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[54] **CORROSION-RESISTANT AUSTENITIC-FERRITIC STAINLESS STEEL**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 317,494, Dec. 21, 1972, abandoned.

[30] **Foreign Application Priority Data**

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[58] **Field of Search**.......... 75/128 A, 128 C, 128 N, 75/128 W; 148/37, 38

[56] **References Cited**

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[57] **ABSTRACT**

A corrosion resisting steel with considerably higher yield point and ultimate tensile strength as well as good ductility and impact strength is achieved by adding a comparatively large quantity (2–4% by weight) of Si to a high chromium austenitic-ferritic steel. The resultant steel typically has a composition (percent by weight):

C	max	0.15						
Si		2.0	–	4.0	preferably	2.5	–	3.5
Mn		0.5	–	3.0	"	0.7	–	2.5
Cr		23	–	27	"	24	–	26
Ni		3.5	–	8.0	"	4.5	–	7.0
Mo		0.5	–	2.0	"	1.2	–	1.8
N	max	0.1						

and the balance substantially iron and impurities.

2 Claims, No Drawings

CORROSION-RESISTANT AUSTENITIC-FERRITIC STAINLESS STEEL

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of applicants' prior copending U.S. application Ser. No. 317,494 filed Dec. 21, 1972, for "Corrosion-Resisting Austenitic-Ferritic Stainless Steel with High Strength", now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to a corrosion-resisting austenitic-ferritic stainless steel with high strength and good ductility and impact strength. The steel according to the invention is intended for use when there are severe requirements for corrosion-resistance and strength.

Austenitic-ferritic stainless steels with a high chromium content are particularly characterized by very good corrosion resistance even in aggressive environments. Steels of the Swedish standard type SIS 2324 (26 Cr, 5 Ni, 1.5 Mo) for instance, have many uses where a very high degree of corrosion resistance is required. This type of steel has rather high strength, but there is a demand for a corrosionresisting steel of this type with still higher strength and good ductility and impact strength.

Common methods of increasing the strength of steel are:

martensitic hardening
precipitation hardening
strain hardening (cold-working)
solution treatment

Martensitic hardening cannot be used for this type of steel (SIS 2324), since the ferritic matrix cannot be transformed into martensite, and the relatively small portion of the austenite phase present is comparatively stable (metastable). The possibilities of applying precipitation hardening on ferritic and austenitic-ferritic steels with a higher chromium content and thereby increasing the strength by adding some alloying elements, and by solution treatment and ageing, are very limited. The ageing necessary for precipitation hardening must take place at temperatures at which steels of this type are embrittled and/or sensitized, i.e. sensitive to intercrystalline corrosion. These types of steel are therefore instead used in a quench-annealed condition (from approx. 1000°C).

The possibility of obtaining higher strength by cold-working is also limited, as the matrix in these steels is ferritic to a major extent, which means that the strain hardening effect will be rather insignificant.

Solution treatment with substitutional alloying elements normally gives little increase of the strength. The normal increase of the yield point of ferrite that can be expected by a solution treatment is approx. 1–2 kp/mm^2 for each percent by weight of alloying elements.

THE PRESENT INVENTION

The main objective of the present invention is to provide a steel with

1. High general corrosion resistance in salt water, chloride solutions and others,
2. High resistance to stress corrosion in chloride solutions,
3. High resistance to intergranular corrosion in warm chloride solutions,
4. High tensile strength,
5. High ductility and impact strength. A steel with this specific combination of properties has long been sought for use in centrifugal separators. Prior to the present invention, no such steel was available. The steel according to the present invention thus represents a major improvement for this specific application, as well as in other applications where high tensile strength, ductility and impact strength in combination with corrosion resistance are required.

According to the present invention, it has now, quite surprisingly, been established that a corrosion-resisting steel with considerably higher yield point and ultimate tensile strength as well as good ductility and impact strength, for use in the applications discussed above, can be achieved by adding a comparatively large quantity (2–4% by weight) of Si to a high chromium austenitic-ferritic steel.

A steel according to the invention is therefore mainly characterized by the following composition (percent by weight):

C	max	0.15						
Si		2.0	–	4.0	preferably	2.5	–	3.5
Mn		0.5	–	3.0	"	0.7	–	2.5
Cr		23	–	27	"	24	–	26
Ni		3.5	–	8.0	"	4.5	–	7.0
Mo		0.5	–	2.0	"	1.2	–	1.8
N	max	0.1						

and the balance substantially iron and the impurities common for this type of steel.

It is desirable that the contents of N and C are kept as low as possible, and a lower limit of approx. 0.01 % is possible in practice.

In order to improve the resistance of the steel to intercrystalline corrosion, the steel can contain such strong carbide forming elements as Ti, Nb and Ta. These elements should be included at least in a stoichiometric quantity in relation to the content of C + N.

P and S are present in small contents (up to approx. 0.05 %) as impurities.

The invention will be described in more detail with reference to the steels of which examples are given in the following Tables.

The composition of the steels examined are given in Table 1.

Table 1:

Steel No.	C	Si	Mn	P	S	Cr	Ni	Mo	N
	(Composition in per cent by weight)								
1	0.12	1.7	0.70	0.004	0.002	25.0	4.8	1.46	0.02
2	0.08	1.5	0.74	0.009	0.016	25.7	5.1	1.35	0.03
3	0.12	2.3	0.76	0.005	0.006	24.7	4.7	1.44	0.03
4	0.09	3.1	0.79	0.003	0.010	24.1	6.6	1.51	0.02
5	0.06	2.7	1.8	0.003	0.015	24.3	4.9	1.50	0.03
6	0.09	3.2	2.2	0.012	0.012	25.1	5.7	1.54	0.05

Table 1.-continued

Steel No.	C	Si	Mn	P	S	Cr	Ni	Mo	N
	(Composition in per cent by weight)								
7	0.07	0.62	2.7	0.012	0.011	25.7	3.6	1.51	0.03
8	0.09	0.74	0.97	0.016	0.020	26.0	5.0	1.45	0.01

As will be noted from the table, steels 1 and 2 have Si contents which exceed those normally used (0.5 – 1 %) but are nevertheless definitely lower than those used according to the invention. Steels 3 – 6 are entirely according to the invention, while steels 7 and 8 have a normal Si content and are included only for the sake of comparison. Steel 8 is a defined Swedish standard steel (SIS 2324).

Table 2

Mechanical properties at room temperature and austenite content (per cent by volume) of the steels indicated in Table 1 in quench-annealed condition.

Steel No.	0.2 % proof stress $\sigma 0.2$ kp/mm²	Ultimate tensile strength σB kp/mm²	Elongation δ5 %	Reduction of area ψ%	Impact strength KCU kpm/cm²	Hardness HV	Austenite content per cent by Volume	Heat-treatment
1	54.1	69.1	26.0	59.7	10.0	244	21	975°C,1h,water
2	58.0	69.4	22.0	57.8	11.4	245	13	"
3	62.8	74.5	23.5	53.2	8.9	265	10	"
4	71.1	83.1	21.7	52.7	7.8	278	11	1025°C,1h,water
5	69.8	79.3	22.5	57.2	8.5	280	10	975°C,1h,water
6	72.1	85.6	21.7	51.8	8.0	291	14	1025°C,1h,water
7	59.7	67.7	22.3	51.7	9.1	227	5	"
8	51.0	64.3	27.0	60.4	9.7	230	26	975°C,1h,water

The mechanical properties and the austenite contents of the steels indicated in Table 1 were examined in a quench-annealed condition, and the results are given in Table 2, above. Table 2 clearly proves that Si has a striking strength-increasing effect, and particularly steels 4,5 and 6 with more than 2.5 % Si have both $\sigma 0.02$ and σB far above those of the standard brand steel (steel 8). In spite of this, the elongation, the reduction of area and the impact strength of this steel are still favourable. An extremely attractive feature of this hardening effect of Si is also that it is obtained already in the normal quenchannealed condition. The hardening effect given by Si is therefore to be regarded as an extremely strong "solution hardening".

The above tables do not indicate any upper limit of Si. Higher Si contents have been tested, and it has been found that increase in the quantity of this element then gives still higher hardness values. However, higher Si contents than those used do not appear to be realistic. At Si contents ≥ 4%, hot-working might become difficult. This seems to be the case particularly in combination with a high Mn content (≥ 3%). With an increasing shear resistance of the ferrite, i.e., an increasing hardening effect, there is a greater risk of embrittlement of the steel. This is inter alia due to the fact that a sufficiently small grain size cannot be obtained.

All of the steels as exemplified contain austenite after quench-annealed. The austenite phase is softer than the ferrite phase, which means that particularly the proof stress and the hardness decreases somewhat with increasing austenite content. In spite of this steel 7, which has the lowest austenite content but only 0.62 % Si, has a much lower strength than e.g. steel 6 which has 3.2 % Si, but with a considerably higher austenite content. This further illustrates the strong hardening effect obtained with a high Si content.

For ductility and impact strength reasons, however, it is desirable that there be at least approx. 10 % by volume austenite in the structure. On the other hand, considering the strength, the austenite content should not exceed 35 % by volume. The austenite content should appropriately be kept between 10 and 25 % by volume.

In order to obtain the desired austenite-ferrite proportion in the steel, consideration must be taken to the ferrite and austenite-stabilizing effect to the elements included. This can be done approximately by means of a socalled Schaeffler diagram.

The invention is not limited to the steels as exemplified above, but the properties can of course be modified by adding other conventional alloying elements while maintaining the basic composition indicated and the desired balance between austenite and ferrite-stabilizing elements.

We claim:

1. Corrosion-resisting austeniticferritic stainless steel having an austenite content of between 10% and 25% by volume and a ferrite content of between 90% and 75% by volume, said steel having high tensile strength, high ductility and impact strength, high general corrosion resistance, high resistance to stress corrosion in chloride solutions, and high resistance to intergranular corrosion in warm chloride solutions, said steel consisting essentially of (percent by weight):

C max	0.15
Si	2.0 – 4.0
Mn	0.5 – 3.0
Cr	23 – 27
Ni	3.5 – 8.0
Mo	0.5 – 2.0
N max	0.1

and the balance substantially iron.

2. Steel according to claim 1, consisting essentially of (percent by weight):

C max	0.15		
Si	2.5	–	3.5
Mn	0.7	–	2.5
Cr	24	–	26
Ni	4.5	–	7.0
Mo	1.2	–	1.8
N max	0.1		

and the balance substantially iron.

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