Welding in the Boiler Industry

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The increasing tempo of power generation in India has resulted in the starting of basic industry for the manufacture of power house equipment. The Heavy Electrical unit at Bhopal and the Bharat Heavy Electricals' units at Hardwar, Hyderabad and Tiruchy will together meet the requirements of large power houses. The Tiruchy Unit, in particular, has an annual manufacturing capacity of 0.8 million KW power generation equipment. The capacity of the boilers manufactured in this factory ranges from small package boilers to power house boilers feeding 100 and 110 MW Turbo sets. The number of joints in a boiler depends upon the design and the length of seamless steel tubes. According to Muller (1), the number of joints varies from 20 to 120 per ton of steam generated. Table I gives an idea of the total weld joints in various types of boilers and their division between fabrication in the shop and at erection site.

We can reckon about 30,000 joints in a typical 60 MW boiler (260 ton per hour, 96 atm and 535°C). These 30,000 joints in a boiler are spread over different types of carbon and alloy steels and each one of these joints presents innumerable welding problems. Should a boiler feeding the 60 MW Turbo set come to a stop due to a failure of a single weld, it will result in enormous financial losses to the power houses. It is often said that the boiler is as strong as the weakest welded joint just as a chain is as strong as the weakest link.

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There are three main activities of the welding technology centre and they are—

(1) Training of high pressure welders to Indian Boiler Regulations and Lloyds Requirements.

(2) Testing and approving welding consumables for the manufacture of boilers, high pressure valves, etc.

(3) Collaboration and its implications.

Training of Welders

Today a qualified high pressure welder is a rare commodity in the Indian market. The few available are highly migratory in their behaviour. While the demand for high pressure welders is increasing, the training facilities are rather limited. A few of the Indian electrode manufacturers have programmes for training welders, but they restrict their training mostly to plate and structural welding. Since the high pressure welders are the backbone of the boiler industry, the BHEL management took a wise decision in setting up a welding technology centre whose first job was to train welders for pipeline and tube welding.

Generally, welders with at least 6/8 years' structural welding experience, preferably at erection sites, are recruited. After they are selected, they are given an intensive course of training for three months, which consists of 300 hours of practice and 60 hours of theory. While the stress is on practical training, equal importance is attached to certain theoretical aspects of welding, TABLE—I

No. of Weld Joints as a Function of Type and Capacity of the Boiler

Sl. No.		*Type of Boiler*	*Steam Capacity t/hr.*	*Total Heating Surface in M^2*	*Total No. of weld joints incl. arc, gas & flash butt welding*	*No. of joints per sq. mtr. of heating surface*	*No. of joints/ ton of steam*	*Analysis of Welding*			
								Shop Weld		*Site Weld*	
								No.	%	*No.*	%
1.	Natural Circulation Boiler	Sectional Header Boiler	10	714	504	0.71	50.4	352	69.9	152	30.1
2.			50	3135	994	0.32	19.9	528	53.2	466	46.8
3.		Inclined Tube Boiler	64	1850	5033	2.72	78.6	3345	66.5	1688	33.5
4.			270	7938	17703	2.23	65.5	9312	52.6	8391	47.4
5.		Once through Boiler	120	4200	14392	3.42	120.2	10276	71.3	4116	28.7
6.			230	5123	18910	3.68	82.0	12084	64.2	6826	35.8
7.			450	29371	43132	1.47	95.8	23862	55.3	19270	44.7

especially with reference to the provisions of the Indian Boiler Regulations. Every week they will have either a theory examination or a practical examination and if their results are consistently satisfactory, they are presented to the Boiler Inspectorate for a theoretical and practical examination. Successful candidates will be posted to various production shops as assistants to other high pressure welders who have been on the job for a longer period. In this way the high pressure welders will be gradually initiated to various production jobs. So far 75 high pressure welders have been trained in this manner in carbon steel welding and in alloy steel welding. Apart from manual welding, welders are trained for submerged arc welding, CO_2 shielded welding, stud welding, flash butt welding and electro-slag welding.

The experience in training automatic welders is worthwhile mentioning. The general education of a manual welder need not be of a very high order since the only parameter which he is likely to vary during the welding operation is the current. A submerged arc welder on the other hand has to vary, during welding, three parameters, viz, voltage, current and the speed of welding. Similarly in flash butt welding, there are 6 to 8 parameters which the operator has to set before he can achieve a successful weld. In the case of electro-slag welding the parameters are even more numerous and the electro-slag welding operator should be conversant with the proper setting of these parameters. The automatic welding machine operator should, therefore, have a better educational background than a manual welder. In teaching such welders, the necessity for setting proper parameters of various sophisticated equipment available in the factory is particularly stressed.

Since the production at the Tiruchy Unit has been diversified to include pressure vessels also, welders are tested by the Lloyds Surveyor as per ASME, Section IX—Qualification for Welders, 1953 prior to their being employed on production welding. Quite a few of the welders possess certificates according to Indian Boiler Regulations and also according to Lloyds Specifications.

Testing of Welding Consumables

There are about ten different types of steel used for pressure parts and about the same number for the non-pressure parts of a boiler. For most of the pressure parts welding consumables are at present being imported although concerted efforts are being made to introduce indigenous consumables for this work also. A large number of types of electrodes, wire and flux for submerged arc welding, gas welding wire, etc, have been tested for conformity to Indian Boiler Regulations and other international standards. Most of the electrode manufacturers furnish the mechanical properties at room temperature according to the relevant IS Specification. Only very rarely are provided the high temperature properties of the weld metal. In certain cases, say for the manufacture of Liquefiable Petroleum Gas Tanks, etc, low temperature impact values at -15°C and -30°C are required. These properties expected from various electrodes are not normally provided by the indigenous manufacturers and hence these elaborate tests are carried out at BHEL before the consumables are accepted for production purposes.

Submerged arc welding is used on a large scale in this unit, but all welding consumables meant for welding of pressure parts are imported. In certain specific cases of non-pressure parts of the boiler—for welding of main boiler structures made of St. 55HTW steels—imported wire and flux are used. Very recently a series of tests were conducted on an indigenous submerged arc welding flux under Lloyds supervision with the object of selecting a wire/flux combination for welding St. 55HTW steels and the results have been very encouraging.

Details of the various types of steel which go into the manufacture of pressure parts of the boiler are shown in Table II. The various welding techniques adopted at BHEL, Tiruchy are briefly explained.

St. 35.8

This is a plain carbon manganese steel with carbon limited to 0.17%. It can be welded by arc, oxy-acetylene or by submerged arc welding processes. Since the diameter of the tube used in the design is less than 45 mm, gas welding is generally adopted. The filler wire is imported. The process does not present any difficulty for a qualified welder.

Flash butt welding is also adopted and this process gives a very high output with consistently good quality of weld joints.

St. 45.8

This is a plain carbon manganese steel with carbon limited to 0.22%. Again this steel can be welded by arc, oxy-acetylene and by submerged arc processes. The size of the tubes vary from 32 mm to 273 mm. The filler rod for gas welding is imported, but for arc welding an indigenous electrode is used. This was decided on after a series of tests including high temperature properties of the weld metal deposit. A comparative analysis between corresponding Czech, German and Indian electrodes is shown in Table III.

TABLE—II

Chemical & Mechanical Properties of Seamless Steel Tubes Used in Boiler Manufacture

DIN 17175	*Chemical Analysis of Steel*						*Ultimate Tensile Strength Kg/mm²*	*Elongation %*	*Permitted Wall Temperature*
	C	*Si*	*Mn*	*Cr*	*Mo*	*V*			
St 35.8	0.17 Max	0.35 Max.	0.40 Min.	—	—	—	35 — 45	25 Min	450°C
St 45.8	0.22	0.35	0.45	—	—	—	45 — 55	25 Min.	475°C
15 Mo 3	0.12 0.2	0.15 0.35	0.50 0.80	—	0.25 0.35	—	45 — 55	22	530°C
13 CrMo 44	0.10 0.18	0.15 0.35	0.4 0.7	0.7 1.0	0.4 0.50	—	45 — 58	22	560°C
14 Mo V 63	0.10 0.18	0.15 0.35	0.30 0.60	0.3 0.6	0.5 0.65	0.25 0.35	50 — 70	20	560°C
10 CrMo 910	0.15	0.15 0.50	0.4 0.6	2.0 2.5	0.9 1.1	—	45 — 60	20	590°C

TABLE III

Comparison between an Indian, Czech & German Electrode for Welding St. 45.8 Steels

Name and Designation of Electrode	*Chemical Analysis of Weld Metal*			*Mechanical Properties of Weld Metal*				*High Temp. Properties kg/mm²*	
	C	*Si*	*Mn*	*Yield Point kg/mm²*	*Ultimate Tensile Strength kg/mm²*	*Impact kg/cm²*	*% Elongation*	*350°C*	*400°C*
Czech Origin E 44.83	0.08	0.4	0.7	32	44	13	22	24	20
German Origin SH Gelb B	0.08	0.2	0.55	38 42	46 51	11 14	21 26	—	30
Indian Electrode (Figures according to Manufacturers)	0.07	0.15	0.45	39 45	47 52	12 16	28 32	—	27
Indian Electrode (Tests according to BHEL)	0.07	0.20 0.22	0.55	44 46	51 52	13 15	26 28	—	35.4

Flash butt welding has been successfully adopted. The initial results of experiments to flash butt weld 60×5 mm size tubes are very encouraging.

Similarly, submerged arc welding of St. 35.8 and St. 45.8 do not present any difficult problems.

15 Mo 3

This is a molybdenum bearing steel. For tubes less than 45 mm, gas welding is adopted. For higher thicknesses either Argonarc (TIG) or arc welding is practised. Gas welding is done in the usual manner except that the high pressure welder should exercise great care in setting and maintaining an absolutely neutral flame.

Flash butt welding of 15 Mo 3 steel is extensively adopted. Argon is used to fill the tube during flash butt welding operation.

13 Cr Mo 44

This is a chromium molybdenum group steel used for superheater headers. Arc welding is used extensively while gas welding is also possible. Again great care is required in setting the flame in case of gas welding.

14 Mo V 63

This is a chromium molybdenum vanadium steel used for Platen superheaters and it is one of the most difficult steels from the welding and heat treatment points of view.

Although West Germany was adopting gas welding for this type of steel till a few years back, this has since given way to Argonarc welding. The difficulties connected with gas welding of 14 MoV 63 and 10 Cr Mo 910 steels are referred to later in the paper. At BHEL, Tiruchy, TIG welding is used for butt joints and arc welding for fillet joints. The tungsten electrode should be either thoriated or zirconiated in order to minimise the contamination of tungsten in the weld metal. The argon should be of welding quality as otherwise the shielding of the arc will not be perfect giving rise to bad welds.

For bigger diameter pipes of 14 MoV 63 material there is a choice of the following three methods :—

(a) Root welding by TIG process with subsequent layers deposited by manual arc welding using basic coated electrodes.

(b) Root welding by specially developed rutile electrodes with subsequent layers by the use of basic coated electrodes.

(c) Root welding by specially developed basic coated electrodes with further layers deposited by basic coated electrodes.

10 Cr Mo 910

This again is a chromium molybdenum steel used in the exit superheater. Gas welding is generally adopted and arc welding of tubes less than 60 mm is very difficult with basic coated electrodes. Hence TIG process has been adopted throughout. It has been mentioned earlier that gas welding is not recommended for 14 MoV 63 and 10 Cr Mo 910 tubes. In the eventuality of gas welding, the flame setting has a great influence on the carbon pick up by the weld metal. According to the experience of a well-known German boiler manufacturer (2), the carbon pick up in the weld metal with different flame settings is as follows :—

Sl. No.	*Ratio of Oxygen and Acetylene*	*Carbon percentage in the weld metal deposit*
1.	0.9 : 1	0.94
2.	0.95 : 1	0.40
3.	1.00 : 1	0.19
4.	1.10 : 1	0.11
5.	1.15 : 1	0.10
6.	1.25 : 1	0.11

Carbon pick up is least in the weld metal if the ratio of oxygen and the acetylene is 1.15 : 1. Conventional 2-stage oxygen and acetylene regulators will feed the blowpipe with the set pressure irrespective of the drop in cylinder pressure. However, the setting of the flame either neutral or oxidising is done entirely by the skill of the gas welder. Hence a high degree of personal factor is brought in. If gas welding of the above steel is to be adopted, a special regulator maintaining the ratio of oxygen and acetylene should be used in addition to the conventional 2-stage oxygen and acetylene regulators.

With the above difficulties as the background, the trend is to adopt TIG process which is a highly refined process for welding of chromium molybdenum steels. In case of gas welding, a typical variation of the hardness of the weld joint (material 10 Cr Mo 910) with different flame settings is shown in Table IV.

13123

This steel is a manganese vanadium steel used for the boiler drums. The longitudinal seams of the boiler drum are welded by the electro-slag process and the circumferential seams by submerged arc welding. Encouraging results have been obtained in a series of tests with electro-slag welding machines and three 60 MW boiler drums have already been manufactured using the electro-slag process.

Combination Welds

As the temperature of steel increases from the feed water inlet temperature (230°C) to superheated steam temperature (535°C) the quality of seamless steel tubes also improves in the ascending order with respect to alloying elements. From plain carbon steel the next jump will be ½% molybdenum steel followed by chromium molybdenum vanadium steel. The sequence is as follows :—

35.8 — 45.8 — 15 Mo 3 — 13Cr Mo 44 — 14 MoV 63 — 10Cr Mo 910 — 14MoV 63 — To Turbine.

Hence a necessity arises for various combination joints between dissimilar metals and such joints are always faced with anxiety. Volumewise the bulk of the seamless steel tube used in the pressure parts of the boiler will be either St. 35.8 or St. 45.8 and they do not present any difficulty from the welding point of view. The difficulties, however, increase in proportion to the alloying elements, type of joint, location of joint, etc. When combination between carbon and alloy steel occurs the general practice is to choose a consumable matching with the carbon steel. Similarly, in a combination between two grades of low alloy steels, the welding consumable matches with the lower one. In choosing a combination there should not be too high a jump in the alloying element. Some combination joints require an intermediate electrode or filler wire not matching with either of the steels.

TABLE IV

Experiment No.	Ratio between oxygen & acetylene	Vickers Load 10 kg/mm²				
		Parent material	Transition	% increase in hardness	Weld Metal	% increase in hardness
1	0.9 : 1	181	221		383	
		170	200		373	
		176	212		372	
		176	211		376	
		176	211	19.8	376	11.4
		176	208		258	
		174	220		250	
2	0.95 : 1	175	216		254	
		175	215		254	
		175	215	22.7	254	45.1
		176	193		236	
		176	197		251	
3	1.0 : 1	170	202		245	
		174	197		244	
		174	197	13.4	244	40.2
		165	176		199	
		172	189		205	
4	1.10 : 1	176	180		213	
		171	182		206	
		171	182	6.3	206	20.3
		187	187		193	
		187	186		199	
5	1.15 : 1	815	187		196	
		186	187		196	
		186	187	0.3	196	5.2
		176	187		197	
		176	185		191	
6	1.25 : 1	181	184		203	
		177	185		197	
		177.5	185	2.7		11.0

The mechanical properties of the weld metal are usually a compromise between those expected of the parent materials. However, the weld metal itself should have the necessary strength and ductility and while conducting tests on such weld metals, dilution of the weld metal from parent material should also be taken care of (3). Table V indicates the welding techniques practised at BHEL, Tiruchy for different qualities and sizes of seamless steel tubes.

Collaboration and its implication

Most of the units manufacturing boilers and pressure vessels have foreign collaboration for design as well as for manufacturing technology. Regarding boilers, the design and the manufacturing processes should also meet the requirements of Indian Boiler Regulations. The foreign collaborator chooses the steels and matching electrodes from his own country. The welding practices

TABLE V

Welding Techniques Practised at B.H.E.L., Tiruchirapalli

Sl. No.	Size / Steels	d ⊁ 32 mm t ⊁ 3 mm	d> 32 <45 t> 3 <4mm	d> 38 <89 t> 4 <6mm	d>60 mm t> 5 mm	d> 159 mm t> 14 mm
1.	St 35.8	△	△ AIR	△ †	†	† ∴
2.	St 45.8	△	△ AIR	△ †	†	† ∴
3.	15 Mo 3	△ *	ARG △ *	△ † *	†	† ∴
4.	13 CrMo 44	△ *	* ARG △	* △	†	† ∴
5.	14 MoV 63	*	*	* †	†	† ∴
6.	10 CrMo 910	*	*	*	†	†
7.	15123	△	△ ARG	† △	†	† ∴

Note :

△ — Gas Welding
AIR — Flash butt welding with air
ARG — Flash butt welding with argon gas
† — Arc Welding
∴ — Submerged Arc Welding
* — Argonarc Welding

adopted by each country varies so widely that the Indian participant in a joint venture will be on the horns of a dilemma. A few examples are cited :—

(a) In Russian practice, packing ring technique (use of a small circular strip of metal for guaranteed root penetration) for downcomer tubes, etc is standard practice. In Czechoslovakian practice this is not looked upon with favour. Hence a high pressure welder who may have worked in the erection of numerous Russian boilers in India requires a re-orientation training if he is to be of further use where this technique is not used.

(b) Czechoslovakian practice specifies semi-basic electrodes for welding of water wall tubes made of St. 45.8 material. German practice is to use rutile electrodes. In India, rutile electrodes are far cheaper than basic coated electrodes.

(c) Czech practice adopts arc welding of platen superheaters made of 14MoV63 material. German practice for a similar application recommends TIG welding only.

(d) According to Section 94 of Indian Boiler Regulations, electrodes less than 3/32″ (2.3 mm) shall not be used for welding of tubes and pipes whereas German and Czech practices do permit the use of 2 mm diameter electrodes. (This rule has since been amended).

(e) In German practice, for welding of main steam lines, etc. root welding is done either by TIG or gas and subsequent layers by arc welding. Such procedure is not viewed with favour in Czechoslovakia.

(f) Gas welding of water wall tubes is predominant in the German boiler industry whereas Czechs and Russians prefer arc welding for similar work.

Similarly, there are innumerable differences in the welding technology of different countries.

Conclusion

With the establishment of heavy industry for the manufacture of boilers and pressure vessels there is wide scope for developing our own welding technology based on indigenous design and welding consumables. Unfortunately, the quality of available welding consumables like electrodes, gas welding wires, submerged arc welding wires and fluxes, etc are not sufficiently high to meet the demand of this industry.

A typical 60 MW boiler with its associated pipelines, etc may require about 35 tons of welding consumables. Hence if we are to enlarge the scope of automatic welding, we should be first self-sufficient in consumables and then machines themselves. While automation of welding is definitely more productive, it may not prove economical as long as we are dependent on imported welding consumables. Perhaps the only exception is the flash butt welding process which does not call for any additional consumables. A careful cost analysis will be necessary if we are to go the whole hog for automation in welding.

As all joints are not accessible to automatic welding, manual arc and gas welding have still a dominant role to play. Hence intensive training in manual welding and further development of indigenous welding consumables should not be sacrificed for the prospect of introducing automatic welding processes.

None of the Indian electrode manufacturers, with a few exceptions, give the high temperature properties of weld metal. The ISI grades of steels for which their electrodes are matching are not also specified. In Europe when new steels are introduced, the steel manufacturers invariably mention a recommended electrode and other suitable matching welding consumables. Unfortunately, this is not the practice in India and the matching is left entirely to user's discretion.

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