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Influence of Processing Temperatures on Surface Characteristics of AISI 1045 Steel

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***Abstract*: By using low temperature plasma nitro carburizing over the surface of AISI 1045 steel was investigated through the effect of processing temperatures. The carbon enriched layer below the nitrogen enriched layer was found in the resultant dual layer structure. The surface hardness and thickness of the layer have increased to about $HV_{0.05}$ 1000 and 20 µm by increased temperature respectively. Improved corrosion resistance prevailed, while treating the specimen at 400 °C when it was compared to the non treated steel. The formation of Cr_2N affects the corrosion resistance property when the specimens were treated above 430 °C**

Key words: Hardness; corrosion resistance; AISI 1045 steel; low temperature plasma nitro-carburizing.

I. INTRODUCTION

AISI 1045 steel in the austenitic condition has low hardness, wear resistance and poor friction, but it possesses good corrosion resistance in different environmental situations. To improve surface hardness and wear resistance of 1045 steel, several experiments have been made for the past decades. Surface hardness, wear and corrosion resistance and fatigue strength can be significantly improved by a thermo chemical process named plasma ion nitriding. The specimen will lose its corrosion resistance property, when it is heated above 500 °C due to the presence of chromium nitrides. It can be rectified by providing low temperature plasma treatment over its surface.

AISI 1045 steel contains nickel, manganese and nitrogen. In order to produce austenitic stainless steel, stabilizers such as copper, nitrogen and cobalt are added. These steels became popular in the early 1950s. The main objective of the addition of nitrogen is to stabilize the austenite against the formation of ferrite at elevated temperatures and against formation of martensite at low temperatures. Normally, manganese has an effect on increasing the solubility of nitrogen in the austenite phase. It has been found that the alloying of copper leads to enhanced cold forging properties [1]. Low-temperature plasma nitriding, carried out at temperatures below 450 °C for up to several tens of hours, produces a nitrogen-enriched layer up to about 20 µm in thickness [2−6]. Excellent corrosion resistance and high hardness possess face-centered cubic (FCC) lattice in the nitrogen-enriched layer. Due to minimum thickness, poor toughness and high hardness of the nitrided layer, a low-load bearing capacity can be encountered. So as to improve the weakness, small amount of methane (CH_4) may be added.

Introduction of both nitrogen and carbon atoms over the steel surface in austenite condition produced uniform thickness of nitrogen enriched layer, which improves the hardness, resistance to corrosion and enhanced load-bearing capacity, when it is compared to ordinary nitride layer [2−6]. Only few works have been done on 200 series steel, compared to that of 300 series. Hence it is more forcussed in this paper to optimize the condition of 200 series steel to be

recommended for industrial applications. The present work is dealt with the effect of temperature to characterize the layered surface developed on AISI 1045 stainless steel in the austenitic condition with the aid of plasma nitro-carburizing.

II. EXPERIMENTAL

The suitable material of AISI 1045 steel was selected for this research. The dimension of sample dies were 20mm diameter and 5mm height respectively. After cleaned and polished, the samples were loaded into the pulsed plasma ion nitriding system. By closing the vacuum chamber and pumped down to 6.65Pa further cleaning the surface at about 300^0C for 40mins by applying a voltage of 350V and pulse duration of 135s and 15s to carry out the plasma nitro-carburizing process. The temperature ranges in between 300^0C and 460^0C for near about 15h discharge a gas mixture of nitrogen, hydrogen and methane.

Then evacuation was done in the vacuum chamber after

Table 1 Chemical composition of AISI 204Cu austenitic stainless steel (mass fraction, %)

Fe	C	Mn	Cr	Ni	Mo
Bal.	0.034	8.3	16.03	1.78	0.12
Si	Cu	N	P	S	
0.43	2.01	0.15	0.031	0.0022	

treatment to cool the sample in room temperature. The samples treated by plasma were undergone for metallographic examination and determination of micro hardness. Etching was done on the polished cross sectional surface with special reagents containing 20% H_2O, 30% HNO_3 and 50% HCl. The microstructure of nitro-carburizd layers were observed with the help of optical microscope. The phase formation over the plasma treated surface was analyzed by D/Max-200 X-ray diffractometer. Vickers Hardness Tester (Mitutoyo) was used by applying 50gm of indentation load and duration of 15s to measure the micro hardness.

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III. RESULTS AND DISCUSSION

The X-ray diffraction patterns obtained from the hardened layer through a processing temperature of 300−460 °C at a pressure of about 5.32 × 10^2 Pa for a time interval of 15 hours is indicated in the figure 1. The diffraction peaks are shifted from the treated surfaces to lower angles with improving treatment temperatures. This shows the addition of carbon and nitrogen atoms into face centered cubic structure leads distortion and expansion of lattice. It produces new phases as nitrogen enriched in the surface region and a carbon enriched beneath the nitrogen enriched layer.

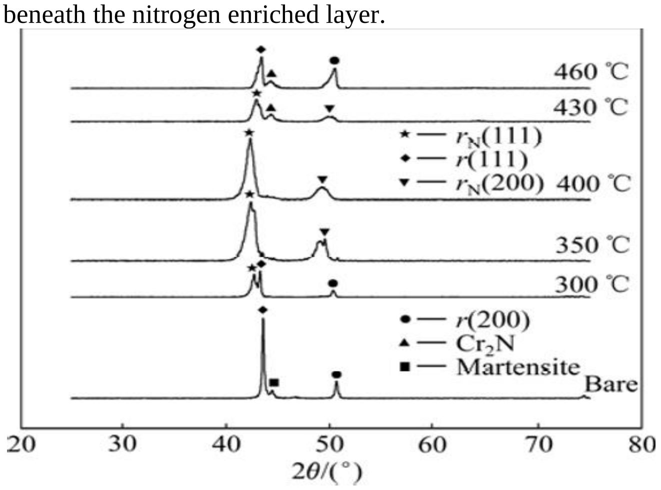

Fig. 1 XRD analysis of nitro-carburized layers formed on AISI 1045 steel at different treatment temperatures

It reveals that the controlled diffusion process leads to bigger amounts of carbon and nitrogen atoms with higher temperature treatment. In other part, the movement of diffraction peaks to angle that are in a higher mode, when it is compared with the specimen treated in 400°C .The generation of Cr_2N in the nitrogen enriched layer reduces distortion and expansion of lattice, by releasing nitrogen atoms. The phase quality can be improved by increasing the treatment temperature up to 460°C. The various profiles of carbon and nitrogen concentration obtained for different temperatures are illustrated in figure 2.

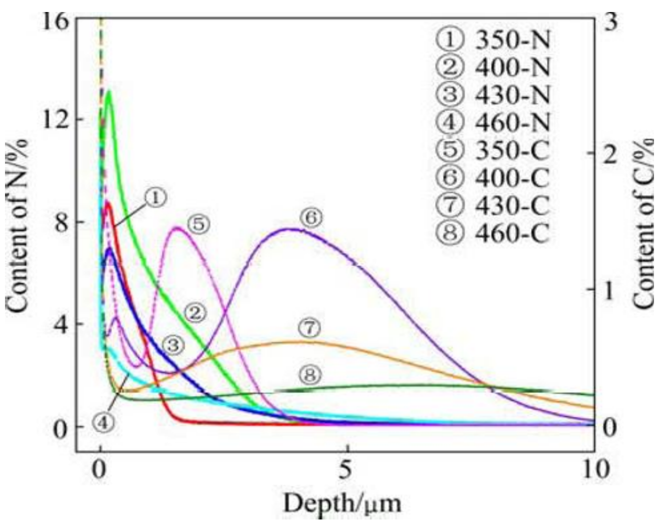

Fig. 2 Contents of carbon and nitrogen profiles of nitro-carburized layers produced on AISI 1045 steel at several ranges of temperature

The obtained dual-layer structure is an evident of high carbon content below the enriched nitrogen content. By raising temperature up to 400^0C increases the carbon and nitrogen concentrations in the depth and surface of penetration. This reveals at this particular temperature, the rate of diffusion of carbon and nitrogen atoms towards the inner part of the steel is higher than the supply rate of atoms to surface from plasma. In higher temperatures, the rate of penetration of carbon and nitrogen atoms into the substrate materials will be quit more. In austenite, the diffusion rate of carbon is faster than nitrogen. The improved solubility of nitrogen increases the level of nitrogen in the surface and pushes the carbon atoms to the lower part of the hardened layer, thus it concludes minimum level of carbon in the nitrogen enriched layer. Thus the low temperature nitriding and carburizing processes are an integration of plasma nitro-carburizing process.

In figure 3, it is revealed about the cross sectional morphology of AISI 1045 steel. The hardened layer shows the enrichment of carbon and nitrogen concentration measured with the help of GDS. The XRD analysis confirmed the precipitation of Cr_2N, that are observed in the nitrogen enriched layer at a temperature of above 430^0C. It is also clear that the hardened layer is resistant to the etchant (30% HNO_3 + 50% HCl + 20% H_2O, volume fraction) due to their bright appearance under an optical microscope, implying their good corrosion resistance compared with the substrate material [7−13].

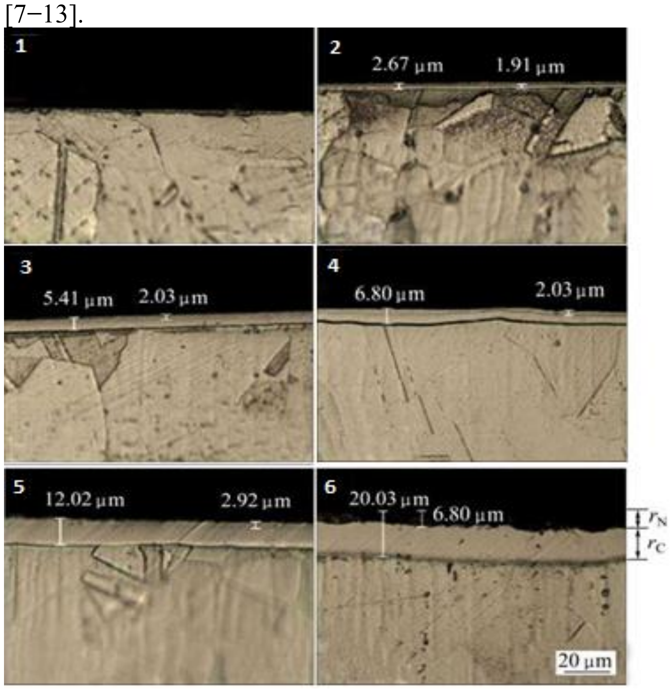

Fig. 3 cross sectional morphology of nitro-carburized layers formed on AISI 1045 steel at different ranges of processing temperatures: (1) 300 °C; (2) 350 °C; (3) 380 °C; (4) 400 °C; (5) 430 °C; (6) 460 °C

The precipitation of chromium nitride decreases corrosion resistance. By increasing the temperature of treatment the thickness of the hardened layer can be increased. Surface hardness and thickness of nitro-carburized layer are a function of treatment temperature under a constant time of 15 hours, is illustrated in figure 4.

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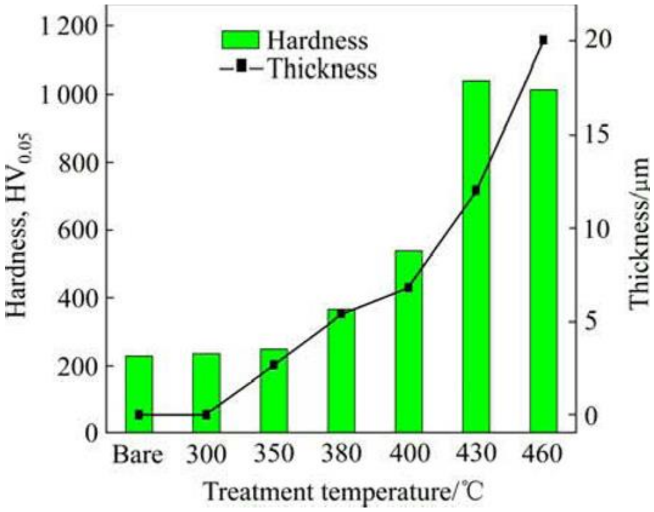

Fig. 4 thickness and Surface hardness of nitro-carburized layers formed on AISI 1045 steel at different processing temperatures

By selecting a minimum indentation load of 15 gram is used to reduce the effect of substrate material owing to minimum thickness of nitro carburized layer. The hardness of surface layer increases correspondingly to the thickness of the layer. The addition of interstitial atoms of hydrogen and carbon into FCC austenitic stainless steel leads to the distortion and expansion of lattice. Also it creates possibility to generate internal stress that are responsible for retarding the dislocation motion and increases the surface hardness. The obtained hardness of the surface has touched up to $HV_{0.05}$ 1000, that is four times more than the untreated sample ($HV_{0.05}$ 230).

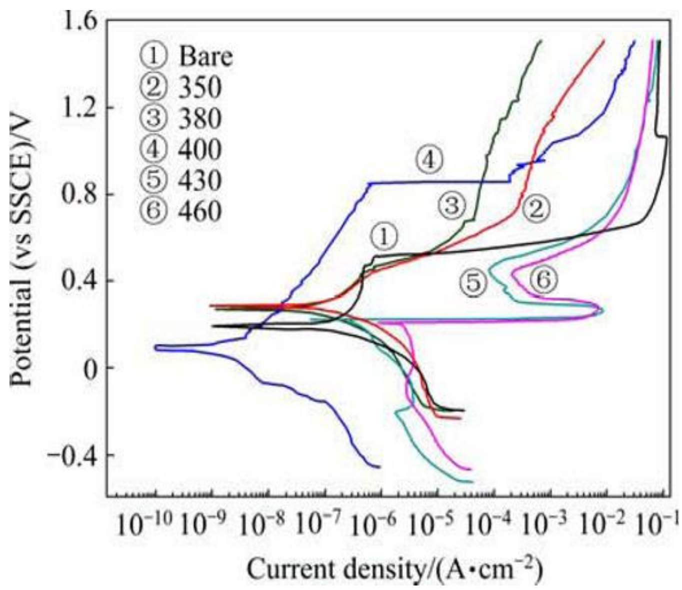

Fig. 5 polarization curves of nitro-carburized layers at various processing temperatures

The polarization curves of the layers in a 3.5% sodium chloride solution are shown in figure 5. By treating the specimen at 400^0C proportionately reduces the corrosion density. A possible mechanism for the enhancement in corrosion resistance due to nitrogen supersaturation in austenite is that the presence of high concentration of nitrogen on the surface enhances the corrosion resistance by the increase of pH associated with the formation of NH $^{+}$ ($N + 4H^{+} + 3e^{-} \rightarrow NH^{+}$) in the acid pits, resulting in increasing the passivation ability and retarding the corrosion rate [14−15]. When the specimen is treated at 400^0C, it registers a lower amount of current density and higher pitting potential to about 300mV, with an improvement in corrosion resistance.

Then testing to a potential of about 1500mV, there was no pitting found on the surface, at the same temperature of 400^0C.

IV. CONCLUSIONS

1. The dual-layer structure obtained, comprising nitrogen enriched layer over the carbon enriched layer, leading to increased surface hardness and corrosion resistance. By applying low temperature of 400^0C provides a precipitation-free sub layers with austenite structure.
2. By increasing the temperature of treatment, it produced a significant layer thickness and surface hardness of 20 µm and $HV_{0.05}$ 1000 respectively. Also it was found a reduction in corrosion resistance, when it was treated at 430^0C due to the formation of Cr_2N in the nitrogen enriched layer.

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