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Effect of carbon on the hardness of ASTM A182.Gr F6NM alloy for oil and gas industries.

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Abstract:- This article presents a relationship between the hardness and the carbon content of the ASTM A182 Gr. F6NM alloy mainly used for oil and gas industries. This study was initiated because of the frequent rejections of the F6NM alloy components due to their increased hardness leading to embrittlement problems while serving applications at high temperature and pressure. The repetitive method was adopted to analyse the relationship between the hardness and carbon content, by utilizing various samples of F6NM alloys with varying compositions of carbon ranging between 0.009-0.05percent following the standard [1] and by measuring their hardness using a Rockwell hardness tester. The focus is on investigating the role of carbon in altering the hardness of the F6NM alloys as it was found that the hardness remained unchanged even after the double tempering operation. To study the exact effect of carbon on hardness, the percentage of manganese was maintained as a constant between 0.54-0.58percent. Hence, it was concluded that even though the ASTM specifications of carbon are between 0.009-0.05, the percentage of carbon has to be controlled between 0.009-0.02percent from the production of F6NM alloys in order to control the hardness as the tempering operations seemed to be ineffective for this high alloyed steel.

Keywords: - Hardness, Double tempering, Normalising, Quenching, Carbon content, F6NM

I. INTRODUCTION

For several years, the oil and gas industries have been using 13%Cr-4%Ni – type Martensitic stainless steel for the manufacture of valves, pump casings, cases, and stator parts of centrifugal compressors as forgings[3] (for example ASTM A182 Grade F6NM). For steels of this grade, the combination of low carbon content and the addition of 3.5 to 4.5% nickel produce a fine, lath martensite structure which, after tempering heat treatment, can exhibit mechanical properties that are superior to those of typical martensitic stainless steels[2]. Thus, the F6NM(ASTM A182) finds a range of application for production fluids containing CO_2 and H_2S, but it must be noted that such alloy steels are potentially susceptible to Sulfide stress corrosion cracking(SSCC) in H_2S environments particularly when hardness is high. Sensitivity to sulfide stress corrosion cracking increases at high levels of hardness that the standard NACE MR0175-ISO 15156-3 (2009) limits to a maximum of 23 HRC for applications intended for the production of oil and gas in environments containing H_2S. Attainment of such a hardness level requires careful consideration of tempering procedure.

The presence of nickel depresses the A_{c1} temperature of the steel and hence F6NM is tempered at lower temperature. Even though the tempering procedure plays a vital role in controlling the hardness, experience has shown that the production of F6NM components poses considerable difficulties in holding the hardness below 23HRC even after performing the double tempering operation. Accordingly the present investigation was carried out to examine the role of carbon with the aim of defining conditions giving minimum hardness so as to avoid embrittlement problems.

The carbon levels of the F6NM as specified under the **ASTM A 182/A 182M[1]** is 0.05% which when hardened and tempered under the given conditions will result in a hardness of 31HRC. But as NACE MR0175-ISO 15156-3 (2009) limits hardness to a maximum of 23 HRC for oil and gas industries, controlling the hardness under this limit becomes a problem if the carbon content is more than 0.02%. This was proved by employing various heat treatment cycles on different samples of F6NM alloys with carbon content varying between 0.009-0.044percent where the hardness of each sample was measured in a Rockwell scale. The gradual decrease in tensile stress as the carbon content decreases was also compared in the inspection as various mechanical properties of the sample was also studied and investigated.

II. EXPERIMENTAL WORK

The experiments were carried out on five test coupons of steel ASTM A182 Gr.F6NM identified as S1, S2, S3, S4 and S5 in Table 1, in which each of the samples had different chemical composition. The major change in the chemical composition was mainly the percentage of carbon as its effect on the hardness was the objective of study. The test coupons were subjected to a heat treatment sequence of hardening and double tempering. The hardening treatment was done at a temperature of 1050^{o}C for 4 hours, the primary tempering at

680°C for 6 hours and the secondary tempering at 620°C for 6 hours. The heat treated specimens were mechanically tested for tensile properties, ductility and hardness.

Table 1- Material Composition

Test Coupon	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
S1	0.009	0.34	0.58	0.012	0.0046	12.7	0.54	3.77	0.06
S2	0.01	0.33	0.57	0.015	0.001	12.7	0.53	3.8	0.05
S3	0.018	0.44	0.54	0.019	0.001	12.75	0.54	3.8	0.09
S4	0.043	0.45	0.756	0.020	0.006	12.22	0.538	3.69	nil
S5	0.046	0.47	0.739	0.023	0.007	12.14	0.530	3.77	nil

A. HEAT TREATMENT.

The heat treatment process was carried out in sequence with the standard procedure outlined below.

1) Hardening:

Hardening treatment consists of heating to a predetermined temperature, usually known as the hardening temperature, holding at that temperature, followed by rapid cooling for the formation of martensite[4]. F6NM is a high alloy steel and hence it air hardens.

The hardening treatment involved the following steps in sequence:

- The samples were surface cleaned.
- Slowly heated to a temperature of 1050°C.
- Holding time of 4 hours was maintained.
- Sample was placed in air for air hardening to take place.

2) Tempering:

Hardening treatment develops maximum hardness, excellent wear resistance and high strength levels in the steel. At the same time, it adversely affects the properties such as ductility, toughness and impact strength. It also imparts brittleness to steel because of the internal stress developed by quenching. Thus, steel in as-hardened state is unsuitable for service conditions. A relatively stable state can be attained by providing thermal energy to the steel. Such a process is called as tempering heat treatment which consists of heating the hardened steel below the lower critical temperature, followed by cooling in air which results in the decrease of internal stresses and reduction in degree of brittleness[4].

The tempering treatment involved two main stages, namely:

Primary Tempering:

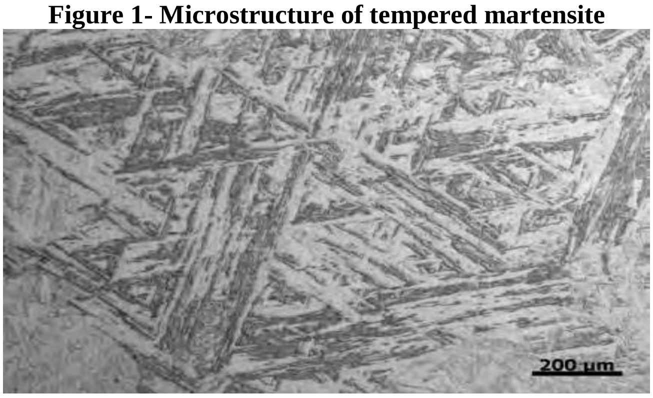
- The hardened sample was heated to a temperature of 680°C.
- Holding time of 6 hours was maintained.
- Sample was placed in air for primary tempering to take place.

Secondary Tempering:

- The primary tempered sample was heated to a temperature of 620°C.
- Holding time of 6 hours was maintained.
- Sample was placed in air for secondary tempering to take place.

The double tempering operation resulted in a microstructure of tempered martensite with broken martensite needles as represented in figure 1 with the properties of reduced hardness and improved ductility.

Figure 1- Microstructure of tempered martensite



B. MECHANICAL TESTING:

Heat-treated samples of F6NM were tested for various mechanical properties. For hardness testing, oxide layers etc formed during heat treatment were removed by stage-wise grinding. Average *HRC* readings were determined by taking five hardness readings at different positions on the samples, using a digital Rockwell hardness tester. For tensile properties, standard tensile specimens were loaded into a universal testing machine hooked up to a data logger. Load-elongation data were recorded and converted into stress-strain graphs. Ultimate (tensile) strength, yield strength and ductility (% elongation) were determined from these graphs, reported values being average of three readings. All testing was done in accordance with ASTM standard test procedures. The values are tabulated in table 2.

Table 2-Mechanical properties

Test coupon	Yield Strength(psi)	Tensile Strength(psi)	Temp	A%	Z%	Hardness (HRC)
S1	85000	105000	RT	24	78	22
S2	82000	109000	RT	27	77	22.3
S3	84000	112000	RT	25	77	23
S4	93000	118000	RT	24	66	26
S5	95000	125000	RT	26	67	29

III. RESULT AND DISCUSSIONS.

The five test coupons of F6NM that were subjected to the heat treatment process were studied for their mechanical properties so as relate them to the carbon content. As tabulated in table 3, the mechanical properties are compared with the carbon content as follows.

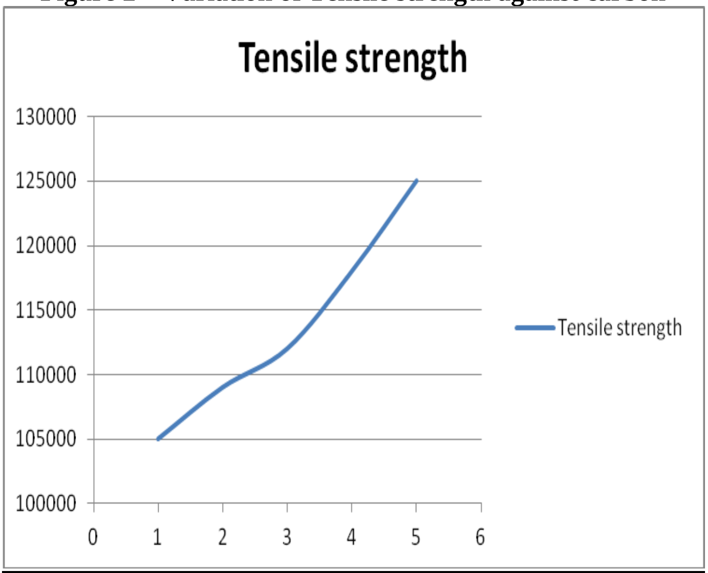
Table 3: Comparison table

Test coupon	%C	Yield stress(psi)	Tensile stress(psi)	Hardness (HRC)
S1	0.009	85000	105000	22
S2	0.01	82000	109000	22.3
S3	0.018	84000	112000	23
S4	0.043	93000	118000	26
S5	0.046	95000	125000	29

A. ULTIMATE TENSILE STRENGTH:

The variation of tensile strength against the carbon content is shown in figure 2. It can be seen that as the carbon content of F6NM increases, the tensile strength also increases. This is because Carbon increases the stress that is needed to deform the steel by stopping the dislocation movements. With higher carbon content, the tensile stress of an F6NM alloy is three times more than its yield stress.

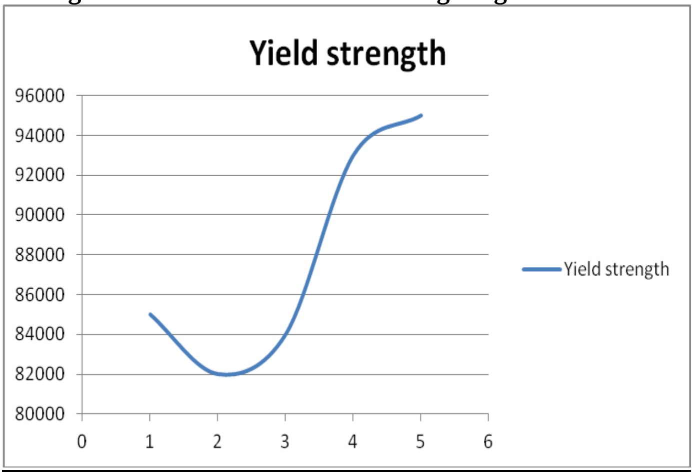
Figure 2 – Variation of Tensile strength against carbon



B. YIELD STENGTH:

The variation of yield strength against the carbon content is shown in figure 3. Increasing the dislocation density increases the yield strength which results in a higher shear stress required to move the dislocations. The reduction in the yield strength at certain points may be due to the microstructural changes mainly because of grain coarsening. In general, more the amount of carbon more will be the yield strength.

Figure 3 – Variation of Yield strength against carbon

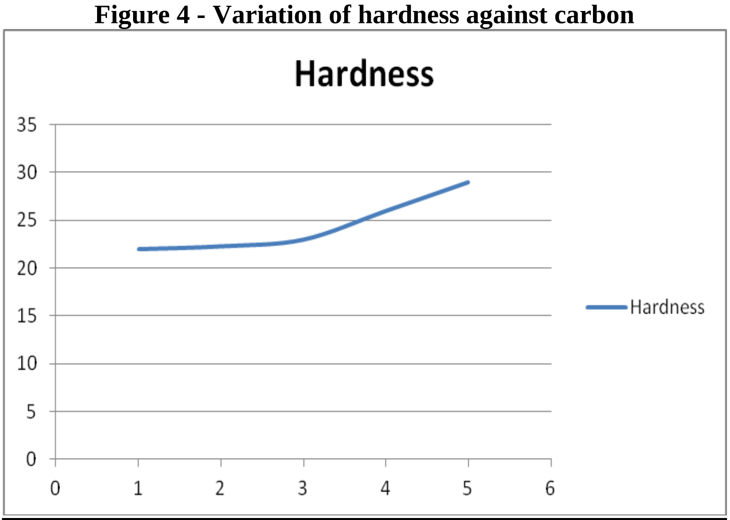


C. HARDNESS:

The variation of hardness against the carbon content is shown in figure 4. The carbon present in F6NM alloy will greatly influence the formation of martensite which plays a major role in increasing the hardness of the alloy. The martensite needles that are formed during hardening have high hardness and extreme brittleness which are reduced during the tempering operation by breaking the martensite needles to form tempered martensite.

The hardness of F6NM alloy is very sensitive to the carbon content, as very small changes in the carbon content will result in an enormous change in the hardness. From the test coupons being inspected, the samples S1, S2 and S3 with carbon contents 0.009, 0.01 and 0.018 respectively has the hardness range below 23HRC thereby meeting the NACE MR0175-ISO 15156-3 (2009) hardness limit for oil and gas industries. The samples S4 and S5 have higher carbon content i.e. above 0.02%, which reproduced hardness levels exceeding 23HRC.

Figure 4 - Variation of hardness against carbon



IV. CONCLUSION.

The following conclusion has been drawn from the experimental result and discussions made. In this work, five samples of F6NM with varied carbon levels were inspected. The samples with carbon less than 0.02% had the hardness limit meeting the NACE MR0175-ISO 15156-3 (2009) standards i.e. less than 23HRC for oil and gas industries. The samples with carbon more than 0.02% had hardness greater than 23HRC even after performing the double tempering heat treatment. The double tempering treatment was ineffective to the samples with higher carbon content in bringing down the hardness below 23 HRC.

The ASTM A182 limits the carbon content of F6NM grade to a maximum of 0.05%. Even though the standard specification for carbon is up to 0.05%, the carbon percent has to be limited to 0.02 % to achieve the NACE MR0175-ISO 15156-3 (2009) standard for hardness in oil and gas industries. Hence, for the acceptance of F6NM alloy in oil and gas industries, the hardness has to be less than 23HRC and such hardness range will be achieved only if the carbon percentage is controlled below 0.02% from the production of the F6NM alloy and cannot be controlled in tempering operations if the carbon content exceeds the critical limit.

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REFERENCES

[1]. ASTM Designation: A 182/A 182M – 02., Standard specification for forged or rolled alloy – steel pipe flanges, forged fittings, and valves and parts for High – Temperature service.

[2]. J. Svoboda, Literature Review of Martensitic Stainless steels, Steel Founders' Society of America, 1982

[3]. Raymond A., Higgins B., 1985, Properties of Engineering Materials. Hoodder and Stonghton.

[4]. T.V.Rajan, C.P. Sharma and Ashok Sharma, "Heat treatment – Principles and Techniques" second edition, pp 87-95

[5]. F6NM (UNS S42400), OILFIELD MODIFIED DATA SHEET , Special quality alloys.