Welding of Straight Chrome Stainless Steels

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This article highlights the welding of martensitic & ferritic stainless steels and presents in a concise form the various data which will be useful for the welding engineers.

1. INTRODUCTION

The stainless steels can be broadly grouped into five categories depending on their metallurgical structure. They are (a) Martensitic (b) Ferritic (c) Austenitic (d) Precipitation hardening and (e) Duplex. By suitably varying the addition of alloying elements particularly Carbon, Chromium, Nichel (and precipitation hardening elements like Cu, Al, Cb etc. in the case of precipitation hardening stainless, steels), the matrix structure of the stainless steel can be modified and a specific structure can be retained at room temperature. The matrix structure of the stainless steel influences not only the mechanical properties of the stainless steel but also enhances the resistance to corrosion in specific media. Each group finds specific application and forms the most economical choice for a service condition. Of the above groups, the most popular group, the austenitic stainless steels, is widely used and therefore its weldability and related phenomenon have become quite common. The martensitic and ferritic stainless steels, though not so popular,. have specific properties especially mechanical and corrosion properties which make them the candidate material for several applications. To the welding engineer, therefore, it becomes necessary to understand the welding of martensitic and ferritic stainless steels in order to fabricate equipments which will operate satisfactorily in service.

Both martensitic and ferritic stainless steels contain chromium as the main alloying element, unlike the austenitic stainless steels which in addition to chromium contain nickel for stabilising austenite at room temperature. Because of this both martensitic and ferritic stainless steel are called as "straight chromium" steels also.

In this paper, an attempt has been made to present in a concise form, the weldability of straight chromium stainless steels, the various consumables, techniques, heat treatment for the same in order to obtain sound joints.

2. MARTENSITIC STAINLESS STEELS

These are basically iron-carbon alloys containing chromium approximately in the range of 11.5 to 18%. The additions of nickel, molybdenum, tungsten, vanadium are also done to enhance specific properties. Table 1 details the commonly available wrought alloy, cast alloys and nonstandard alloys of martensitic stainless steel type.

In general the properties of these stainless steels are:

a) Martensitic structure of matrix.
b) Magnetic; therefore attracted by magnets.
c) Can be hardened and tempered; High strength.
d) High hardness and excellent wear properties.
e) Excellent resistance to oxidation.
f) Excellent high temperature properties.

2.1 Welding Metallurgy

The TTT diagram (Fig.1) of a typical martensitic stainless steel clearly brings out the behaviour of this steel while cooling from high temperature. The addition of chromium imparts a high hardenability to this steel and produces a martensitic structure at room temperature even under slow cooling rates. The carbon content of the stainless steel plays a vital role in deciding the final metalurgical structure. Since the addition of chromium prevents the formation of austenite, higher carbon contents are necessary to produce austenite at higher temperatures so that martensite will form on cooling. Therefore, there exists a relation between the carbon content and the chromium content which will permit the formation of austenite and hence martensite on cooling. Higher addition of chromium virtually removes austenite region (Fig.2). The carbon content also decides the hardness of the martensite that is formed. The following table shows the increase of hardness with carbon content in the quenched condition.

Table 1.

Type	UNS number	C	Mn	Si	Composition % Cr	Ni	P	S	Others
403	S40300	0.15	1.00	0.50	11.5 - 13.0	...	0.04	0.03	...
410	S41000	0.15	1.00	1.00	11.5 - 13.0	...	0.04	0.03	...
414	S41400	0.15	1.00	1.00	11.5 - 13.5	1.25 - 2.50	0.04	0.03	...
416	S41600	0.15	1.25	1.00	12.0 - 14.0	...	0.04	0.03	0.6 Mo
416Se	S41623	0.15	1.25	1.00	12.0 - 14.0	...	0.06	0.06	0.15 min Se
420	S42000	0.15min	1.00	1.00	12.0 - 14.0		0.04	0.03	...
420F	S42020	0.15min	1.25	1.00	12.0 - 14.0		0.06	0.15min	0.6 Mo
422	S42200	0.20 - 0.25	1.00	0.75	11.0 - 13.0	0.50 - 1.0	0.025	0.025	0.75 - 1.25 Mo; 0.75 - 1.25 W; 0.15 - 0.3V
431	S43100	0.20	1.00	1.00	15.0 - 17.0	1.25 - 2.50	0.04	0.03	...
440A	S44002	0.60 - 0.75	1.00	1.00	16.0 - 18.0	...	0.04	0.03	0.75 Mo
440B	S44003	0.75 - 0.95	1.00	1.00	16.0 - 18.0	...	0.04	0.03	0.75 Mo
440C	S44004	0.95 - 1.20	1.00	1.00	16.0 - 18.0	...	0.04	0.03	0.75 Mo
501	S50100	0.10min	1.00	1.00	4.0 - 6.0	...	0.04	0.03	0.40 - 0.65 Mo
501A	S50300	0.15	0.30 - 0.60	0.50 - 1.00	6.0 - 8.0	...	0.03	0.03	0.45 - 0.65 Mo
501B	S50400	0.15	0.30 - 0.60	0.50 - 1.00	8.0 - 10.0	...	0.03	0.03	0.9 - 1.1 Mo
502	S50200	0.10	1.00	1.00	4.0 - 6.0	...	0.04	0.03	0.40 - 0.65 Mo
503	S50300	0.15	1.00	1.00	6.0 - 8.0	...	0.04	0.04	0.45 - 0.65 Mo
504	S50400	0.15	1.00	1.00	8.0 - 10.0	...	0.04	0.04	0.9 - 1.1 Mo
Casting Alloys									
CA-6NM	J91540	0.06	1.00	1.00	11.5 - 14.0	3.5 - 4.5	0.04	0.04	0.40 - 1.0 Mo
CA-15	J91150	0.15	1.00	1.50	11.5 - 14.0	1.0	0.04	0.04	0.5 Mo
CA-40	J91153	0.20 - 0.40	1.00	1.50	11.5 - 14.0	1.0	0.04	0.04	0.5 Mo
Nonstandard Alloys									
410Cb (XM-30)	S41040	0.18	1.00	1.00	11.5 - 13.5	...	0.04	0.03	0.05 - 0.30 Nb
410S	S41008	0.08	1.00	1.00	11.5 - 13.5	0.60	0.04	0.03	...
414L	...	0.06	0.50	0.15	12.5 - 13.0	2.5 - 3.0	0.04	0.03	0.5 Mo; 0.03 Al
416Plus (XM-65)	S41610	0.15	1.50 - 2.5	1.00	12.0 - 14.0	...	0.06	0.15min	0.6 Mo

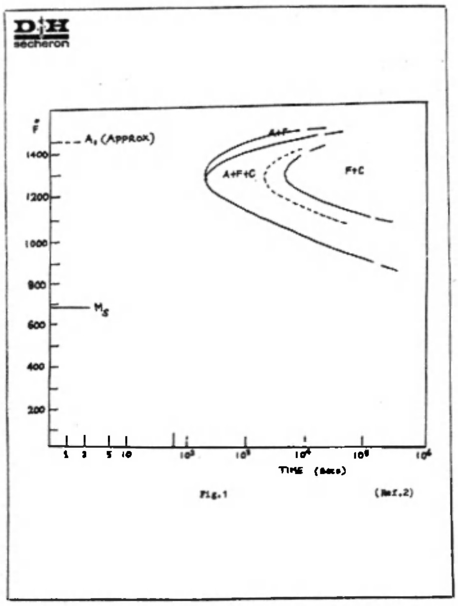

Fig. 1. *TTT diagram.*

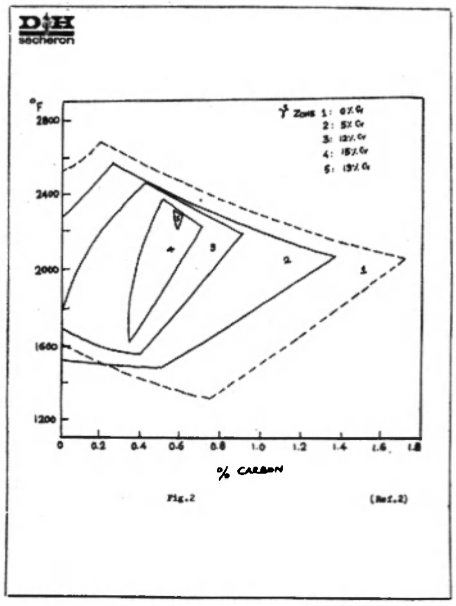

Fig. 2.

Carbon content (%)	0.068	0.133	0.206	0.45	0.60
Hardness (HV)	364	462	480	580	620

It is also evident from the above that with increasing carbon content, the risk of cracking increases and consequently the weldability is reduced.

From the above it can be visualised that the behaviour of martensitic stainless steels is similar to that of hardenable carbon, low alloy steels. Hence, during welding these steels also require precautions like preheating, slow cooling and post weld heat treatment etc. depending on the actual job. These steels are susceptable to cracking, by physical effects, metallurgical effects, and due to hydrogen embrittlement. The physical effects constitute of the joint irregularities, defects, joint restraints which impose strain on the solidifying weldmetal which by itself is hard and has low ductility. The metallurgical effects constitute the structural change from austenitic to martensite which induces a large amount of stress in the matrix.

2.2 Welding Processes

Though there do not seem to be any restriction for the application of any welding process for the welding of martensitic stainless steels, the most commonly used processes are the SMAW and GTAW, of which the SMAW is widely used for the fabrication of different components. Here the discussion will be restricted to SMAW in view of its wide usage in India.

2.3 Welding Procedure for SMAW

In welding martensitic stainless steels the following aspects will have to be carefully determined to get sound weldments.

a) Choice of welding electrode
b) Preheat and Interpass temperature
c) Technique and procedure for welding
d) Postweld heat treatment

2.3.1 Choice of Welding Electrode

The martensitic stainless steels can be welded using

(i) matching composition electrode
(ii) an austenitic stainless steel electrode like E 309.

Both have advantages and disadvantages and a judicious choice is to be made depending on the actual job requirement. The advantages and disadvantages for the above types are as follows:

	Matching Composition S.S.	Austenitic S.S.
(i)	The weld metal is also hardenable and therefore is susceptible for cracking.	Non-hardenable and hence not susceptible for cracking.
(ii)	Because of the above requires a high preheat and interpass temperature.	Because of the above preheat can be lesser and may not be necessary also in certain cases.

Matching Composition S.S.	Austenitic S.S.
(iii) The joint may require PWHT depending on base material composition.	PWHT is not required; in fact it is not recommended.
(iv) The weld metal more or less matches the wear properties of the base material, and hence enhanced service life of base material and weld metal.	The weld metal does not possess the hardness of the base material and hence the wear properties are not so good.
(v) Ideal choice for resisting corrosive environments for which the base material is intended.	May not be suitable for all service requirements since the weld metal is of austenitic structure.
(vi) Not suitable for dissimilar welding like strip welding on mild steel.	Suitable for dissimilar joints of martensitic stainless steels to mild /carbon steels.

The above factors will guide in the choice of welding electrode. The matching composition electrodes and the austenitic stainless steel electrodes commonly used are listed in Table 2. Besides the Ni alloy metals can also be used but they will prove very costly.

2.3.2 Preheat and Interpass Temperature

The advantages of preheating the joint before welding any hardenable steel like martensitic stainless steel are well known. From Fig.1 it can observed that the formation of martensite takes place at a relatively high temperature, Ms. It has been established that if the temperature of the joint is kept between room temperature and Ms, the sensitivity to cracking are reduced. The carbon content of the martensitic stainless steels also determine the preheat temperatures. Guidelines are available for the preheat temperature based on carbon content and as per ASME (Table 3). As a general rule a preheat in the range of 250 degree C should be used for welding martensitic stainless steels. As indicated earlier, the use of an austenitic stainless steel electrode helps in reducing or even eliminating preheat. Therefore, wherever it is not possible to use higher preheat, the use of austenitic stainless steel electrodes can be contemplated. The interpass temperature when preheat is employed should be same as that of the preheat temperature.

Table 2. Electrodes for Martensitic stainless steels

AWS Classification	Grades of Martensitic stainless steels welded
E 410	403, 410, 414, 416, 416Se, 420, CA15, CA40
E 410 Ni-Mo	CA6NM
ER 420	420
E 309/E 310	All grades to themselves and to mild steel
E NiCrFe 3	-do-

Table 3. Preheat Temperature based on carbon percentage

%C	Preheat Temp. degree C	Post weld heat treatment
0.10	—	Optional
0.10-0.20	200-260	Cool slowly; heat treatment Optional
0.20-0.50	260-315	Heat treatment required
0.50	260-315	-do-

Preheat Temperature as per ASME Sec.VIII Div.1

For P - 6 group : 204 degree C

2.3.3 Technique and Procedure for Welding

The welding technique for welding martensitic stainless steels is similar to hardness steels. The matching composition welding electrode will be a basic coated, low hydrogen type and it is preferable to use this electrode on DC(+). It should be noted that martensitic stainless steels are also susceptible to hydrogen embrittlement like low alloy steels. Short arc and stringer bead technique is to be adopted so that the loss of alloying elements during transfer is reduced to a minimum. The martensitic stainless steels can be welded in annealed or hardened or tempered condition.

2.3.4 Post Weld Heat Treatment

The post weld heat treatment is done to the martensitic stainless steels in order to temper the hardened

Table 4(a). Post weld heat treatment as per ASME Sec.VIII Div.

(a) For all grades :	Stress relieve @ 676 degree C-One hour/inch upto 2".
(b) For 410 grade :	No heat treatment if (i) C 0.08 (ii) Non hardening weld metal (iii) Preheat of 232 degree C for thicknesses over 10mm and upto 38mm. (iv) Joints to be radiographed.

Table 4(b). Post weld heat treatments for martensitic weld metals

Type	Subcritical annealing temp. °C (air cool)	Full annealing Temp. range °C (Furnace cool upto 593°C)
403, 410, 416	648-760	826-882
414	648-732	Not recommended
420	676-760	826-882
431	621-704	Not recommended
440A,B,C	676-760	843-898
CA6NM	593-621	787-815
CA15, CA40	621-648	843-898

martensite. The carbon content and the weld metal used influence the post-weld heat treatment. Postweld heat treatment may not be essential in the case of low carbon content materials. The use of austenitic stainless steel electrodes also eliminates the PWHT. The ASME Sec. VIII details under UHA 32 the requirements for PWHT for this group of material (Table 4a). The subcritical annealing temperatures and full annealing temperatures for various grades are indicated in Table 4(b).

2.4 Effects of Alloying Additions in Martensitic Stainless Steels

As can be observed from the Table 5 a number of alloying additions are made to the martensitic stainless steels. In addition nickel forms one of the popularly used alloying additions.

It was seen earlier that with the increasing additions of chromium the steel loses its ability to form austenite at elevated temperatures. Nickel, being an austenitiser, help in the formation of austenite at higher temperatures. Therefore, the addition of nickel helps in,

(a) reducing the carbon content for the same chromium levels.
(b) achieving better weldability because of lower carbon.
(c) introducing better ductility and toughness of the material.

The electrode for welding this material is classified as E 410 Ni-Mo and has the following typical chemical composition.

Element					
C	Mn	Si	Cr	Ni	Mo
Percentage					
0.06 max.	1.0 max	0.90 max	11-12.5	4-5	0.4-0.7

The addition of Molybdenum helps in improving the elevated temperature properties. The addition of Mo is particularly preferred in many applications where the component is to serve in elevated temperatures.

2.5 Dissimilar Joints

The dissimilar joints are a common feature in martensitic stainless steel to mild steel. For this, the E309 type weld metal is ideally suitable. Thus E-309 type electrode becomes not only suitable for similar material welding but also for dissimilar material welding.

3. FERRITIC STAINLESS STEELS

These are basically iron-carbon alloys containing sufficient amount of chromium i.e. 17-30% and low carbon levels which prevents the formation of austenite at elevated temperatures and renders the room temperature structure as ferritic. The ferritic stainless steels have the following properties in general:

(i) Ferritic structure of matrix.
(ii) Magnetic and hence attracted by magnets.
(iii) Non-hardenable; cold working enhances strength to a small extent.
(iv) Less ductile than austenitic grades.
(v) Poor toughness in general.
(vi) Excellent resistance to chloride stress corrosion cracking, resistance to pitting and crevice corrosion in chloride media,resistance to oxidation at high temperature.
(vii) Excellent elevated temperature properties.

From the above, it can be observed the ferritic grades have distinct properties and their only draw back was their poor weldability and subsequent low notch toughness associated with grain coarsening and

Table 5. Effect of alloying elements in straight chrome stainless steels

Element	Grade	Effects
1. Aluminium	Ferritic	— Ferrite former — Scaling resistance — Grain refiner — Improves electrical properties — Generally not added in electrodes
2. Columbium	Ferritic	— Carbide former — Ferrite Stabiliser — Makes steel less susceptible to high temperature embrittlement — Improves corrosion resistance.
3. Molybdenum	Martensitic	— Refines grain size — Improves creep strength — Improves corrosion resistance — Reduces weldability.
	Ferritic	— Ferrite former; suppress austenite formation — Improves corrosion resistance — Improves weldability
4. Nitrogen	Ferritic	— Grain refiner — austenite former — Improves weldability — At specific levels improves toughness
5. Phosphorus	Ferritic & Martensitic	— Produces hot shortness at higher levels — Reduces corrosion resistance
6. Silicon	Ferritic & Martensitic	— Improves scaling resistance particularly in S-bearing atmospheres. — Ferrite former — Higher Si content produce larger grain size in ferritic grades — In martensitic grades toughness is further reduced. — Improves weldability slightly.
7. Sulphur	Ferritic & Martensitic	— Improves free machining characteristics — In ferritic grades porosity, small checks appear thus preventing welding.
8.Titanium	Ferritic & Martensitic	— Great affinity For C,N. — Ferritic former — Grain refiner
9.Tungsten	Martensitic	— Reduces softening tendency — Elevated temp. strength is increased.
	Ferritic	— Grain refinement.

embrittlement. Subsequent to the developments in the manufacturing techniques of ferritic grades, these difficulties have been eliminated to a large extent and this group finds extensive use in industries like automobile, petrochemical, chemical, marine industries. Table 6 gives the various grades of ferritic stainless steels.

Table 6.

Type	UNS number	C	Mn	Si	Composition % Cr	Ni	P	S	Others
405	S40500	0.08	1.00	1.00	11.5- 14.5	...	0.04	0.03	0.10-0.30 A1
409	S40900	0.08	1.00	1.00	10.5- 11.75	...	0.045	0.045	6X% C min Ti
429	S42900	0.12	1.00	1.00	14.0- 16.0	...	0.04	0.03	...
430	S43000	0.12	1.00	1.00	16.0- 18.0	...	0.04	0.03	...
430F	S43020	0.12	1.25	1.00	16.0- 18.0	...	0.06	0.15min	0.6 Mo
430FSe	S43023	0.12	1.25	1.00	16.0- 18.0	...	0.06	0.06	0.15 min Se
434	S43400	0.12	1.00	1.00	16.0- 18.0	...	0.04	0.03	0.75- 1.25
436	S43600	0.12	1.00	1.00	16.0- 18.0	...	0.04	0.03	0.75-1.25 MO 5X%c MIN Nb + Ta
442	S44200	0.20	1.00	1.00	18.0- 23.0	...	0.04	0.03	...
446	S4460	0.20	1.50	1.00	23.0- 27.0	...	0.04	0.03	0.25 N
<u>Casting Alloys</u>									
CB-30	J91803	0.30	1.00	1.50	18.0- 21 0	2.0	0.04	0.04	
CC-50	J92616	0.50	1.00	1.50	26.0- 30.0	4.0	0.04	0.04	
<u>Nonstandard Alloys</u>									
Type 404	...	0.05	1.00	0.50	11.0- 12.5	1 25- 2.00	0.03	0.03	...
Type 430Ti	S43036	0.10	1.00	1.00	16.0- 19.5	0.75	0.04	0.03	5X%C min Ti
Type 414(18-2)	S44400	0.025	1.00	1.00	17.5- 19.5	1.00	0.04	0.03	1.75 - 2.5Mo; 0.035 max N; 0 2 + 4(%C + %N)min (Ti + Nb)
18 SR	...	0.04	0.3	1.00	18.0	...	...	...	2.0 Al; 0.4 Ti
18-2 FM	S18200	0.08	2.50	1.00	17.5- 19.5	...	0.04	0.15min	
E Brite 26-1 (XM-27)	S44625	0.01	0.40	0.40	25.0- 27.5	0.50	0.02	0.02	0.75 - 1.5MO; 0.015 N; 0 2Cu; 0 5Ni + Cu
26-1 Ti (XM-33)	S44626	0.06	0.75	0.75	25.0- 27.0	0.50	0.04	0.02	0.75-1.5Mo; 0.04N; 0 2Cu; 0.2-1.0 Ti
29-4	S44700	0.010	0.30	0.20	28.0- 30.0	0.15	0.025	0.02	3.5 - 4.2 Mo
29-4-2	S44800	0.010	0.30	0.20	28.0- 30 0	2.0- 2.5	0.025	0.02	3.5 - 4.2 Mo
MONIT	S44635	0.25	1.00	0.75	24 5- 26.0	3.5- 4.5	0.04	0.03	3.5 - 4.5mO; 0.3 - 0.6(Ti+nB)
Sea - cure/Sc-1	S44660	0.025	1.00	0.75	25.0- 27.0	1.5- 3.5	0.04	0.03	2 5 - 3 5Mo; 0.2 + 4(%C+%N) min (Ti + Nb)

3.1 Welding Metallurgy

As indicated earlier, these stainless steels contain large additions of chromium which renders the formation of austenite impossible even at elevated temperatures. Fig. 2 shows the shrinking of the loop with increasing percentages of chromium and carbon. Therefore, the relative amounts of carbon and chromium decide the formation of austenite/ferrite at elevated temperatures. In some grades of ferritic steels, during welding, the formation of austenite takes place and this cools down to martensite thus embrittling the weldment by its presence at the grain boundaries.

Unlike martensitic stainless steels, the ferritic stainless steels are not hardenable and during welding therefore do not require preheating. However, the following aspects require careful consideration for achieving sound welds.

(a) Grain coarsening and subsequent loss of toughness.
(b) Formation of austenite.
(c) 475°C embrittlement.
(d) Formation of sigma phase.
(e) Notch sensitivity.
(f) High temperature embrittlement.

Let us understand these aspects in more detail in the following paragraphs.

3.1.1 Grain Coarsening

During welding, owing to the heat of welding, the single phase ferritic structure corsens in the HAZ. The extent of grain coarsening is dependent on the time and temperature to which the base material was exposed during welding. The thermal conductivity of ferritic stainless steel is only half that of carbon steels but higher than austenite stainless steels. Hence, large heat inputs, excessive heating during welding are not preferred for this material.

Various alloy additions are done to reduce the grain size and to prevent coarsening. Aluminium upto 0.05% is very effective in controlling the grain size and amounts over and above will result in grain coarsening. Nitrogen is also an useful addition for controlling the grain size. It also inhibits grain growth at elevated temperatures. Titanium in amounts of 0.20-0.45% is another useful element which acts as an effective grain refiner.

Eventhough the control of grain size is possible with effective additions of alloying elements in base material and weld deposits, as indicated earlier, grain coarsening can take place if a carefully designed welding procedure is not adopted. Coarsened grains can be refined by cold working and annealing procedures wherever feasible.

3.1.3 475° C Embrittlement

This occurs when ferritic steels are soaked in the temperature range of 400-540° C. The exact reasons for this embrittlement are not clear. But however, it can be said that this embrittlement is along the grain boundaries and therefore hardness measurement may or may not reveal the brittleness but the impact tests and elongation percentages will reveal the embrittlement. Normally in welding of ferritic stainless steels, this embrittlement does not occur unless the material is exposed in this temperature range for longer periods such as in thicker plates etc. A post weld annealing at 595° C will remove this embrittlement effect.

3.1.4 Formation of Sigma Phase

The occurance of sigma phase is only when the stainless steel is exposed for very long periods in the temperature range of 540-815° C. The alloy content, the time of exposure decide the temperature range at which considerable amount of sigma is precipitated. Normally in welding, this phase does not form but prolonged heat treatments and slow cooling in this temperature range can cause the information. Dissolution of sigma is possibly by solution annealing heat treatment at 870° C. The formation of sigma phase renders the material susceptible to corrosion.

3.1.5 High Temperature embrittlement

As seen earlier, the higher percentages of Cr stabilises ferrite phase at all temperatures. With the absence of austenite at higher temperatures, the ferrite phase is super saturated with carbon which is in the form of atomic clusters and this causes embrittlement. The steel get embrittled when cooled from temperatures above 1093°C. The toughness of the material reduces and grain coarsening also takes place. During welding owing to the higher cooling rates, the steel becomes susceptible to the phenomenon.

3.1.6 Notch Sensitivity

The ductile-brittle transition for ferritic stainless steels is well above room temperature. Also with higher percentages of Cr the material becomes brittle. Therefore, the ferritic stainless steels are used normally in elevated temperature applications. However, the grain size plays an important role in determining the ductile-brittle transition temperature Here again the grain coarsening leads to an increase of transition temperature and careful welding practice is necessary. Reducing the interstitial alloy content i.e. (C+N) can also help in reducing the notch sensitivity.

3.2 Effect of Alloying Additions

Table 5 shows the various alloy additions made to ferritic steels and their relevant effects.

3.3 Welding Processes

For welding of ferritic stainless steels, SMAW, SAW, GTAW and GMAW are suitable. SMAW is more popularly used while the gas shielded processes like GTAW, GMAW are used for welding Extra Low Interstitial grades and ultra pure grades of ferritic stainless steels. The use of SAW is limited because of the higher heat inputs during welding and consequent grain growth in the base materials.

3.4 Welding Ferritic Stainless Steels with SMAW Process

As indicated above,the SMAW process is best suited for most of the ferritic stainless steels and lets us look into the welding procedural details for SMAW.

3.4.1 Selection of Electrodes

The ferritic stainless steels can be welded with any of the following category of electrodes

(a) Matching composition weld metal
(b) Austenitic stainless steel weld metal

The advantages and disadvantages of these weld metals are as detailed below:

	Matching	Austenitic
(i)	Matching chemical composition. Hence matching corrosion properties.	Composition not matching; Hence corrosion properties are not similar.
(ii)	Post weld annealing is required in many cases for improving ductility, toughness.	Post weld annealing not required for weld metal. But sometimes the base material may require.
(iii)	May require transfer of Al, Ti for grain refinement through the arc which will be very difficult.	Does not require grain refining
(iv)	Not suitable for Cr percentage above 23%Cr.	Ideal for welding higher Cr ferritic stainless steels.
(v)	Weld metal susceptible to high temperature embrittlement.	Not susceptible to high temperature embrittlement.
(v)	Thermal Expansion & contraction is similar. Hence less distortion.	Thermal expansion & construction not similar; Hence more distortion.

Apart from these two categories, use of Nickel alloy electrodes like ENiCrFe-3 and semi-ferritic electrodes are also used. The ENiCrFe-3 electrodes have the same features like the austenitic stainless steel electrodes but however, their coefficient of thermal expansion and contraction which decided the residual stresses and distortion is less but are however costly. The semiferritic electrodes have small percentages of austenite and they have,

(a) similar thermal expansion and contraction
(b) better ductility and toughness.

By increasing the percentage of carbon, manganese and with the addition of Ni and N_2 some amount of austenite can be retained in the room temperature structure.

A judicious choice of the welding electrode is necessary keeping in mind the job requirements and the easiness of producing a good weld. Table 7 shows the electrodes for various electrodes for ferritic stainless steels.

3.4.2 Preheat and Interpass Temperatures

Unlike martensitic stainless steels, the ferritic grades do not require a high degree of preheat. Preheat when employed excessively can lead to

(a) slow cooling and hence grain coarsening
(b) relatively longer exposures at temperatures in the range of 475° C to get embrittled.

Normally ferritic grades can be welded without pre-

Table 7. Electrodes for ferritic stainless steels

Electrode classification	Grades welded
E 430	405, 446, 430, 405
E 309/E310	405, 430, 430F, 430F(Sc), 446 and their joints with mild steel.

heat. But however, when the Cr content increases, preheat becomes essential. For steels containing more than 25%Cr a preheat and interpass temperature of 150-200 degree C is employed. In case of thicker plates again preheat is required.

3.4.3 Welding Procedure

The welding procedure should take care of the following aspects:

(a) Use of minimum heat input,

(b) Lowest size of electrodes possible,

(c) Stringer beads and shortest possible arc.

3.4.4. Post Weld Heat Treatment

A number of post weld heat treatments may have to be adopted depending on the desired end results.

Table 8. Post weld heat treatment for ferritic stainless steels as per ASME Sec. VIII Div.1.

For P-7 group 1,2 Materials	Stress relieve at 732° C for one hour/inch upto 2". Cool rapidly after 648° C. Heat treatment not required if (i) C $\leq$ 0.08 (ii) Non hardening weld metal (iii) Preheat of 232° C for thicknesses over 10 mm and upto 38 mm. (iv) Joints radiographed.

These are indicated below:

	Heat Treatment	Objective
i)	Soak at 704°C - 843°C and cool. Cool rapidly around 475°C.	Useful for grain refinement
(ii)	Soak at 595°C and air cool thin sections/ quench thicker sections.	For removing 475°C embrittlement.
(iii)	Soak at 760 - 870°C and water quench	For removal of sigma phase.
(iv)	Annealing at 730°C - 790°C	Removes high temperature embrittlement; improves toughness.

Table 9

Property	Martensitic	Ferritic	Austenitic
1. Thermal conductivity	1.38	1.22	1
2. Thermal Expansion	0.66	0.64	1
3. Magnetic property	Magnetic	Magnetic	Non Magnetic
4. Corrosion resistance	Good resistance to Gen. corrosion	Good resistance to Gen. corrosion Good resistance to SCC	Good resistance to Gen. corrosion Resistance to oxidising, reducing environments.
5. Weldability	Poor	Poor	Good
6. Ductility	Poor	Poor	Good
7. Wear resistance	Good	Medium	Medium
8. Toughness	Poor	Poor	Good

The post weld heat treatment indicated by the ASME codes are indicated in Table 8.

3.5 Dissimilar Joints

Frequently the ferritic stainless are joined with mild steel for overlay applications etc. The ideal electrode for this dissimilar joint will be the E-309 type weld metal. The ENiCrFe3 weld metals can also be considered but they may prove expensive.

4. APPLICATION AREAS OF VARIOUS GROUPS OF STAINLESS STEELS

Having studied in detail the welding aspects of martensitic, ferritic stainless steels, let us briefly have a look at the application areas of both these steels and how they stand against the more popular group the austenitic stainless steels. Table 9 shows the details. It can be observed that each group has its own uniqueness and an area where its use will be the ideal one.

CONCLUSION

The straight chromium stainless steels have a range of applications and are fabricated frequently for the construction of equipments. A knowledge of the various phenomena that occur during welding of these materials will be of immense help in producing a sound joint which will perform satisfactorily in service. Choices exist for selection of welding consumables and the service requirements decide the ideal welding consumable. Concurrent to the choice on welding consumables, the welding procedure also gets altered. A knowledge of these factors will also help in selecting the ideal consumable,welding procedure and also for analysing the reasons for failure.

References:

1. Metals Handbook, ASM Vol.3
2. AWS Welding Hand Book Vol.4
3. Source book on ferritic stainless steels- ASM publication

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AME-IIW EXAMINATION JANUARY 1992
WINTER SESSION 1991

TIME TABLE

FIRST HALF TIME

10.00 Hrs. TO 13.00 Hrs.	13TH JAN. 1992	14TH JAN. 1992	15TH JAN. 1992	16TH JAN. 1992	17TH JAN. 1992
PART A	Elementary Mathematics	—	Chemistry	—	Workshop Technology
PART B	Aplied Mechanics & Strength of Materials	—		—	* Engineering Drawing
PART B SEC-II	—	Welding Metallurgy-I		Welding Procedure	—
PART C SEC-I	Engineering Mathematics		Welding Metallurgy-II	—	—
PART C SEC-II	Welding Equipment	—	Welding Consumables		Inspection Testing *Quality Assurance

SECOND HALF TIME

14.00 Hrs. TO 17.00 Hrs.	13TH JAN. 1992	14TH JAN. 1992	15TH JAN. 1992	16TH JAN. 1992	17TH JAN. 1992
PART A	—			General English	—
PART B SEC-I	—	Electrical Engineering & Electronics	Material Science	Production Engineering	—
PART B SEC-II	Material Joining Process	—	Physics of Welding	—	Weld Quality Standards & Codes
PART C SEC-I	—	Welding Design	—	Industrial Engineering	—
PART C SEC-II	Application	Welding			

TIME FOR EXAMINATIONS FOR EACH PAPER — 3 HOURS
TIME FOR EXAMINATIONS FOR DRAWING ONLY — 4 HOURS