Weldability of Structural Steels

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Introduction

Weldability is one of the important requirements in assessment of structural steels. Very little information is available on the response to welding in the specifications dealing with commonly used structural steels to Indian Standards viz., IS : 226/62[1], IS : 2062/62[2], IS : 961/62[3] and IRS M23[4]. Weldability of steel depends on various factors like the chemical composition and degree of purity, the heat treatment condition, the thickness and temperature of the weld joints, welding processes and procedures, the rigidity of construction, not neglecting the skill and reliability of the welder[5]. The type of weldability test selected for a particular material, mainly depends upon its end use and the stress conditions to which it is subjected. The most commonly used types are :

(i) The underbead hardness test which decides the response of the material for welding operations without being subjected to external stresses.

(ii) The CTS Test (Controlled Thermal Severity Test) which more or less stimulates the high stress service conditions of the material.

In the present work, both underbead hardness and CTS Tests were conducted for some of the Indian structural steels with different thickness ranges, using different types and diameters of electrodes, with and without preheating. The results of these tests are discussed in this article so that the information furnished may be useful for the industry.

Experimental Programme :

Steels (Table No. 1) to specifications IS : 226/62, Is : 2062/62, IS : 961/62 and IRS-M23 were subjected to UBH and CTS tests, using four types of electrodes (Table No. 2) of varying diameters and in different welding conditions viz., with or without preheating. Standard procedures were adopted in making UBH and CTS Tests[6,7]. The acceptance criterion in the CTS test is the presence/absence of cracking in the weld or heat affected zone, while in the UBH test, the hardness at the HAZ is not to exceed 350 HV measured under 10 Kg. load. (It is reported in the literature[5,8] that the risk of underbead cracking increases, when the hardness in the transformation zone is higher than' 400 HV and hence the level of 350 HV in HAZ has been taken as the safe limit).

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TABLE 1

Details of the Steels Studied

Steel Designation	*% Chem. composition*				*Mech. properties*			*Weldability*
	C max.	*Si*	*S max.*	*P max.*	*Y.S. Kg/mm²*	*T.S. Kg/mm²*	*% Elong. on 5.66/A*	
IS : 226/62 St 42S	0.25	—	0.060	0.060	26 min.	42.0 54.0	23 min.	No details given.
IS : 2062/62 St 42W	0.22	0.10 min.	0.060	0.060	26 min.	42.0 54.0	23 min.	Sections below : 28 mm weldable if C<0.22%. For thickness 28-50 mm a weld bending test prescribed.
IS : 961/62 St 55 HTW	0.22	0.10	0.060	0.060	36 min.	55.0 min.	20 min.	Underbead Hardness Test prescribed for all thicknesses of plates. HV10 in HAZ not to exceed 350.
	(% Mn+% Cr not to exceed 2%)							
IRS M23	0.30	0.20	0.05	0.05	36.2	58.1	15	No details specified.

TABLE 2

Details of the Electrodes Used

Electrode Designation	*Equivalent ASTM*	*Type*	*% Chemical composition*				
			C	*Mn*	*Si*	*S*	*P*
A	E 6013	Rutile	0.07	0.40	0.15	—	—
B	E 6016	Basic Low Hydrogen Electrode	0.06	0.60	0.20	—	—
C	E 7016	Basic Low Hydrogen	0.10	0.90 1.15	0.60 1.00	0.030	0.030
D	E 7016	Basic Low Hydrogen	0.08	0.80	0.25	—	—

I. Discussion of the results :

1. IS : 226/62

(*a*) *Underbead hardness test* :

Tests were done with electrodes types A and B (dia 4 mm) on plates of thickness 22 mm and with electrode type A of different diameters on 32 mm and 63 mm plates. The results are given in Table No. 3. (Further trials with electrode type B were discontinued, due to unsatisfactory arc characteristics, presence of porosity and poor radiographic quality of the welded joint).

In case of 22 mm plate, both types of electrodes (dia 4 mm) give almost similar values and are satisfactory. In case of 32 mm plate, where electrodes of type A, of diameter 2.5, 4.0 and 6.0 mm are used, the results with dia 6.0 mm are satisfactory, whereas with dia 4 mm, the hardness values are in the border line (322 HV against the max. of 350 HV). The use of dia 2.5 mm electrode is not advocated, as this gives a hardness of 442 max. in the HAZ. Similarly for 63 mm thick plate also, of different diameters of electrodes used, only 6.0 mm dia electrode has given satisfactory results.

TABLE 3

Results of under Bead Hardness Tests on IS : 226/62 and IS : 2062/62

Material	*S. No.*	*Plate thickness (mm)*	*% Chemical composition*						*Electrode Details*	*Hardness (HV 10) at HAZ (Range)*
			C	*Mn*	*Si*	*S*	*P*	*C.E.+*		
IS : 226/62	1	22	0.24	0.75	0.11	0.031	0.029	0.37	A ϕ4.0 mm (250A)+	212—262
									B ϕ4.0 mm (275A)+	219—254
	2	32	0.24	0.86	0.08	0.021	0.027	0.38	A ϕ2.5 mm	442 max.
				—	—			—	ϕ4.0 mm	322 max.
	3	32	0.26	—	—	0.025	0,015	—	ϕ6.0 mm	221 max.
	4	63	0.31	1.00	0.09	0.027	0.029	0.48	ϕ2.6 mm	442 max.
									ϕ4.0 mm	348 max.
	5	63	0.28	—	—	0.022	0.026	—	ϕ6.0 mm	240 max.
IS : 2062/62	6	22	0.14	0.98	0.05	0.040	0.016	0.30	A ϕ4.0 mm (260A)+	219—243
									B ϕ4.0 mm (275A)+	183—202

* C. E.—Carbon Equivalent (%+%Mn)
+ Current used.

(b) CTS Tests

Plates of thickness ranging from 18 mm to 63 mm were welded for CTS Tests with the electrode type A (2.0, 2.5 and 4.0 mm) and type B (4.0 mm). The results are shown in Table No. 4.

No cracks were observed in the HAZ of bithermal and trithermal weld specimens. Though the test does not call for hardness survey, hardness tests (HV10) were done in the HAZ for information.

Upto 25 mm thick, the hardness values are satisfactory with electrode type A 4.0 mm. In case of 32 mm plates the values are satisfactory in one plate, while in another plate, the values are in the border line. Again the usage of smaller dia electrodes 2.0, 2.5 mm and 4.0 mm results in higher hardness in the 32 and 63 mm plates.

For comparison, the 22 mm plate was subjected to both UBH and CTS Tests with the electrodes A and B of dia 4.0 mm and in both cases, the results are satisfactory and the hardness values are generally on the lower side for electrode B than A, in both tests. The higher hardness observed in the UBH tests may be attributed to lower amperage involved during welding.

II. IS : 2062/62

(a) Underbead hardness test

A plate of thickness 22 mm was tested with electrode A and B of diameter 4.0 mm and the results are shown in Table No. 3. The hardness values in both cases were found to be satisfactory though with electrode type B, the values are on the lower side.

TABLE 4

Results of CTS tests on IS : 226/62

S.No.	Plate thickness (mm)	% Chemical composition						Electrode Details	Hardness (HV10) at HAZ Range)	Hard Zone Cracking
		C	Mn	Si	S	P	C.E.*			
1	18	0.17	0.82	0.18	0.030	0.018	0.31	A ϕ4.0 mm	136—166	Nil
2	22	0.24	0.75	0.11	0.031	0.019	0.37	A ϕ4.0 mm (300A)+	206—219	Nil
								B ϕ4.0 mm (290A)+	145—206	Nil
3	25	0.22	0.88	0.28	0.020	0.036	0.37	A ϕ4.0 mm	139—175	Nil
4	25	0.25	0.92	0.14	0.034	0.037	0.40	A ϕ4.0 mm	145—194	Nil
5	32	0.20	1.14	0.16	0.025	0.020	0.39	A ϕ4.0 mm	245—297	Nil
6	32	0.26	—	—	0.025	0.015	—	A ϕ2.5 mm	442—max	Nil
								A ϕ4.0 mm	322 max	Nil
7	45	0.19	1.03	0.18	0.023	0.011	0.36	A ϕ4.0 mm	247—254	Nil
8	63	0.28	—	—	0.022	0.026	—	A ϕ2.0 mm	442 max	Nil
								A ϕ2.5 mm	348 max	Nil

* C.E.—Carbon Equivalent (%C+%Mn)
6
+ Current used.

(*b*) *CTS Tests*

Plates of thickness ranging from 18 to 28 mm were tested and the results are shown in Table No. 5.

No cracks were observed in any of the specimens, and the hardness values (measured for information purposes) were satisfactory in all cases. For 22 mm plate, the hardness values with electrode type B were on lower side than the values with A, as observed in UBH test results.

III. IS : 961/62 St 55 HTW

Only UBH tests were carried out on this material using electrode types C and D on plates of thickness 20 mm and 28 mm, with and without preheating. The results are given in Table No. 6.

TABLE 5

Results of CTS Tests on IS : 2062/62

Plate S. No.	*thickness (mm)*	*% Chemical composition*						*Electrode Details*	*Hardness (HV 10) at HAZ (Range)*	*Hard zone Cracking*
		C	*Mn*	*Si*	*S*	*P*	*C.E.**			
1	18	0.22	0.98	0.05	0.055	0.025	0.38	A ϕ4.0 mm	203—262	Nil
2	22	0.18	0.83	0.05	0.034	0.031	0.32	A ϕ4.0 mm	228—281	Nil
3	22	0.14	0.98	0.05	0.040	0.016	0.30	A ϕ4.0 mm	183—210	Nil
								B ϕ4.0 mm	156—176	Nil
4	25	0.20	1.06	0.05	0.038	0,020	0.38	A ϕ4.0 mm	225—292	Nil
5	28	0.22	1.04	0.05	0.026	0.018	0.39	A ϕ4.0 mm	196—281	Nil

* C.E.—Carbon Equivalent $(\%C+\frac{\%Mn}{6})$

TABLE 6

Results of UBH Tests on IS : 961/62

S.No.	*Plate thickness (mm)*	*% Chemical composition*						*Electrode Details*	*Preheating Details*	*Hardness (HV 10) at HAZ*	
		C	*Mn*	*Si*	*S*	*P*	*Cr.*			*Range*	*Average*
1	20	—	—	—	—	—	—	C ϕ4.0 mm	—	351 max	
								D ϕ4.0 mm	—	345 max	
2	28	0.20	—	—	0.032	0.016	0.69	D ϕ2.5 mm	—	336—480	394
								ϕ3.25mm	—	330—437	390
								ϕ4.0 mm	—	322—401	375
								ϕ5.0 mm	—	336—383	357
								ϕ2.5 mm	Plates preheated to 150°C	322—366	339
								ϕ3.25mm	-do-	254—336	292
								ϕ4.0 mm	-do-	264—302	287
								ϕ5.0 mm	-do-	254—285	266

In case of 20 mm plates, both electrodes of types C and D resulted in hardness around 350 HV. With the 28 mm plate, different dia of electrode type D were tried without preheating as well as after preheating to 150°C. In the non-preheated condition, even 5.0 mm dia electrode was found to be not satisfactory whereas with preheating to 150°C, the hardness values were brought down to satisfactory level in all the cases. (Further trials with electrode C were not conducted due to low strength properties of the weld metal, peeling of the electrode coating and the rusting of core wire).

IV. IRS M23 :

Only UBH tests were conducted using electrodes on plates of 28 mm thick. The results are shown in Table-7.

Without preheating, all the electrodes upto 5.0 mm dia had given unsatisfactory results. With preheating, electrode of diameter 3.0 mm and above are satisfactory, while in another plate of same thickness, electrode diameter of 4.0 mm and above are satisfactory with preheating.

Conclusion

The results of the UBH and CTS tests conducted on the different steels confirm that increase in carbon equivalent increases the hardness in the HAZ and that an increase in plate thickness also raises the HAZ hardness. The higher hardness in HAZ, above 350 HV may lead to cracking in certain situations and this can be overcome by modifications in the welding techniques—like preheating or usage of large dia electrodes to result in more heat input. However, the utility of the large dia electrodes is limited and it is not advisable, if the purity of the materials being welded is not satisfactory with high sulphur/phosphorus and inclusion contents[7].

TABLE 7

S.No.	thickness (mm)	% Chemical composition							C.E.*	Electrode details	Preheating details	Hardness (HV10) at HAZ Range	Average
		C	Mn	Si	S	P	Cr	Cu					
1	28	0.33	1.29	0.11	0.049	0.036	—	0.31	0.55	D ϕ2.0 mm	—	351—503	413
										ϕ3.0 mm	—	336—455	393
										ϕ4.0 mm	—	351—394	372
										ϕ5.0 mm	—	345—425	350
2	28				—do—					D ϕ2.0 mm	Preheated to 150°C	322—383	343
										ϕ3.0 mm	—do—	245—317	289
										ϕ4.0 mm	—do—	245—345	281
										ϕ6.0 mm	—do—	228—297	253
3	28	0.33	0.86	0.12	3.036	0.017	—	—	0.46	D ϕ2.5 mm	—	279—542	480
										ϕ3.25mm	—	322—514	453
										ϕ4.0 mm	—	283—421	398
										ϕ5.0 mm	—	236—464	379
4	28				—do—					D ϕ2.5 mm	Preheated to 150°C	336—413	372
										ϕ3.25mm	—do—	322—383	359
										ϕ4.0 mm	—do—	264—327	292
										ϕ5.0 mm	—do—	262—304	284

* C.E.—Carbon Equivalent $\left(\%C+\frac{\%Mn}{6}\right)$

The test results indicate that in structural steels like IS : 226/62 and IS : 2062/62, the weldability may be improved by selecting larger dia electrodes for higher thicknesses, without resorting to preheating, whereas for high tensile steels like IS : 961/62 and IRS M23 even 5 mm electrodes give unsatisfactory results without preheating and it is necessary to resort to preheating even for plates exceeding 20 mm thick.

It is felt that further work has to be conducted on these lines utilising various electrodes and steels to build up more data for incorporation in the national standards in course of time.

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