Characterization of Nickel Free Stainless Steel
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Abstract—Stainless steel is defined as a steel alloy with a minimum of 10.5-11% chromium content. It is produced, basically having three types of structures-ferritic, martensitic and austenitic. Generally, steels contain nickel as one of the alloy that increases its hardenability. But due to high cost and its reactivity with organic matter an alternative i.e. nickel free stainless steels are developed. High-strength austenitic stainless steels can be produced by replacing carbon with nitrogen. Nitrogen has greater solid-solubility than carbon, is a strong austenite stabilizer, potent interstitial solid-solution strengthener, and improves pitting corrosion resistance. The introduction of nitrogen causes linear increase in yield and tensile strength at room temperature. The increase in N2 concentration strengthens the austenitic steels further with the greater planar slip and higher density of deformation twin. The cold deformation of these steels later increases their hardness but at the same time decreases the ductility of these steels. So, these steels are properly heat treated to regain ductility.

Key words: Stainless steel, Nickel Free Stainless Steel

I. INTRODUCTION
Stainless steel does not stain, corrode, or rust as easily as ordinary steel. The Schaeffler diagram does evaluate the presence of austenite, ferrite, bainite and martensite depending on chemical composition and ‘proper cooling’ after pouring. The reality will always be somewhat less austenite because in the case of austenitic stainless steel cooling will be slower than required. This diagram is intersecting because, by quantifying the amount of types of structures, it does give an indication that the material will comply with the standard [2]. The development of nitrogen stainless steel with nickel as major content being replaced by nitrogen and manganese is a matter of high importance due to restricted availability and high cost of nickel.

![Schauffler Diagram][1]

Fig. 1: Schaufller Diagram [2]

Alloying with nitrogen has several advantages over alloying with carbon: (1) Nitrogen is more effective solid solution strengthener than carbon and enhances grain size [8,9]; (2)Nitrogen is a strong austenite stabilizer thus reduces amount of Ni required for stabilization; (3) Nitrogen reduces the tendency to form ferrite and martensites; (4) Nitrogen has greater solid-solubility than carbon, thus decreasing the tendency for precipitation at a given level of strengthening [10]; and (5) Nitrogen is beneficial for pitting corrosion resistance [11]. (6) Yield and tensile strengths of high-nitrogen alloys can exceed those of conventional AISI 200 and 300 series stainless steels by 200-350% in the annealed condition, without sacrificing toughness [12]; (7) Cold deformation can produce further increases in strength resulting in materials with yield strengths above 2 GPa [9].

II. NITROGEN SOLUBILITY IN LIQUID IRON BASED ALLOY
At room temperature, the solubility of nitrogen in liquid iron is 0.045 wt% at 1600 deg. C. This is a major obstacle in production [10]. It follows Sievert’s Law which states that the solubility of nitrogen is directly proportional to square root of N2 gas pressure over the melt [10,11]. However, at high pressure there is a deviation from this law because addition of Cr, Mn causes decrease in N2 solubility. Hence, nitrogen solubility in Fe-Cr-Mn steel is greater than Fe-Cr-Ni steel. Elements helping N2 solubility are Zr, Ti, V, Nb, Mn as they have strong tendency to form nitrides. Chromium significantly increases N2 solubility in liquid iron alloys with a lesser tendency for nitride formation in solid state [2].

![Sievert's Law][2]

Fig. 2: Sievert’s Law [4]

III. EFFECT OF NITROGEN ON STAINLESS STEEL
A. Strength
Interstitial element like N increase the strength of austenitic steels much more than substitutional elements like W,Mo,V,etc. Nitrogen increases the strength of austenitic steels but lowers the ductility and fracture toughness [2]. Fig shows the strengthening effect of interstitial nitrogen for a series of Fe-18Cr-13Mn-N alloys. The ultimate tensile strength and yield strength increase linearly at room temperature with increasing interstitial N content of the steel. The YS of steel at room temperature is due to solid solution hardening (Sievert’s Law).

Theoretical tensile strength can be calculated by Pickering Model [2]

\[
0.2 \text{ pct YS (MPa)} = 15.4(4.4+2 \ 3(C) +1.3(Si) +0.24(Cr) +32(N) +0.16(\delta-\text{ferrite}) +0.46d^{1/2})
\]

\[
\text{UTS} = 15.4(29+35(C) +5 \ 5(N) + 2.4(Si) +0.11(Ni) +0.14(\delta-\text{ferrite}))
\]

(\delta\text{-ferrite and d) neglected}
B. Microstructure

The noticeable microstructural features of annealed and 30% cold-worked sample are as follows:
- Austenite matrix
- Annealing twins in the annealed plate and deformation twins in the cold-worked ones
- Smaller grain size in cold-worked ones
- Small amount of scattered precipitated particles, possibly chromium nitride Cr2N and/or sigma phase
- Absence of deformation-induced martensites

Reportedly, N assists the twinning of austenite on \{111\} planes under deformation. Therefore, an increase in N concentration strengthens the austenitic steels further with the greater planar slip and higher density of deformation twin. Fig.2 depicts the microstructures of specimens subjected to different aging treatments. In specimens aged at 700 °C, 800 °C, and 900 °C, the precipitates were found along grain boundaries. In specimens aged at 800 °C, the precipitates start to grow inward austenitic grains. It is obvious that 800 °C is the most sensitive temperature to precipitation. The microstructure of specimen aged at 950 °C for 96 hour is as similar to that of the fully austenitic microstructure, which suggests that the ceiling temperature for precipitation is 950 °C, and no precipitation will occur above this temperature [5].

C. Hardness

Hardness essentially depends on the interstitial content as it was shown by Hsiao and Dulis that the effect of chromium and Manganese on hardness was minimal. The variation of hardness (Hv) with cell size (d) of discontinuous precipitation was found to follow the Hall–Petch relationship:

\[ \text{Hv} = H_{ov} + k_{H} d^{-1/2} \]

Where \( H_{ov} \) and \( k_{H} \) are constants.

D. SEM-Scanning Electron Microscopy

SEM examination is carried out on fractured specimens of the three batches. Fractographs are taken on fracture surface from different area at various magnifications ranging from 50X. The fractures of the tensile specimens are observed with the help of SEM. The fracture surface essentially consisted of dimples indicating that fracture is due to micro void coalescence which is a characteristic feature of ductile fracture [2].
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IV. EFFECT OF COLD DEFORMATION ON NITROGEN STEEL

A. Yield Strength
Cold working is an effective method for increasing the strength of austenitic steel over solid solution strengthening, since these single phase austenitic materials are not strengthened by heat treatment. It is found that increasing nitrogen concentration in a series of Fe-18Cr-13Mn-N alloys systematically increased the strength coefficient (K1), thereby increasing the ability of the austenite to be strengthened by deformation [2].

![Fig. 7: SEM fracture of specimen--(a) Annealed Condition (0.05%N, 1000X), (b) 30% reduction (0.05%N, 5000X), -(c) Annealed Condition (0.2%N, 1000X), (d) 30% reduction (0.2%N, 5000X)](image)

![Fig. 8: Yield strength vs. Cold deformation curve](image)

![Fig. 9: Curve showing decrease in ductility of specimen i.e. increase in hardness](image)

B. Hardness
Hardness is lowest for the sample which is at annealed condition and increases as sample is cold rolled. It is highest for the sample that is 30% cold rolled. The reason for this is the work hardening which takes place in the sample during cold rolling. The disadvantage of this is the decrease in ductility. Thus after cold rolling samples have to be given proper heat treatment in order to restore ductility of samples.

V. OBSERVATION
Nitrogen is a very powerful solid-solution strengthening element, and high-nitrogen austenitic stainless steels can have yield strengths exceeding those of the standard, carbon-based, austenitic grades by 200-350%. Yield strengths can be increased an additional 300% through cold working. However, high-nitrogen stainless steels are thermally metastable, and in the absence of strong nitride formers, such as Ti, V, and Nb, are prone to the rapid precipitation of Cr2N within a broad temperature regime. Due to their high contents of chromium, molybdenum, and nitrogen, these steels are highly corrosion resistant. Therefore, they do dissolve neither in human organic fluids nor in sweat and thus do not emit any ions to the human body to any measurable degree. [1]

![Fig. 10: Influence of nitrogen on the temperature sensitivity of flow stress in austenitic stainless steel](image)

VI. APPLICATIONS
Due to non magnetic property of austenite steels it is used in making household utensils. Industrial applications where high-nitrogen austenitic stainless steels may be utilized include the power-generating industry, ship building, railways, cryogenic processes, chemical equipment, pressure vessels, and the petroleum and nuclear industries.

A few of the specific applications where high-nitrogen stainless steels are either being applied or considered for use are: (1) bolt materials for high-strength and high-temperature applications in which YS values in excess of 900 MPa are required; (2) superconducting...
magnet housings which require structural alloys that can withstand the large magnetic forces of superconducting magnets, have low potential for martensites formation, high elastic moduli, low thermal and electrical conductivities, and excellent fracture toughness at cryogenic temperatures; and (3) wire ropes, springs, and railroad wheels. In medical fields, it is used for biological implants due to low reactivity with the organic fluids [1].

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