

1

3,563,813

CONTROLLING FRACTURE TOUGHNESS OF HIGH-STRENGTH STAINLESS STEELS

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6 Claims

ABSTRACT OF THE DISCLOSURE

A method of controlling fracture toughness in high-strength stainless steels by heat treating procedures. The heat treated alloy retains a controlled amount of austenite which imparts fracture toughness along with a minor increase in strength.

This invention relates to heat treating of stainless steel but more particularly it relates to a process of heat treating of high-strength stainless steel to control the amount of residual austenite and thereby obtain an alloy with excellent fracture toughness as well as high strength.

It has not been possible in the past to make stainless steel with high strength and fracture toughness comparable to commonly used low alloy steels. There are stainless steel alloys which do have the high strength, but heretofore it has not been possible to obtain a high-strength alloy which also has good fracture toughness. High-strength stainless steel alloys are defined as those alloys with ultimate tensile strength (UTS) of 220K. s.i. or greater.

This invention discloses a heat treating process that will impart both strength and toughness to high-strength stainless steel alloys. The improvement in toughness without a sacrifice in strength is made possible by controlling the austenite content of the treated and tempered alloy.

A soft tough phase (austenite) is present as a fine dispersion in martensite. The martensite gives high strength, but it is brittle. A controlled dispersion of austenite imparts toughness without impairing strength.

Using presently practiced heat treating methods for this class of alloy causes more austenite to be converted to martensite than is desirable. If higher than normal austenitizing temperatures are used the austenite becomes more stable, and a higher percentage remains in dispersion during the transformation into martensite. With stainless steels there has been a limit on the maximum austenitizing temperatures that can be used, because at higher temperatures delta ferrite is formed. This delta ferrite is undesirable as it reduces strength and imparts brittleness. It is standard practice to heat treat by using an austenitizing temperature which is just lower than the point at which delta ferrite forms in the attempt to obtain the maximum amount of austenite which is free from delta ferrite.

This invention uses higher austenitizing temperatures than those customarily used by industry. This dissolves a large quantity of particles which normally remain out of solution, and thereby creates an austenite which remains stable during subsequent treatment. This higher heat also generates delta ferrite which is removed by the novel step of lowering the material while in the furnace to a temperature which is just lower than the point at which delta ferrite is formed. The melt is held at this temperature while the delta ferrite is transformed into austenite. These steps create a stable austenite such that

2

from 5 to 30% austenite remains in the alloy after oil quenching, refrigerating, and tempering in the normal way.

An object of this invention is to obtain a high-strength stainless steel with good fracture toughness.

Another object of this invention is an increase in strength due to increased alloy content of the matrix.

Another object of this invention is to produce a structure which can be cold worked to a higher strength level without loss of toughness.

Another object is to control the retained austenite content of high-strength stainless steel.

A further object of this invention is to obtain an enhanced level of stress corrosion resistance.

Heat treating high-strength stainless steel alloys using the methods discovered and disclosed in this invention is carried out using the following steps.

Step 1 uses a high temperature treatment in which the austenitizing temperature is between 1950° F. and 2300° F., but is preferably at 2100° F. and is held at that temperature for approximately 1 hour. This increases the alloy content of the matrix by dissolving alloy carbides and intermetallic particles to form a stable austenite.

Step 2 calls for cooling the steel in the furnace to a temperature in the range of 1700° F. to 1900° F., but preferably about 1800° F., and holding at that temperature for about 5 hours. The dissolved particles remain in solution, but the delta ferrite formed at the step 1 temperature is transformed into austenite.

Following step 2 the steel is further treated by use of conventional steps which are as set out below.

Step 3 calls for an oil quench followed by refrigeration to a temperature between -65° F. and -120° F. and to be held at that temperature for 30 minutes.

Step 4 is a tempering step and calls for a temperature in the range of 500° F. to 1100° F. This temperature is held for 2+2 hours. The 2+2 hours means to soak at temperature for 2 hours followed by air cooling to about room temperature, and then to soak at temperature again for 2 more hours.

Step 5 can be used as an alternative to step 4. The steel is tempered for 2 hours at 500° F. and then cold worked 10-50% followed by retempering for 2+2 hours at temperatures in the range of 500° F. to 1150° F. This step produces higher strength than step 4 while maintaining a high toughness.

The invention method of heat treating will yield an alloy with a controlled, retained austenite content which imparts fracture toughness.

Conventional heat treating would replace steps 1 and 2 with a single step of using an austenitizing temperature of about 1900° F. which is just below the temperature at which delta ferrite forms.

Increase in toughness produced by retained austenite is apparently due to its crack arresting ability. The austenite is a soft tough phase in which crack propagation is difficult. Therefore when a crack growing through a martensitic region meets an area of austenite it must either continue through the austenite or trace a zig-zag path through interlocking martensite needles.

It was discovered that our invention heat treat gave considerably increased fracture toughness.

The unit of measure for fracture toughness is the plane strain fracture toughness parameter (K_{IC}) and is shown as K s.i. $\sqrt{\text{in.}}$ units in Table I below. The ultimate tensile strength of high-strength stainless steels is shown as K s.i. in Table I. That table illustrates the maximum ultimate strength obtainable at various fracture toughness values.

TABLE I.—FRACTURE TOUGHNESS AND ULTIMATE TENSILE STRENGTH

Plane strain fracture toughness parameter (K _{1c} , K.s.i. $\sqrt{\text{in.}}$)	Ultimate tensile strength (UTS), K.s.i.	
	Conventional heat treat	Invention heat treat
1200.....	-----	243
75.....	-----	245
150.....	-----	248
125.....	-----	250
100.....	-----	253
680*.....	220	255
575.....	226	259
5.....	230	264
2**.....	239	286
40.....	246	-----
28***.....	264	-----

* 80 Kic's were the maximum obtained using conventional heat treat.
** 52 Kic's were the lowest obtained with invention heat treat.
*** 28 Kic's were the lowest obtained with conventional heat treat.

The foregoing table is based upon alloy AFC77, the chemical composition of which is set out in Table II.
It is readily apparent to one skilled in the art that this heat treating process applies to all high-strength stainless steel alloys.

TABLE II.—CHEMICAL COMPOSITION OF AFC77 STAINLESS STEEL

	Percent by weight	
	Minimum	Maximum
Carbon.....	.13	.17
Manganese.....	-----	.25
Phosphorous.....	-----	.010
Sulfur.....	-----	.010
Silicon.....	-----	.30
Nickel.....	-----	.25
Chromium.....	14.0	14.7
Vanadium.....	.3	.4
Cobalt.....	13.0	14.0
Nitrogen.....	.03	.06
Molybdenum.....	4.7	5.1
Iron.....	Balance	-----

- I claim:
1. A method of controlling fracture toughness in high-strength stainless steel with steps comprising:
- (a) heating to a temperature which is from 50° F. to 400° F. higher than the temperature at which delta ferrite starts to form to dissolve the large quantity of particles which would normally remain out of solution at a lower temperature.
 - (b) cooling in the furnace to a temperature which is from zero to 200° F. lower than the temperature at which delta ferrite will form to transform any delta ferrite formed in step (a) into austenite,

- (c) quenching in an oil bath and then refrigerating to a temperature of -65° F. to -120° F., and holding at that temperature to reduce the austenite by transforming it into martensite,
 - (d) tempering at temperatures between 500° F. and 1150° F.
2. A method of heat treating as set out in claim 1 wherein step (d) comprises:
- (1) tempering at about 500° F.,
 - (2) cold rolling the steel to reduce the thickness by 10 to 50%, and
 - (3) tempering at temperatures between 500° F. and 1150° F.
3. A method of controlling fracture toughness in high-strength stainless steel with steps comprising:
- (a) heating in a furnace to an austenitizing temperature of 1950° F. to 2300° F. to create a stable austenite,
 - (b) cooling in the furnace to a temperature of 1700° F. to 1900° F. to convert delta ferrite to austenite,
 - (c) quenching in an oil bath and then refrigerating to a temperature of -65° F. to -120° F. to reduce the retained austenite by transforming it to martensite,
 - (d) tempering at temperatures between 500° F. and 1150° F.
4. A method as in claim 3, wherein the austenitizing temperature is held for about 1 hour.
5. A method as in claim 3, wherein the temperature for converting delta ferrite to austenite is maintained for about 5 hours.
6. A method as in claim 3, wherein tempering comprises:
- (1) tempering at about 500° F.,
 - (2) cold rolling the steel to reduce the thickness by 10 to 50%, and
 - (3) tempering at temperatures between 500° F. and 1150° F.

References Cited

UNITED STATES PATENTS
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L. DEWAYNE RUTLEDGE, Primary Examiner
W. W. STALLARD, Assistant Examiner
U.S. Cl. X.R.
148—37, 135

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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Inventor(s) Donald Webster

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, Table I, after "parameter "(Kic," should read
-- (Kic) --; same table, first vertical row reading

1200		200
75		175
680*		80*
575	should read	75
5		65
2**		52**

Signed and sealed this 17th day of August 1971.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

WILLIAM E. SCHUYLER,
Commissioner of Patents