - 1Mo filler is that the manipulation of the weld pool is easier. The matching filler with higher alloying content is slightly difficult to manipulate as the weld is quite viscous. This technique can be used for thick piping and is not recommended for thinner tube wall thickness. The high temperature properties are not significantly affected by adopting this technique. In addition to the aforementioned aspects, the cracking tendency at the root is reduced. The typical arrangements for pre-heating and PWHT using resistance pad and induction coil for X20 pipings are shown in Fig 7 to Fig. 9.

Summary

The modified 9Cr - 1Mo steel with ASTM A 335 P91 (Piping) Steel with superior creep properties, better workability and good welding characteristics is the steel for elevated temperature piping. While X20 Cr MoV 12 1 steel also possess good creep properties welding of this steel requires stringent adherence to the procedure.

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