NEW MATERIALS FOR HIGH TEMPERATURE STEAM PIPING

P. K. SAHA
Bharat Heavy Electricals Limited

INTRODUCTION

For non-corrosive fluids like steam, piping material used depends on the temperature of the fluid. Where a number of material grades may be considered oxidation resistance, freedom from graphitisation, fabricability, weldability and economic availability determine which material grade should have preference for use. In general, use of good quality carbon steel has been restricted to 400°C. For higher temperatures, certain additional properties viz. creep strength and rupture strength come into consideration and these make it imperative to use alloy steel. In this sense, temperatures above 400°C may be considered to be high temperature for piping materials.

Highest fluid temperature occurs generally in the main steam line which passes from the boiler final superheater outlet to the steam turbine inlet and/or the hot reheat steam line which passes from the boiler final reheater outlet to the turbine. In most of the modern steam power stations in India, the temperature is 540°C for main steam as well as hot reheat line. Higher temperature (565°C) for hot reheat steam line was first used for the first time in TEC's 6th Unit at Trombay (500MW). NTPC is going to build at Sipat (Madhya Pradesh) a 660MW unit employing supercritical once through steam cycle (for the first time in India) where also a hot reheat steam temperature of 565°C is being considered.

Following alloy steel grades listed in order of suitability for higher temperatures have generally been used for high temperature steam piping in India :

MATERIAL	ASME / ASTM	GRADE BS 3604	DIN 17175
1/2 Mo	5A335 Gr P1		
1 Cr 1/2 Mo	SA 335 Gr P12	HFS 620	13CrMo44
1-1/4 Cr 1/2 Mo	SA 335 Gr P11	HFS 621	
2-1/4 Cr 1 Mo	SA 335 Gr P22	HFS 622	10CrMo910
1/2 Cr 1/2 Mo 1/4 V		HFS 660	14MoV63

NEW MATERIAL X20

A departure from the traditional use of P22 in India was made by TEC who selected a material of German origin designated as X20Cr MoV 121 (in short X 20) for main steam (540°C) and hot reheat steam (565°C) pipes of the aforesaid 6th Unit at Trombay. The Unit became operational in 1989. Compared to P22, elevated temperature properties of this material is so high that only about, half the thickness of P22 is required in X20 at 540°C. Because of this superiority of X20 over the P22 equivalent German material 10CrMo910, X20 had been used for more than three decades in steam power stations of unit capacity 150 MW and above where engineering and supply were from German sources.

Table 1 indicates the thickness requirement for main steam pipes of a 500 MW Unit using (i) P22 and (ii) X20 for the sake of comparison :

Drastic reduction in thickness resulted in the following benefits :

- saving in cost of piping materials including hangers and supports, structural steel and thermal insulation
- shorter installed length of piping because of greater flexibility of thinner pipe
- saving in welding consumables and also energy needed for welding
- saving in installation time

Besides, faster start-up, load changes and shutdown of Unit become possible with lower thickness. Overall saving in

Table 1 : Comparison of Thickness Requirement

Material	P22	X20
Design Pressure,kg/sp.cm	192	192
Design Temperature, °C	540	540
Inside Diameter, mm	467	467
Minimum Thickness, mm	101.9	50.7

Table 2 : Comparison of Allowable Stress at Elevated Temperatures (as per ASME B31.1-1995)

	Allowable Stress, N/sp.mm at Temperature, ºC							
Meterial	450	480	500	520	540	560	580	600
P1	90	-	-	-	-	-	-	-
P11	97	94	74	57	43	32	23	-
P12	99	90	81	65	44	32	23	-
P22	98	90	81	68	53	43	34	-
X20	-	189	156	124	98	74	54	39
P91	124	115	110	104	98	91	80	66

Table 3 : Chemical Requirements (% by weight)

Meterial	C	Mn	P max	S max	Si	Cr	Mo	V	Nb (Cb)	N	Al	Ni
P22		0.30				1.90	0.87					
	0.15	0.60	0.03	0.03	0.50	2.60	1.13					
X20	0.17					10.00	0.80	0.25				0.30
	0.23	1.00	0.03	0.03	0.50	12.50	1.20	0.35				0.80
P91	0.08	0.30			0.20	8.00	0.85	0.18	0.06	0.03		
	0.12	0.60	0.02	0.01	0.50	9.50	1.05	0.25	0.10	0.07	0.04	0.40

cost vis-a-vis use of P22 was claimed to be about 40%.

In spite of these advantages, however, X20 did not find application in many countries mainly because it was not included in the ASME Code. ASME perhaps did not include it because USA was also trying to develop a material to bridge the gap that existed between their P22 and next higher grade steel (austenitic stainless steel).

After building eight 500MW sets in the country, NTPC opted for the material X20 in case of their next two 500 MW Units at Farakka (West Bengal). It was the result of a very sustained effort by Mannesmann Seifferte who together with Bhel were jointly selected by NTPC for supply, fabrication and installation of Power Cycle Piping for all the above ten sets.

Following the successful introduction in Farakka, the material X20 found further application in 2 x 500 MW Talcher (Orissa), Tata Chemicals at Mithapur (Maharashtra), 1 x 500MW Chandrapura (Maharashtra), 2x250MW Budge Budge (West Bengal) and 2 x 500 MW Vindhyachal (Uttar Pradesh) where BHEL supplied and installed all X20 materials.

NEW MATERIAL P91

During the period X20 was gaining in popularity in India, the U.S.A. having successfully developed a modified version of their material P9 by the early eighties went on gaining experience with its application and confidence with the material's elevated temperature properties. They designated the modified P9 material as P91. The results with P91 were so encouraging that it is now being preferred to even X20 for all temperature applications from 530ºC upwards. It is even stronger than X20 at temperatures above 540ºC and comparatively easier to fabricate and weld because of lower carbon content in it. The strength advantage of P91 over X20 as well as the other popular alloy steel grades may be ascertained from the Table 2.

Germany also worked on this material and came out with an equivalent designated as X10CrMoVNb91 (in short, X10). They were the first in Europe to use this material in a green field installation at Schkopau (2 x 450MW) for both main steam and hot reheat steam lines in the year 1993/1994.

The first application of P91 was made in India in 1995 when part of an existing hot reheat outlet header in P22 of a 500 MW boiler was replaced with P91. The terminal tubes in T22 connected to the header were also replaced with T91 tubes. A complete main steam header in P91 material has already been in operation since 1999 at SAIL's Bokaro steel plant where currently the replacement of the existing header in 12X1 MO material of Russian origin (GOST) with P91 material is in progress.

First green field application of P91 in India for main Steam line in a steam power station occurred this year at MSEB's 3rd Unit (210 MW) at Khaperkheda (Maharashtra) and installation work for the 4th Unit is in progress. NTPC's 2x500MW Simhadri Project in Andhra Pradesh currently under installation also has P91 pipes for main steam lines. Supply and installation of P91/T91 materials were by Bhel in all the above cases.

P91 material has been used for steam line also in Haldia Petrochemical Project which got operational this year.

COMPARISON OF X20 AND P91 WITH P22

Table - 3 indicates the chemical requirements for the new materials X20 and P91 vis-a-vis P22.

The salient welding and heat treatment requirements for the new materials X20 and P91 vis-a-vis P22 are summarised in Table - 5

SPECIAL CHARACTERISTICS OF X20 AND P91

Welding of P22 and other low alloy steel grades had been well established in India. X20 requires special care and precaution for welding as indicated in the footnotes under Table - V, X20 after welding has to be cooled to between 80 and 100°C and held at that temperature for a minimum period of 1 hour so that the austenite in the weld gets totally transformed into martensite. The martensite formed is very hard, the hardness being greater than 500 BHN (HVID) and therefore requires to be tempered immediately. If the martensite is cooled to room temperature before tempering, chances are very high that cracks will develop in the weldment. If heat treatment cannot be proceeded with immediately, the temperature of the joint must be maintained between 80 and 100°C.

This crack formation possibility is much less for P91 which acquires a somewhat less hardness value of 450 BHN (HV 10) in the as welded condition. Cooling of P91 weld to room temperature has been possible without any detrimental effect even for joint thickness as high as 50mm. It is however imperative that room temperature storage for such joint is dry and stress-free and further, storage is not for an indefinite period (preferably not more than 8 days). Welding and heat treatment of both X20 and P91 are considered done satisfactorily if the hardness is found to be not exceeding 300 BHN (HV10).

Martensite formation temperature for X20 is 300°C. Therefore, X20 welding is carried out at either 250°C (just below the martensite formation temperature) or in the non-transformation range beyond 400°C. Temperature of 400°-450°C is generally preferred to avoid high hardness values and attendant risk of cracking during welding. Root pass of thick -walled X20 pipes, however have been found to be convenient for welding at 250°C using filler wire of the type P22 since welding with filler wire of the type X20 often resulted in notches in the root area.

The martensite nature of X20 demands that no overheating of any portion of the martensite takes place through any tack welding, arc strike, flame corrections or continuous high speed grinding. These operations are, in fact, don'ts for X20 welding.

One important arrangement necessary while undertaking welding of X20 and heavier wall thickness P91 is the provision of a standby power source (a diesel generator of adequate capacity) so that in the event of a power failure, welding operation can continue till completion in one cycle. As an alternative, gas ring burner may be mounted over the joint in progress so that the joint may be kept hot to the required extent during a power failure.

For heavier wall thicknesses, the temperature difference between outside surface and inside surface of pipe could be considerable in case of heating to stress relieving temperature done with the help of resistance heating. Because of the important influence of temperature on the property of the materials X20 as well as P91 and the narrow temperature range recommended for stress relieving, it is highly desirable that heating in such cases is done using induction heating equipment for which this temperature differential is much less.

As may be observed from the above, the materials X20 and P91 are special from the point of view of welding compared to the traditional low alloy materials.Hence, welders to be engaged in welding of X20 or P91 materials should be specifically qualified for the particular material to be welded. The qualification may be obtained through Bhel's Welding Research Institute at Tiruchirapalli which is a Competent Authority recognised by The Central Boiler Board for the issue of Qualified Boiler Welder's Certificate.

FUTURE TREND

P91 has already been used in more than 20 countries and is being preferred even in countries where X20 had its presence. It is now apparent that for quite some time in the near future, P91 will be the

Table 4 : Tensile Requirements at Room Temperature

Material	0.2% Y.S., min, N/sq. mm	U.T.S., min N/sq. mm	Elongation, % min (Gauge Length)
P22	205	415	30(2")
X20	490	690	17(5xd)*
P91	415	585	20(2")

D = Original Diameter of Test Specimen.

Table 5 : Welding Requirements

		P22	X20	P91
1.	Filler Wire (GTAW)	TGS 2CM	CM2. 1G(Bohler)	TGS 2CM/TGS 9Cb
2.	Electrode (SMAW)$	E9018-B3	FOX20MVW(Bohler)	E505-15 CM9Cb
3.	Preheat Temp., °C	150	250	220
4.	Interpass Temp., °C (max)	350	450	350
5.	Postheat (Preheat Maintenance), °C	150	80-100 (1 hr min.)*	250 (2 hrs)
6.	PWHT Temp., °C @	700-760	740-760	700-760
7.	Soaking Time, Minutes/mm $	2.5	–	–
	Minimum Soaking Time, Minutes $$	15	120	15
8.	Shielding Gas	Argon	Argon	Argon
9.	Purging Gas	Nil	Argon**	Argon**

$ Electrodes for X20 and P91 require baking at 300-350°C for 2 hours whereas the electrodes for P22 may be baked at 250-300°C for 2 hours.

\# Preheat is required when joint thickness exceeds 13 mm.

* It is very important for X20 joints to be cooled to between 80 and 100°C after completion of welding and then held at that temperature for a minimum period of one hour so that transformation of the austenite into martensite is completed. Immediately thereafter, the joint has to be heated to the PWHT temperature and stress relieving completed. For P91, this same requirement applies but for comparatively much heavier wall thicknesses.

@ Postweld heat treatment is not required under certain conditions for P22. Except for X20, PWHT temperature ranges indicated are as recommended by ASME. Welding procedure qualification must establish the most appropriate range. 740-760°C is known to have given acceptable results for P91.

$$ Minimum soaking times indicated are as per ASME except for X20. Soaking time of two hours minimum is recommended for P91.

** Purging is recommended to be continued till the first two filler passes are completed.

material chosen for high temperature steam piping in India. P91 has found application in high temperature services in petrochemical projects also. However, a lot of research has already been made for development of more suitable material for even higher temperature applications in order that more fuel efficient steam power stations may be built so as to limit pollution of the environment for which pressures are building up all over the globe. Quite a number of steam power stations have even been built with these developed materials employing live steam temperatures of over 600°C and reheat temperatures upto about 625°C. Field tests of single components are going on to get experience of their service behavior at temperatures of upto 650°C. These new pipe materials are P92 (standardised by ASME/ASTM), Japanese Nf616 and the European E91 1(approved by German TUV). P92 (similar to Nf616) and E91 1 differ from P91 mainly in their tungsten(W) and molybdenum (Mo) content.

Creep rupture strengths for these materials are assumed to be very similar. Compared to P91, an increase of 20-30% has been realised at 610°C and 100000 hours. This increase in creep strength is equivalent to an increase in live steam temperature of 15-25°C. Their fabricability and welding also have been found to be similar to those of P91. But India has to make lot more strides in high temperature boiler and turbine design and operation before the advantages of these new materials may be fully harnessed.

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