Quest Journals
Journal of Research in Mechanical Engineering
Volume 10 ~ Issue 1 (Jan. – Feb. 2024) pp: 01-06
ISSN(Online):2321-8185
www.questjournals.org

Research Paper

Enhancing Material Properties of ASTM 430 Steel through ARCOR Nitrocarburizing Process: Microstructural Analysis and Surface Characteristics

Satpal Singh and Anil Jindal
Department of Mechanical Engineering, GZSCCET, Maharaja Ranjit Singh Punjab Technical University, Bathinda (Pb) India-151001

Abstract
This study investigates the Nitrocarburizing process (ARCOR) applied to ASTM 430Steel, with a focus on understanding the microstructural changes, surface hardness, and surface roughness induced by the treatment. A compound layer and a diffusion zone were identified as distinct regions on the steel surface during experiments. There was a significant difference in hardness between the compound layer and the base metal, but the difference decreased beyond the compound layer. Additionally, the post-oxidation process led to highly porous surfaces, contributing to notably high surface roughness values. The experimental conditions for Sample C achieved optimal micro-hardness values based on the design of the experiment and relatively lower wear resistance, with maximum Nitrocarburizing time, temperature, and pre-heating time. Conversely, Sample H exhibited the lowest surface roughness values at 530 °C temperature and 60 minutes of Nitrocarburizing time. It is clear from these results that the ARCOR Nitrocarburizing process has a significant effect on ASTM 430 steel, shedding light on its potential applications in enhancing material properties for various engineering applications.
Keywords: *Arcor , Nitrocarburizing, ASTM 430steel.*

I. Introduction:

Engineers always focus on economy of the product while designing industrial components. Mild steel materials are cheaper and easily available, also they are used for a large no. of industrial applications. There are many uses for ASTM 430 steel, however, its low hardness, wear resistance, and toughness make it unsuitable for a wide range of engineering components[1]. But in order to consider the economy of the projects these materials are often treated with various process to enhance the mechanical properties. For the present study we have modified the surface properties of ASTM 430 steel using salt bath nitrocarburizing process.

Low and mild carbon steels find diverse uses in multiple sectors, such as pipeline construction, product manufacturing, structural steel in construction, automobile production, and other significant industries. [2-4]. These materials are often cheaper and easily available materials, but also they do not possess the desired mechanical properties to be used directly for the heavy duty mechanical components. For these mild steel components to be useful in industrial machine structures, some methods must be applied to enhance their desired mechanical properties [5]. The surface hardening process improves the wear resistance of metal parts while preserving the soft cores [6]. Bearings, shafts, turbines, and other machine parts can benefit from this combination of hardened surface and soft core by absorbing impact shocks [7].

There are several ways to harden metal, but Nitrocarburizing is the most promising, as it produces thick, dense protective layers of nitrogen and carbon [8]. Specifically, the term "Nitriding" is commonly associated with the Gas Nitriding process that involves the use of ammonia [9]. Nitrocarburizing, on the other hand, encompasses three main methods: Liquid, gas, and plasma Nitrocarburizing [10]. Each of these approaches contributes to the creation of robust and durable surfaces in metal components.

II. Experimentation

ASTM 430 steel specimens were meticulously prepared by grinding and degreasing, ensuring a uniform surface roughness and cleanliness. Subsequently, the test specimens underwent a pre-heating stage at 300°C for durations of 10, 20, and 30 minutes, respectively. The next step involved nitrocarburizing, which was carried out at different temperatures: 500°C, 530°C, and 570°C for time intervals of 60 minutes, 90 minutes, and

120 minutes, respectively. Following the nitrocarburizing process, a post-oxidation treatment was applied in a salt bath using OXINIT solution at 400°C for a duration of 20 minutes. These carefully designed procedures aim to enhance the surface properties and performance of the ASTM 430 steel specimens.

A set of tests were conducted to assess the effects of the surface treatment technique on microstructure, surface roughness, and surface hardening. The micro hardness was determined using the Digital Micro-hardness Tester Mvh-II, applying a test force of 0.98 N (0.1 kgf) for a duration of 15 seconds, and the measurements were recorded in HV units. Surface roughness was evaluated using the "SJ-201P" surface roughness tester manufactured by "Mitutoyo," which has a measuring range of -200µm to +150µm. Additionally, Field Emission Scanning Electron Microscope (FESEM) studies were performed using a Carl Zeiss Field Emission Electron Microscope, and the test specimens were prepared following standard metallographic techniques.

Table 1 shows the experimental conditions. Table 2 shows the design of experiments using Taguchi's L9 orthogonal array.

Table 1. Experimental conditions.

Work specimens	ASTM 430 steel
Hardness	184-190 HV
No. of samples	18
Process parameters	
Nitrocarburizing temp. (ºC)	500 ºC, 530 ºC and 570 ºC
Nitrocarburizing time	60 min., 90 min. and 120 min
Pre-heating time	10, 15 and 25 min.
Post oxidation	450 ºC

Table 1 Design of experiments using Taguchi's L9 approach

Sample	Pre heating time (min)	Nitrocarburizing time (min.) (min)	Nitrocarburizing temp. (ºC)
A	10	60	500
B	20	90	530
C	30	120	570
D	10	90	500
E	20	120	530
F	30	60	570
G	10	120	500
H	20	60	530
I	30	90	570

III. Results and discussions

3.1. Characteristics of the Surface Treatment

Figures 1 and 2 display the FESEM images of Sample C and Sample E treated specimens, respectively. On Sample C, a thick and uniform compound layer with an average thickness of 10.93 µm is evident Fig. 1. Similarly, Sample E shows a relatively similar compound layer with an average thickness of 10.95 µm (Fig. 2).

Beneath the compound layer in Fig. 1, a diffusion zone is apparent, indicated by the dark area between the compound layer and the substrate. This zone contains some small sticks known as Fe4N, found within the grains. Likewise, Fig. 2 also displays a significant diffusion zone, but with a lower intensity of Fe4N compared to Fig. 1. This suggests that temperature 570 °C plays a vital role in the formation of Fe4N sticks.

Moreover, a clear boundary can be observed between the compound layer and the diffusion zone, while the microstructure of the core remains unaltered after the treatment in both Sample C and Sample E. The compound layer in both Sample C and Sample E is composed of compounds containing iron, nitrogen, carbon, sulfur, and oxygen.

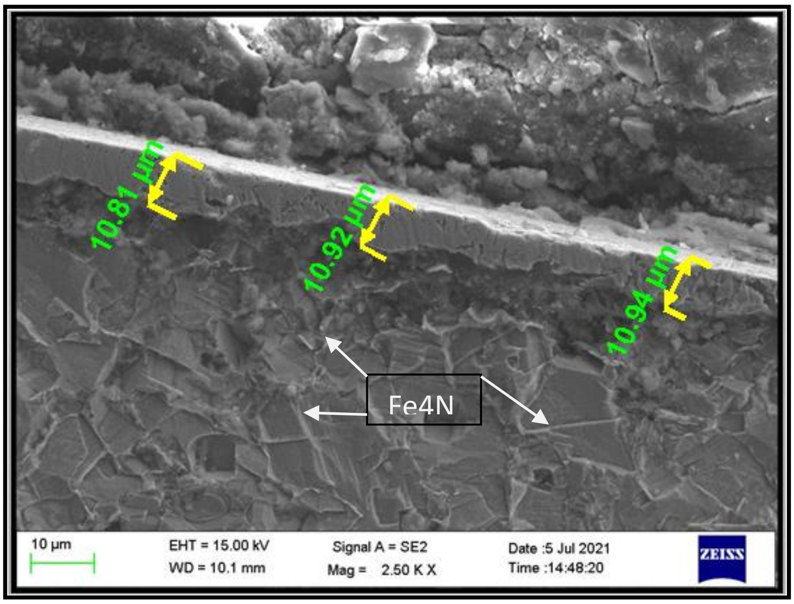

Fig. 1 FESEM cross-section images of sample C at 120X

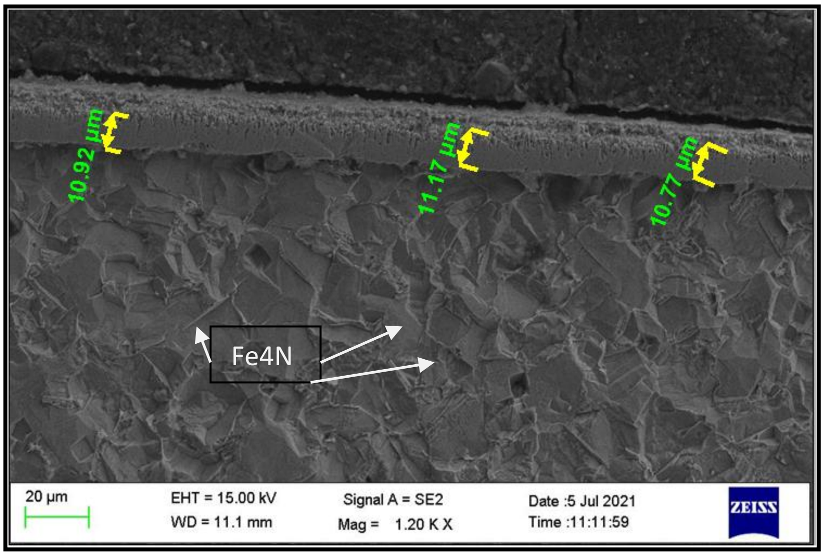

Fig. 2 FESEM cross-section images of Sample E at 151X

3.2. Micro-Hardness

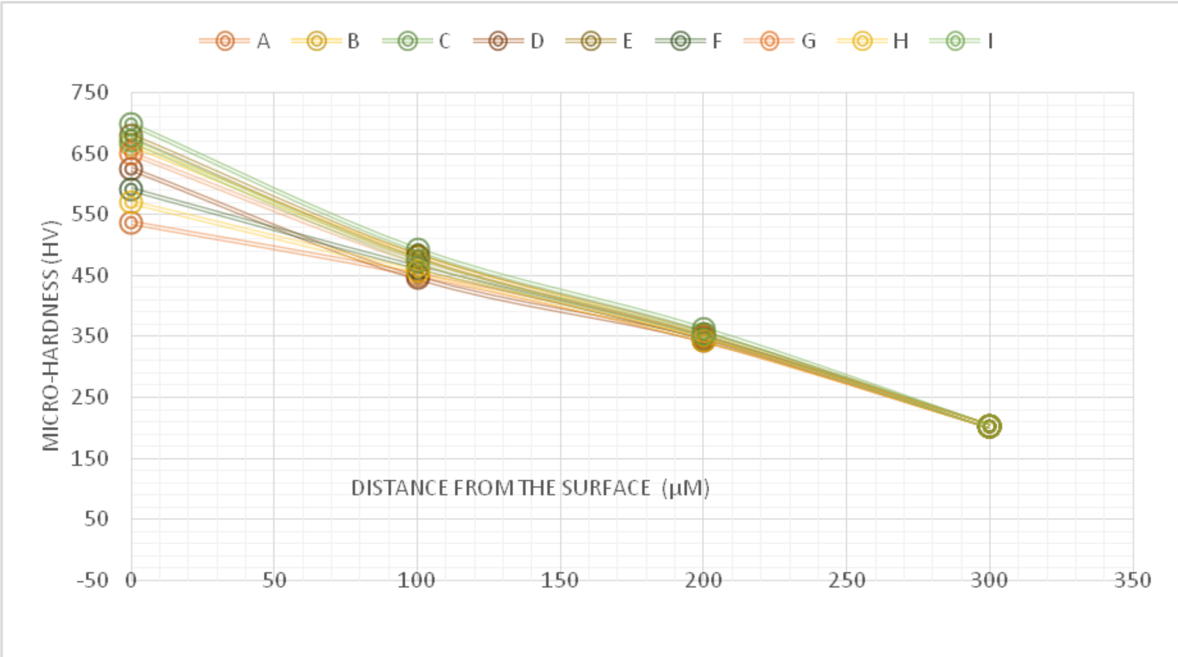

Fig. 4 micro-hardness results

Figure 4 illustrates the impact of Arcor Nitrocarburizing treatment on the micro-hardness of ASTM 430 steel at various input conditions. The measurements of micro-hardness are taken from different regions of the specimen. Specifically, the micro-hardness of the oxide layer and compound layer is assessed from the surface, while the micro-hardness of the diffusion layer is measured from the cross-section of the specimen.

Observations indicate that the hardness values within the compound layer are notably high. However, beyond a depth of 50 µm in the diffusion zone, the hardness starts to decrease. Notably, the micro-hardness of the core remains unchanged, maintaining a value of 184 HV after the treatment. This indicates that Arcor Nitrocarburizing treatment can be significant for improvement in hardness.

3.3. Surface roughness

Table 4. Surface roughness of Specimens

Specimen	R_a (µm)
Untreated	0.8531
FNC without post oxidation	1.3392
FNC with post oxidation	1.6011

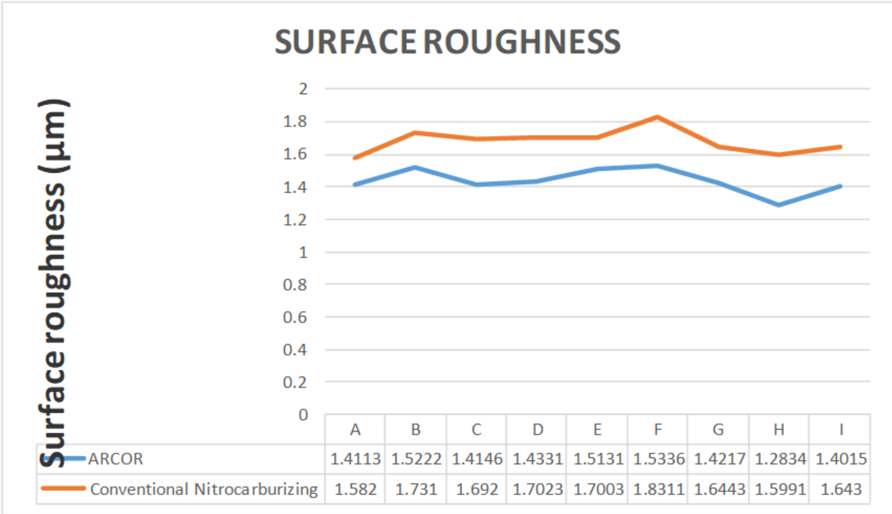

Fig. 5. Effect of the experimental conditions on Surface roughness of ASTM 430 steel.

Figure 5 displays the graph representing surface roughness after the Arcor process. On the other hand. The surface roughness data for untreated, FNC, and post-oxidized specimens are summarized in Table 4. The presence of pores on the compound zone is attributed to the formation of sulfur compounds, providing self-lubricating properties that prevent wear and enable oil retention ability [11].

The treatment has resulted in higher surface roughness values, which can be attributed to the increased porosity of the surfaces obtained after post-oxidation treatment. This is evident from the presence of visible pores on the surface, as observed in the FESEM micrographs. Among the samples, the highest roughness value of 1.5036 µm is found in Sample F, treated at a nitrocarburizing temperature of 570°C. Conversely, the lowest value of surface roughness of 1.2534 µm is observed in Sample H, treated at 530° C. The growth of porosity in the post-oxidized specimens leads to a larger reaction surface compared to the nitrocarburized specimens. This expanded reaction surface contributes to the higher surface roughness values observed in the post-oxidized samples, as indicated by references [12] and [13].

IV. Conclusions

From the analysis of the experimental findings and subsequent discussions, the following conclusions can be deduced regarding the salt bath ferritic Nitrocarburizing process (ARCOR) of ASTM 430Steel:

- • The surface of the steel exhibited two distinct regions: (i) the compound layer and (ii) the diffusion zone. Additionally, clear identification of pores attributed to surface sulfides formed by sulfur compounds is evident in the compound zone. Notably, a substantial presence of oxygen is observed at the outermost surface following post oxidation. Among the different nitrocarburizing temperatures, the highest average compound layer thickness of 10.95 µm is attained at 570 °C.
- Furthermore, it was observed that the hardness of the compound layer significantly exceeds that of the base metal. However, the hardness decreases beyond the compound region. This occurrence is linked to the higher carbon elemental intensities present in the compound layer.
- Moreover, the surface roughness values were determined to be exceptionally high, primarily due to the formation of highly porous surfaces resulting from the post-oxidation process.
- Based on the design of the experiment, it can be inferred that the experimental conditions used for Sample C yield the highest micro-hardness values and relatively lower wear resistance values. This is achieved when the Nitrocarburizing time, temperature, and pre-heating time are at their maximum levels.
- On the other hand, Sample H demonstrates the lowest surface roughness values when the temperature is set at 530 °C and the Nitrocarburizing time is 60 minutes.

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