Journal of Academia and Industrial Research (JAIR)
Volume 4, Issue 3 August 2015

ISSN: 2278-5213

RESEARCH ARTICLE

Effect of Nitriding on the Mechanical Performance of AISI 4140 Steel Using Sodium nitrite at Nano Level

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Abstract

There has been attempt over the years to reduce weight and increase the strength of almost all the materials in the world. Steel is the most widely used element with extensive application in sectors like energy, transportation and medical etc. Steel being abundantly available in nature and nitriding of steel provides path for the application of steel in aviation equipments as well as structural applications. The most important advantages of nitride steels are high pitting corrosion resistant, increased strength and increased wear resistant etc. One of the most important applications of nitrided steel is its usage in biomedical instruments. Many attempts are made to replace nickel as alloying element by nitrogen. Strength and corrosion resistance, high nitrogen stainless steels are gaining importance in material science. Nitrogen can substitute nickel. Since nitrogen solubility in liquid iron at standard pressure is very low about 0.045 wt. %. In this study, an attempt has been made to enhance the solubility limits of nitrogen by using nitriding compound (sodium nitrite) at nanolevel. Flexural test is conducted on steel specimens as per ASTMA355−89 and flexural strength of the specimen can be determined. In order to increase the statistical accuracy, two specimens of same composition were selected for analysis. The deflection values obtained confirms the increase in strength as compared to plain steel specimen. An increase in strength by 71% is observed for nitrided specimens as compared to plain steel specimens. From the findings, it can be concluded that nitrided specimen shows enhanced mechanical performance as compared to plain steel beams. This increase in strength and toxic free element can be utilized for desired specific application.

Keywords: Sodium nitrite, three-point bending, nitriding, metal matrix, nitrogen gas.

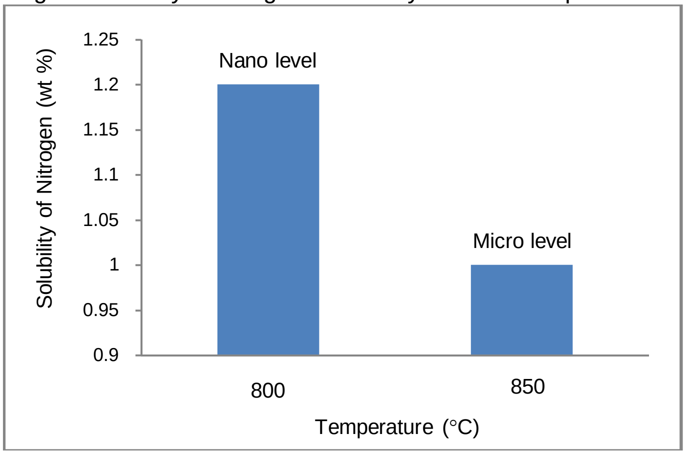
Introduction

Since many years, repeated attempts are been made to replace nickel as an expensive and scarce alloying element with nitrogen because of the strength induced on the austenitic structure of steel without compromise in strength and corrosion resistance. The cost parameters of nickel is also a limit for metallurgists to think for alternative low nickel, high nitrogen alloys, especially when their current stainless contains 12-30% Ni. Apart from economic aspects, nitrogen offers metallurgical property advances in many respects as an alloying element for stainless steels. Nickel free alloys are more suitable for biomedical application. Stainless steel alloys have superior pitting corrosion properties when nitrogen is used. Also, high nitrogen martensitic stainless steels showed improved resistance to localized corrosion (pitting corrosion, crevice corrosion and inter-granular corrosion) over their carbon containing counterparts. For an element like nitrogen, the solubility reaction in liquid iron can be generally written as:

$$2NaNO_2 \longrightarrow Na_2O + NO + NO_2$$

Sodium nitrite above 330°C evolves nitrogen gases containing oxygen at monatomic (NO) and diatomic (NO_2) levels (Feichtinger and Stein, 1999). Since steel is an alloy composed of Cr, Mn, Ni, Ti, Al, Si, Mo and V as traces of metals, some of these constituents like Cr, Mn and Ni have affinity for monatomic oxygen and others have affinity for diatomic oxygen and this affinity could be utilized to enhance the solubility limits of nitrogen in steel (Simmons, 1996) as different traces will try to imbibe the different atomic level gases. Generally, the saturation solubility limits of nitrogen closely follow Sievert's Law and are proportional to the square root of the nitrogen gas pressure above the melt. In stainless and other related alloys, deviations from the law can occur at elevated pressures, at above one atmosphere. Figure 1 shows the solubility of nitrogen in Fe alloys at standard pressure. The possible solubility limit of nitrogen in ferrous alloys at standard pressure, which is an important topic for the melting practice of high nitrogen steels, is presented in Fig. 1. Temperature difference is noticeable with usage of nano additives (Leda, 1995). A similar work of nitrogen precipitation was conducted by (Ashrafizadeh, 2003).

Fig. 1. Solubility of nitrogen in Fe alloys at standard pressure.



Considering the above facts in view, the present study focuses on increasing the nitrogen level in alloyed steels using nano scale additives by dispersing them homogeneously in the matrix leading to the enhancement of mechanical and corrosion properties.

Materials and methods

Experimental program: A small scale experiment was conducted in order to check the feasibility of idea presented. In which a hot rolled quenched bar surface nitriding was carried out.

Preparation of specimen: The properties of the $NaNO_2$ used in the present study are given in Table 1. The specimen characteristics have been mentioned in Table 2. A replica of two samples has been tested in order to increase statistical accuracy. Single point loading on 6 ft beams were carried out to check the strength of plain steel beams v/s nitrided steel beams.

Three-point load test: The mechanical performance of steel beams nitrided with $NaNO_2$ at the nano scale on the surface of steel beams was evaluated by three-point load test. Beam specimen of size 6 ft were tested by three-point loading test as shown in Fig. 2. The nomenclature used for the test specimens are mentioned in Table 3. The results of three-point load test carried on three different specimens are shown in Table 4. It is observed that the increase in load carrying capacity of nitrided steel beams as compared to plain steel beams. Hence, the flexural behaviour of nitrided steel beams is investigated. Nitrided beams were tested under flexural (three-point loading) to evaluate their mechanical properties such as strength, deflection criteria etc. and the results obtained were compared with the results of the plain steel beams.

Results and discussion

Effect of $NaNO_2$ at nano scale on nitriding of steel beams was confirmed by three-point loading test. In this case, the mechanical performance of nitrided steel beams showed optimum results as compared to un-nitrided steel beams.

Table 1. Properties of the sodium nitrite used in the present study.

Melting point	271ºC
Molar mass	68.9953 gram/mole
Appearance	White
Density	2.168 g/cm^3
Auto ignition temp	914ºF
Refractive index	1.65
Crystal structure	Trigonal
Standard molar entropy	106 Joule/mole-Kelvin
Standard enthalpy of formation	-359 KJ/mole
Gibbs free energy	-295 KJ/mole
$NaNO_2$ code	S2252

Table 2. Details of test specimen.

Quantity (wt. or number of pieces)	02
Name of material (alloy steel bars, for nitriding)	AISI 4140
Surface finish	Rough-peeled finish
Cross-sectional shape	Sharp edge square
Size	Flat: Width: 80 mm Thickness: 250 mm
Length	6 ft
Class	B
Thermal treatment	Quenched and tempered
Hardness	Brinell 288
Microstructure when desired	Permissible Free Ferrite Area,1%
Straightness	0.15
ASTM standard	A355−89
Density	7800 kg/m^3

Fig. 2. Universal testing machine used for testing specimen.

These tests helped to evaluate the nitriding effect of $NaNO_2$ at nano level on plane steel beams, which gives highest structural efficiency in terms of load carrying capacity. Figure 3 shows the test results of load v/s deflection for three point bending test.

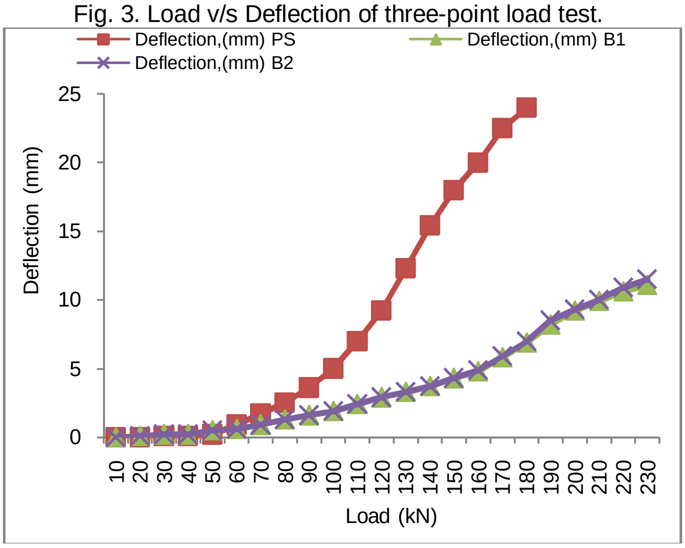
Table 3. Nomenclature of test specimen.

Sample no	Specimen reference	Constituents
1	PS	Plain steel
2	B1	Nitrided steel
3	B2	Nitrided steel

Table 4. Test results of specimen subjected to three point loading test.

Ultimate load (kN)	Deflection (mm)		
	PS	B1	B2
10	0	0	0
20	0	0.1	0.1
30	0.1	0.2	0.2
40	0.1	0.2	0.2
50	0.2	0.5	0.5
60	0.9	0.6	0.6
70	1.7	0.9	0.9
80	2.5	1.3	1.3
90	3.6	1.6	1.6
100	5	1.9	1.9
110	7	2.4	2.4
120	9.2	2.9	2.9
130	12.3	3.3	3.3
140	15.4	3.7	3.7
150	18	4.3	4.3
160	20	4.8	4.9
170	22.5	5.8	5.9
180	24	6.9	7
190		8.2	8.5
200		9.2	9.3
210		9.9	10
220		10.6	10.9
230		11.1	11.5

Fig. 3. Load v/s Deflection of three-point load test.



Conclusion

From above experiment, it can be concluded that steel beams reinforced with sodium nitrite at nano level showed optimum performance in terms of mechanical properties and this could be due to the homogeneous distribution and nitriding effect at nano level for the micro sized steel matrix and this could be also due to the reduction of the pressure and temperature required for homogeneous distribution of nitrogen gas throughout the matrix. From the graphical results, it can be observed that there is a substantial difference between load carrying capacities of plain steel beams and beams subjected to nitriding process. Since Fe-alloy being at micron level and $NaNO_2$ at nano level, there can be effective dispersion of $NaNO_2$ in Fe-alloy matrix. This process may increases the surface nitriding effect of steel beams as compared to existing methods with minimal efforts and simple methods.

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