Strength, Corrosion correlation of thermochemically treated low carbon value-added steel

Somnath Mukherjee[1], B Duari[2] and P. K. Mitra[3]

[1,]Somnath Mukherjee, M.Tech., Department of Metallurgical & Material Engineering, Jadavpur University, Calcutta, India.

[2,]B. Duari, Ph.D (Engg), NACE Corrosion & Protective Coating Specialist, SSPC Protective Coating Specialist. Presently Managing Director of Lalita Infraprojects Pvt. Ltd., Mumbai, India.

[3,]Prof. P. K. Mitra, Ph.D (Engg), Department of Metallurgical & Material Engineering Jadavpur University, Calcutta, India.

Abstract:

In recent times it is very difficult to get only low carbon plain carbon steel. There are always some alloying elements associated with it and are known as value added steel. The effects of different types of chemical heat treatment on such steels have been studied to evaluate how far these steels can be used in those applications where high surface hardness and good corrosion properties are required.

I. INTRODUCTION

Thermo chemical treatment enables hard and wear resistant outer surface in ductile and tough steels. Of the three methods of carburizing, viz., pack, liquid and gas, liquid carburizing is one the most commercially practiced carburizing process. In this process carburizing occurs through molten cyanide (CN) in low carbon cast steel pot type furnace heated by oil or gas. Bath temperature is maintained between 815^oC and 900^oC. The bath surface is covered with graphite or coal to reduce radiation losses and excessive decomposition of cyanide. Besides sodium or potassium cyanide, the bath contains sodium and potassium chlorides and barium chloride, which act as activator[1]. Nitriding is done in a molten salt bath employing a temperature range of 510^oC to 580^oC.Unlike liquid carburizing and cyaniding, which employs baths of similar compositions, liquid nitriding is a sub critical case hardening process; thus processing of finished parts is possible because dimensional stability can be maintained. Also, liquid nitriding adds more nitrogen and less carbon to ferrous materials than that obtained through higher-temperature diffusion treatments[2]. While carburizing and nitriding have their respective applications other combinations of these two processes are carbonitriding and nitrocarburizing[3], each having a few characteristic applications of their own. All these processes are one-step process where depending upon selection of processing parameters there will be variations in degree of penetration of carbon and nitrogen in the case. In the present work effect of nitriding after carburizing and vice a versa on strength and corrosion properties on value added low carbon steel has been studied.

II. EXPERIMENTAL

Composition of the value added low carbon steel used for experiments is given in table1. Thin samples of 3m thickness were pack carburized at 950^oC and 900^oC in a steel box by taking charcoal powder and $BaCO_3$ in the ratio 9:1 by weight for 10 hours. Nitriding of the samples was done at 560^oC for 8 and 16 hours in liquid nitriding bath containing 96.5% NaCN, 2.5% Na_2CO_3 and about 1% NaCNO. Before nit riding, the samples were preheated to 300^oC for 45 minutes. A few carburized samples were nitrided while a few nitrided samples were carburized as per the details given in table2.

Tensile testing of flat specimens of thickness 3mm was done in UTM INSTRON machine using a ramp rate of 0.6 mm/min. Tensile and Microhardness data are given in table 3. To assess of surface modification due to the chemical heat treatment micro hardness rather than macro hardness were taken. Corrosion rates of the samples in NACE solution were experimentally found by conducting potentiostatic polarization tests using three-electrode system. Tafel extrapolation method was employed to estimate corrosion rates. Corrosion data are given in table 4. Microstructures of the samples are given in figures 1 - 12. XRD of the samples were done using Ultima II of Rigaku to identify the different microconstituents. The summery of XRD analysis is given in table 5. SEM was done to see the topographical changes that resulted after the different treatments. SEM photographs are given in figures 13 –18.

III. DISCUSSION

Amount of pearlite and carbides increased with carburizing temperature (figs.2 - 3) and grain refining is observed with nitriding time (figs. 4 - 5). Nitriding after carburizing causes some amount of decarburizing (figs 6 – 9) but figs. 6 - 7 exhibits better nitriding, which are carburized at 950^{o}C. Similarly, carburizing after nitriding results in denitriding (figs. 10 – 12). However carburizing of samples, which were nitrided for longer time, shows somewhat better carburizing. Table 5 reveals that many carbides, Fe_2C and FeC and Fe_3N formed on the case. Traces of few metal oxides and oxalates were also detected which proves that the surface of the specimen was oxidized in the process of carburizing. But no significant oxides could be detected in nitrided samples. Surface topography (figs.13 - 18) shows a wide variation due to formation of carbides and nitrides. Carburized followed by nitrided samples showed homogeneous structure.

Microhardness data as given in table 3 shows that the surface hardness of nitrided samples is higher than those of carburized and as received samples. Surface hardness of carburized samples is higher than that of mild steel. The increase in microhardness is due to the diffusion of carbon and formation of pearlite and various carbides as is seen for microstructures of carburized and grain size reduction in nitrided samples respectively. Surface hardness increased when the samples were nitrided after carburizing due to reduction in grain size and also due to formation of nitrides. However, microhardness of the samples decreased when the nitrided samples were further carburized. The decrease is due to removal of nitrided layer and formation of pearlito-carbidic matrix. The microhardness of the sample that was carburized at 950^{o}C followed by nitriding for 16 hours is highest due to large amount of pearlite and cementite formed and also due to grain refinement. Surface hardness as high as 612.4 HVN is obtained which is comparable to materials with very high hardness.

From Table 2 it is seen that tensile strength increases after carburizing, nitriding and combination of two due to diffusion of carbon and nitrogen at the surface but ductility decreases as less time is required for fracture as compared to the as received sample. The tensile strength of nitrided samples was highest and their ductility were lowest. The as received sample and carburized sample undergo ductile failure showing good amount of necking. In contrast the nitrided sample shows brittle failure. Percentage elongation data also supplement this. The tensile strength of nitrided samples decrease but ductility increases after further carburizing, as the surface is denitrided. The tensile strength of carburized samples increases after further nitriding but ductility decreases. Carburized samples followed by nitriding showed best tensile properties. This is probably due to the development of right combination of pearlitic carbide and nitride. Carburized at 950^{o}C followed by nitriding for 16 hours gives highest tensile strength and ductility was more than that of just nitrided sample.

From the E_{CORR} and I_{CORR} values as estimated by Tafel extrapolation method and presented in table 4 it can be seen that corrosion rate of carburized samples was lower than that of mild steel. Corrosion rate of nitrided samples are lower than the carburized samples. Between the carburized samples corrosion rate of the sample carburized at lower temperature was found to be even lower. Similarly corrosion rate of the sample nitrided for smaller length of time is lower. Corrosion resistance property of the sample that was nitrided followed by carburizing is found to be best. Where as samples those were carburized followed by nitriding gives poor corrosion resistance but better than just carburized or nitrided samples. Decrease in corrosion resistance in nitrided samples is due to the formation of Fe_3N and further decrease of corrosion resistance when nitrided samples are carburized is due to the formation of Fe_3N and Fe_2C. Poor corrosion resistance of carburized samples is due to the oxidation of the surface. Grain refined structure of just nitrided samples is responsible for poor corrosion resistance.

CONCLUSION

1. Carburized samples followed by nitriding show better tensile property, better strength and ductility retained significantly.
2. Corrosion resistance of samples those were nitrided followed by carburizing were superior.
3. Optimum combination of all the properties for the treatment, which comprised of Carburizing at 950^{o}C followed by nitriding for 16 hours.

REFERENCES

[1.] Azaroff, Introduction to Solids, TMH, 1960/77, pages 187-203
[2.] Knowledge Article, http//www.key-to-steel.com
[3.] APT Materials Handbook, TPO-P00-MDD-X-00001, 20001

Table 1 Composition of the sample

Sample No	Treatment
1	Mild steel
2	Carburized 950° C for 10 hrs
3	Carburized 900° C for 10 hrs
4	Nitrided 16 hrs at 550 °C
5	Nitrided 8 hrs at 550 °C
6	Carburized at 900°C followed by Nitrided 8 hrs
7	Carburized at 900°C followed by Nitrided 16 hrs
8	Carburized at 950° C followed by Nitrided 8 hrs
9	Carburized at 950° C followed by Nitrided 16 hrs
10	Nitrided for 8 hrs followed by Carburized at 900° C
11	Nitrided for 16 hrs followed by Carburized at 900° C
12	Nitrided for 8 hrs followed by Carburized at 950° C
13	Nitrided for 16 hrs followed by Carburized at 950° C

Elements	C	Si	Mn	P	S	Cr	Mo	Ni	Balance iron
Percent Composition	0.1183	0.019	0.902	0.0192	0.0007	0.0432	0.0158	0.0294	98.591

Table 2 Treatment Details

Table 3 Mechanical Properties

Sl. No	Sample	UTS (kN/mm^2)	Yield strength (kN/mm^2)	% elongation $((L-L_0)/L_0))$	Microhardness In HVN
1	As received	0.61	0.52	12.2	254.5
2	Carburized 950° C	0.63	0.50	5.75	311.5
3	Carburized 900° C	0.62	0.44	5.82	324.8
4	Nitrided 16 hrs	0.80	0.75	1.40	410.5
5	Nitrided 8 hrs	0.78	0.72	1.35	475.4
6	Carburized at 900°C followed by Nitrided 8 hrs	0.53	0.51	2.24	539.2
7	Carburized at 900°C followed by Nitrided 16 hrs	0.55	0.52	3.16	596.5
8	Carburized at 950° C followed by Nitrided 8 hrs	0.56	0.53	3.42	596.2
9	Carburized at 950° C followed by Nitrided 16 hrs	0.80	0.76	1.82	612.4
10	Nitrided for 8 hrs followed by Carburized at 900° C	0.64	0.49	3.45	408.2
11	Nitrided for 16 hrs followed by Carburized at 900° C	0.68	0.51	2.52	441.9
12	Nitrided for 8 hrs followed by Carburized at 950° C	0.66	0.50	2.91	426.4
13	Nitrided for 16 hrs followed by Carburized at 950° C	0.70	0.52	2.30	479.9

Table 4: Corrosion Data

Sl. No	Sample	I_{CORR} IN mA/sq.cm	E_{CORR} in volts vs SCE
1	Mild steel	0.00800	-2.05
2	Carburized 950° C	0.00310	0.50
3	Carburized 900° C	0.00220	0.40
4	Nitrided 16 hrs	0.00032	0.39
5	Nitrided 8 hrs	0.00030	0.40
6	Carburized at 900°C followed by Nitrided 8 hrs	0.00029	0.32
7	Carburized at 900°C followed by Nitrided 16 hrs	0.00025	0.24
8	Carburized at 950° C followed by Nitrided 8 hrs	0.00026	0.22
9	Carburized at 950° C followed by Nitrided 16 hrs	0.00028	0.23
10	Nitrided for 8 hrs followed by Carburized at 900° C	0.00018	0.10
11	Nitrided for 16 hrs followed by Carburized at 900° C	0.00026	0.12
12	Nitrided for 8 hrs followed by Carburized at 950° C	0.00020	0.18
13	Nitrided for 16 hrs followed by Carburized at 950° C	0.00028	0.13

Table 5: XRD Data

Treatment	Peaks observed
As Received	α-Fe, FeC
Carburized 950º C	α-Fe, FeC, $C_6Fe_2O_{12}$, FeO_2CO_3
Nitrided 16 hrs	α-Fe, Fe_3N, Iron Manganese Nitricle
Carburized 950º C Nitrided 16 hrs	α-Fe, Fe_3N, Fe_2C
Carburized 950º C Nitrided 8 hrs	α-Fe, Fe_3N, Fe_2C, FeC
Nitrided 16 hrs Carburized 950º C	α-Fe, FeO_2CO_3, Iron Manganese Nitricle, Fe_2C

Microstructures of Different sample

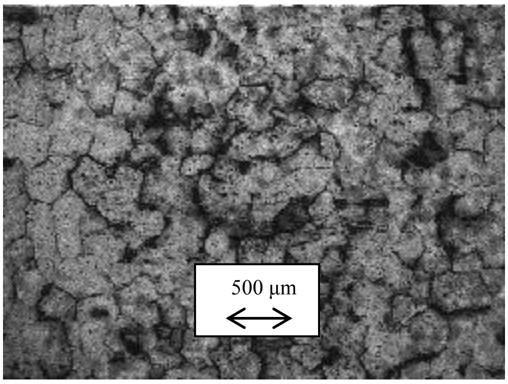

Fig 1. As Received

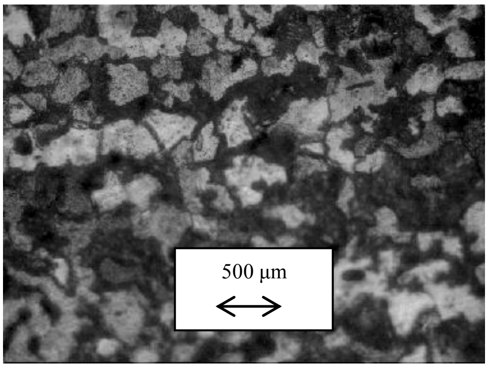

Fig 2.Carburized 900˚C

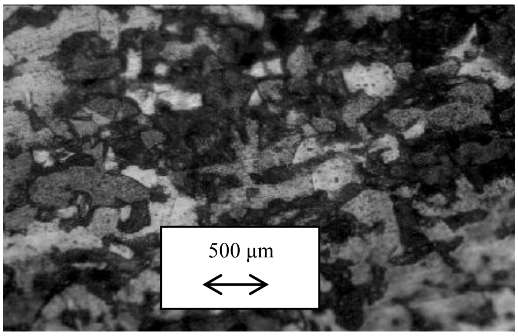

Fig 3.Carburized 950˚C

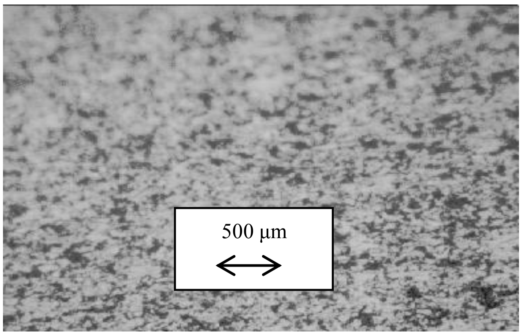

Fig 4.Nitrided 16 hrs

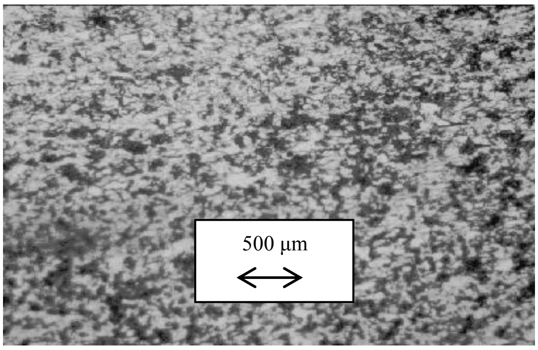

Fig 5.Nitrided 8 hrs

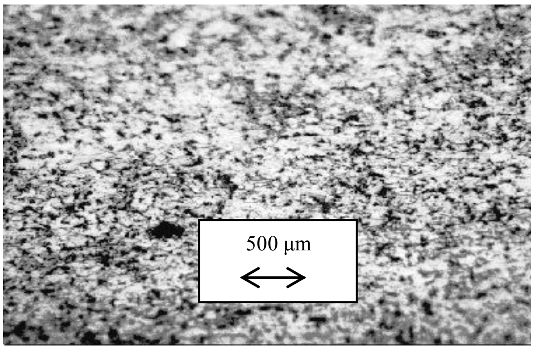

Fig 6. Carburized 950˚C Nitrided 16 hrs

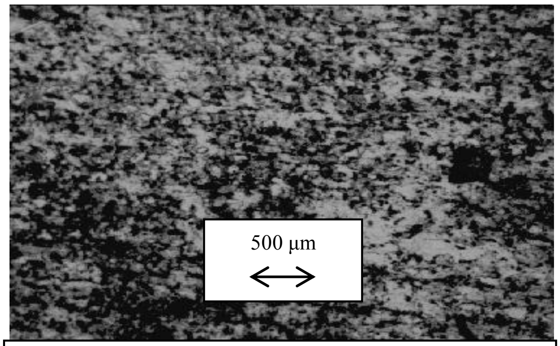

Fig 7. Carburized 950˚C Nitrided 8 hrs

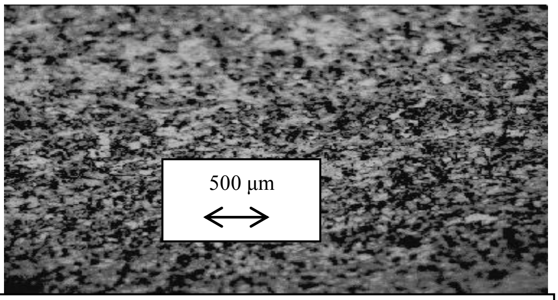

Fig 8.Carburized 900˚C Nitrided 16 hrs

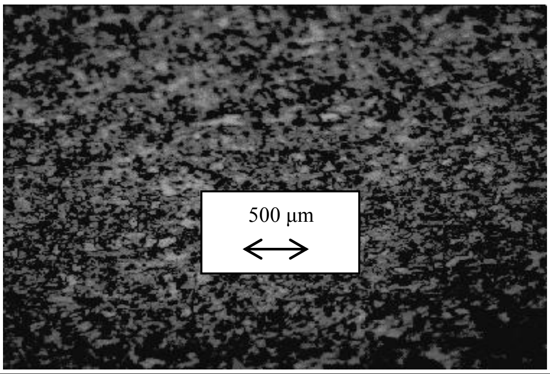

Fig 9.Carburized 900˚C Nitrided 8 hrs

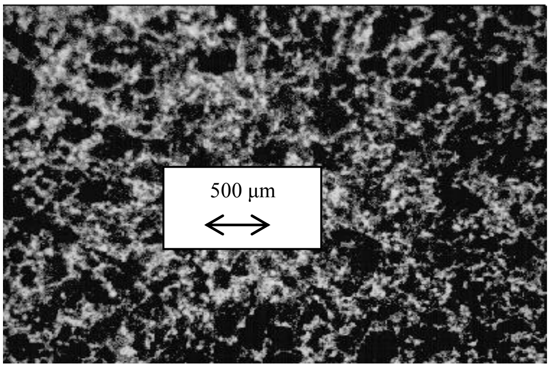

Fig 10 Nitrided 16 hrs Carburized 950˚C

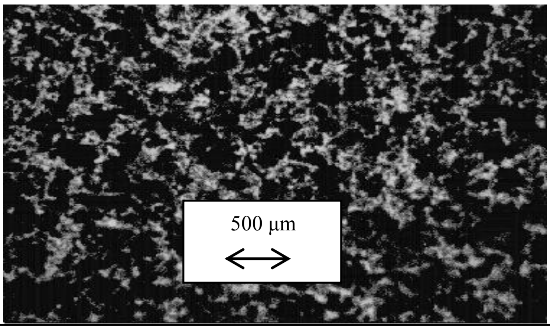

Fig 11 Nitrided 16 hrs Carburized 900˚C

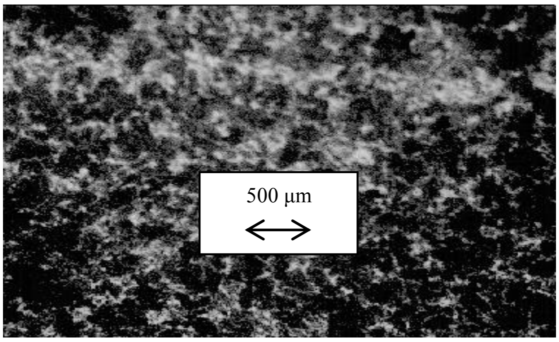

Fig 12. Nitrided 8 hrs Carburized 950˚C

SEM photographs

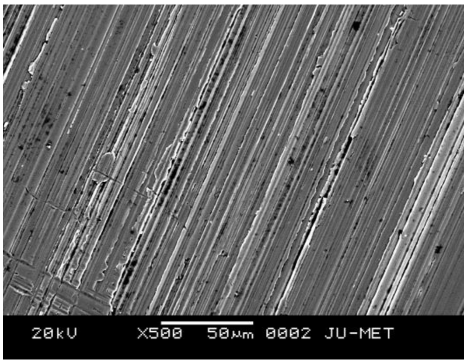

Fig-13 Mild steel 0.2%C

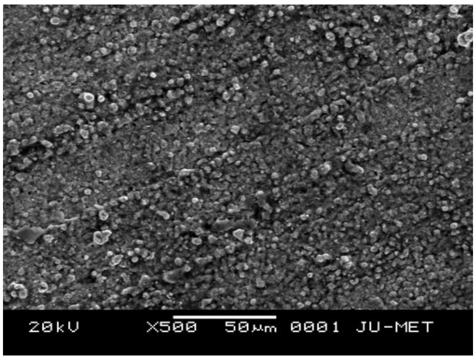

Fig-14 Carburized 950° C

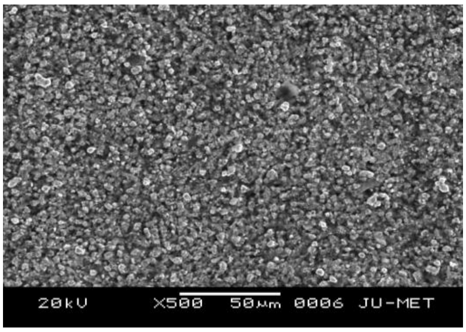

Fig-15 Carburized 950°C Nitrided 8

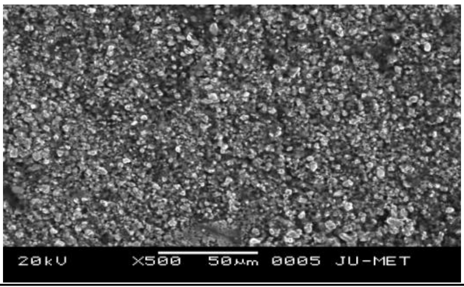

Fig-16 Carburized 950°C Nitrided 16 hrs

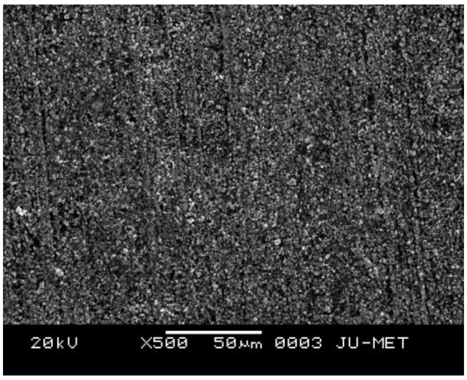

Fig-17 Nitrided 16 Hrs

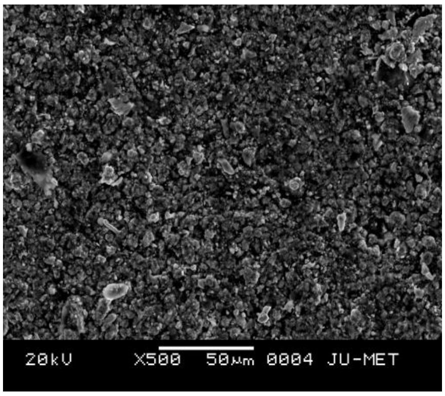

Fig-18 Nitrided 16 Hrs Carburized 950°C