# THE INFLUENCE OF SALT BATH NITRIDING VARIABLES ON HARDNESS LAYER OF AISI 1045 STEEL

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**Abstract**

The aim of this paper is to study and analyze the effects of a surface controlled salt bath nitriding on the microhardness of AISI 1045 steel. The nitriding process was implemented in the salt bath component at ten different times (from 1 h to 10 h) when the temperature was constant at (520ºC). The nitriding process repeated of other specimens at the same times, but the temperature was (580ºC).The microstructure of the surface layers was investigated by scanning electron microscopy (SEM) and optical microscopy. Hardness profiles were measured with low-load hardness testing to determine the growth of the case depth after nitriding. Microhardness testing was carried out on samples to investigate the hardness profile at the transition from the compound to the diffusion layer. The microhardness of the surface of the nitrided sample at 520ºC and 580ºC was observed in the range of 318–430 HV0.3 and 329–421 HV0.3, respectively. Experimental results showed that the nitrides ε-Fe2-3(N, C) and γ'-Fe4(N,C) present in the compound layer increase the microhardness , It also showed that the Increasing the salt bath nitriding parameters (treatment time and temperature) increases the surface hardness and hardness profile.

**Keywords:** salt bath, AISI 1045 steel, microhardness, time, temperature

## 1 Introduction

AISI 1045 steel is widely applied nowadays because of great mechanical properties and commonly used in mechanical constructions and also as a part of design. It's a material with good machinability and has proven to be capable of providing engineers a good and reliable solution when submitted to effort, corrosion, etc [1].

To improving and elevating the alloy's tribological properties, You must use thermochemical techniques such as nitriding, carburizing, and nitrocarburizing [2–3]. Nitriding treatments in several varieties of steel are widely used in industry because of their broad application range [4], Nitriding is a surface treatment technique used to introduce nitrogen into metallic materials to improve their surface hardness, mechanical properties, as well as wear [5–6] and corrosion resistance [7–8], as well as fatigue life [9, 10, 11]. The most important and oldest method of thermo chemical surface hardening operation is nitriding operation of steel which changing the chemical properties of the surface layer [12].

Salt bath nitriding is developed as an industrial process, especially for surface modification of iron-based steels; this process technology has solved environmental problems and can be applied

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to AISI 1045 steel and high alloy steels with high reaction efficiency [13–14]. Salt bath nitriding is done to obtain high surface hardness, to increase wear resistance, to improve fatigue life, and to improve corrosion resistance, high dimensional stability [15–16]. Chosen for this paper work, on the basis of their application and commercial availability, there is insufficient knowledge about the effects of nitriding factor on microstructure and properties when complex salt bath nitriding is done on AISI 1045 steel at low temperature. Therefore, the aim of the paper is to make an attempt to investigate the influence of processing time and temperature on the microstructure, the phase composition and the microhardness in the nitrided layer by using scanning electron microscopy (SEM) and machine Digital Micro Vickers Hardness Tester.

## 2 Experimental procedure

The material used in this paper was AISI 1045 steel with the chemical composition shown in **Table 1**. Chemical composition of AISI 1045 using by SOLARIS CCD Plus spectrometer (is an advanced CCD based optical emission spectrometer for Metal Analysis). The microstructure of AISI 1045 steel after heat treatment (Martensitic) is shown in **Fig. 1**.

**Table 1** Chemical composition of AISI 1045 [wt. %]

| AISI 1045 | C | Si | Mn | Cr | Ni | P | S | Mo | Fe |
|---|---|---|---|---|---|---|---|---|---|
| wt. % | 0.49 | 0.32 | 0.74 | 0.15 | 0.13 | 0.002 | 0.002 | 0.04 | 97.773 |

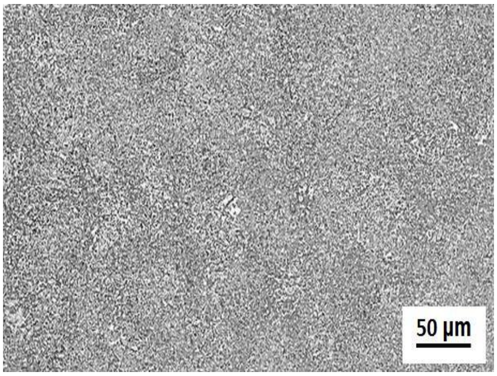


**Fig. 1** microstructure of AISI 1045 steel

In order to improve hardness and toughness for AISI 1045, the specimens were subjected to a heat treatment consisting in: austenitization at 850 °C during 30 min. then fast cooling in Oil, Then tempering at 600 °C for 120 min, with further slow cooling in air. The samples were placed in the oven at 350 °C. Next, the nitriding processes were carried out in salt bath comprising of cyanates and carbonates. The nascent nitrogen diffuses into the surface of steel. The samples were immersed in salt bath for ten different times (1h, 2h, 3h, 4h, 5h,6h, 7h, 8h, 9h, 10h ) at 520 °C, The nitriding process repeated of other specimens at the same times but the temperature was 580ºC.

Microhardness measurements were used to determine the diffusion layer thickness as well as to aid in characterizing the physical properties of the diffusion layer as a function of depth [17]. The surface hardness and the microhardness profile of salt bath nitrided specimens were evaluated using a microhardness tester with a load of 300 g, according to the ASTM E384-99 standard by the machine Digital Micro Vickers Hardness Tester (Model: HVS-1000Z).

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Scanning electron microscopy (SEM) type of JEOL JSM 6060 LA was used to characterize the microstructures of AISI 1045 after salt bath nitriding. Cross sections from nitrided specimens were ground, polished.

## 3 Results and discussion

### 3.1 Microstructure

The morphology and microstructure of nitrided layers produced in near-surface regions of AISI 1045 steel by salt bath treatment at a temperature of 580 °C for 5h were determined by SEM. The specimen was mechanically fine-ground and polished. Could be observed that the presence of a continuous and uniform of two types of surface layers as shows in **Fig. 2**.

During salt bath nitriding, two parts surface layer is formed, an outer compound layer ε-Fe2-3(N,C) and γ'-Fe4(N,C) with a nitrogen diffusion layer (α) below it [13,18,19,20,21,22]. Compound layer on the other hand, it is also referred to as 'white layer' because of its white color after Nital etch on the microscopy [23, 24].

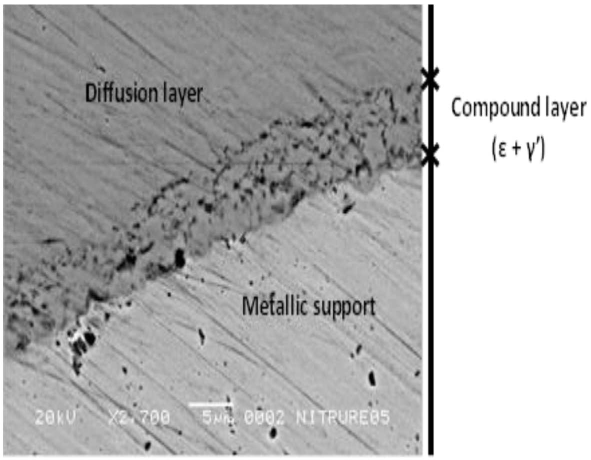


**Fig. 2** Microstructures of salt bath nitrided AISI 1045 (700×) at 580 °C for 5 h by SEM

### 3.2 Microhardness

The cross sectional hardness profiles of nitrided specimens for each studied conditions are shown in **Fig. 3**. All specimens showed high surface microhardness values are in the range of 317–425 HV0.3 and 328–418 HV0.3 for both temperatures 520°C and 580°C for different times (from 1 to 10 ) hr,. The surface hardness increases to reach a maximum value at 10 h for both temperatures 520°C and 580°C, Respectively.

The core hardness values of the specimen nitrided after heat treatment and before salt bath nitriding were 286 HV. It should be noted that the core hardness of all nitrided specimens was recorded at the same level as in the specimen nitrided after heat treatment and before salt bath nitriding (287 HV0.3). This result confirms that the core does not soften by overaging during salt bath nitriding, i.e, microstructure of the core remains unaltered after salt bath nitriding [25].

The microhardness profiles indicate that the hardness decreases from the surface to core, Due to the hardening and trapping effects of the ε-phase (Fe3N, C) and γ'-phase (Fe4N, C) in the nitrided layer and the concentration of the latter decreases towards the core. There is no sharp transition in the hardness values from the compound layer to the diffusion zone, and this can be

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attributed to the high hardness levels achieved in the diffusion zone after the long time nitriding process. The microhardness rapidly decreases in the diffusion layer [26].

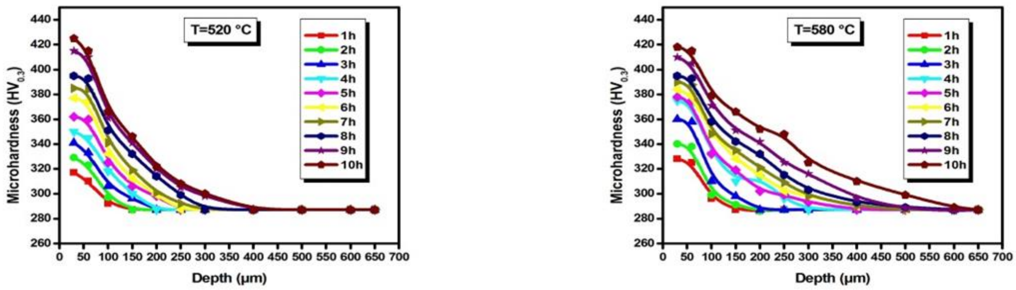


**Fig. 3** Microhardness profiles of AISI 1045 steel, salt bath nitrided at different conditions

**Fig. 4** exhibits the variation in Increase microhardness in the time of nitriding for temperatures 520°C and 580°C. The microhardness values for AISI 1045 steel increased a significant in percentage microhardness after salt bath nitriding in the range of 10.8 % to 49.82 %, 14.63 % to 46.68 % for both temperatures 520°C and 580°C, Respectively. Could be observed that the surface hardness of AISI 1045 steel is increased up to 50% by the salt bath nitriding process at 10 h for the temperature 520 °C.

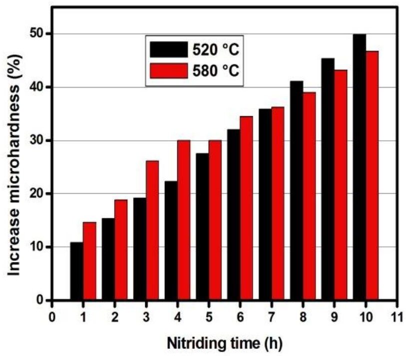


**Fig. 4** Increase microhardness of AISI 1045 steel, salt bath nitrided at different conditions

**Fig. 5** shown the hardness in the diffusion layer of AISI 1045 is improved by increasing the nitriding time at various temperatures. A significant increase in the values of hardness at a small depths. The hardness of salt bath nitrided specimens is in the range of 310–415 HV0.3 and 325–415 HV0.3 for both temperatures 520 °C and 580 °C when the depth was 60μm. This range is gradually decreasing at different depths from the surface of the sample to case core. Can be said that the hardness increases from core to surface with nitriding time. The percentage increase is obvious at small depths of diffusion layer. This is a result of more interaction time, which allows for diffusion of more nitrogen and carbon into the middle layer of the salt bath nitriding process.

**Fig. 6** shown the effect of nitriding temperature and time on surface hardness. we obtained hardness values at 580 °C lower than hardness values at 520 °C in longer treatment periods (from 7 to 10 ) hours . The reduced surface hardness is obtained at a longer nitriding time at high

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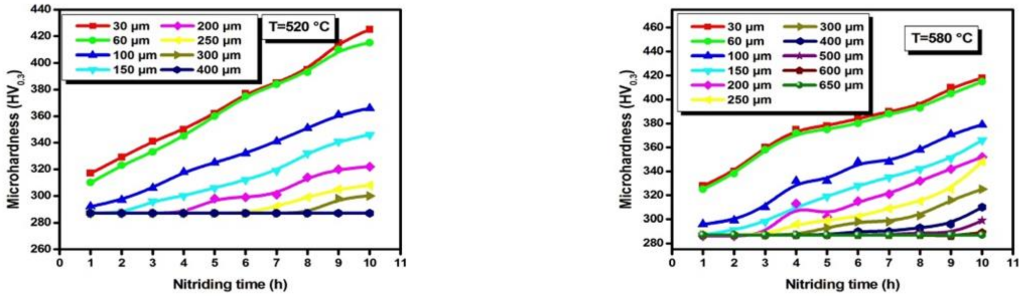


**Fig. 5** Microhardness of AISI 1045 steel and nitriding times at different depths

temperature because of the formation of large nitride precipitates [27-28]. Precipitates with a certain size will be the most effective in obstructing the movement of dislocations and in producing the maximum strengthening and hardening [10]. At longer times, the precipitate particles are larger in size and more prone to coarsening, leading to a lower precipitate density and hence lower hardness [27, 28].

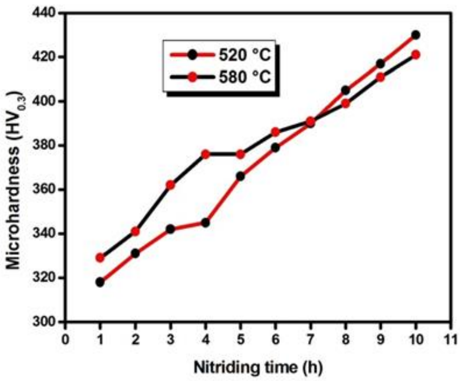


**Fig. 6** Effect of salt bath nitriding temperature and time on surface hardness

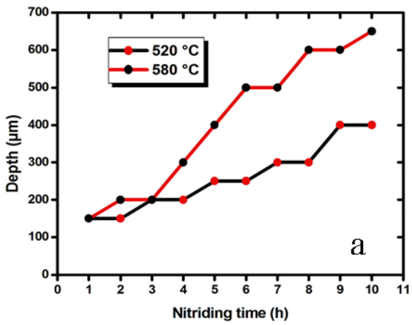


**Fig. 7** Effect of time on depth at 520 and 580 °C

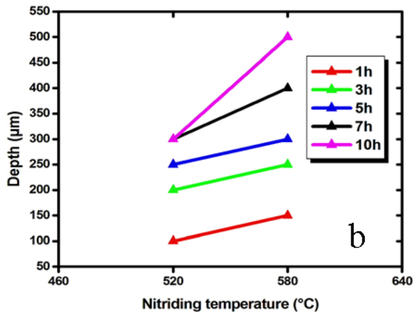


**Fig. 8** Effect of temperature on depth at different times

The depth increases with increasing time and temperature [29]. The higher depth values of the case depth are obtained as the treatment time increases. It can be seen in **Fig. 7** that the case depth has increased with the treatment time of salt bath nitriding at both temperatures as indicated in [30] and the generation of faster at 580 °C than 520 °C. It can be seen from **Fig. 8** that higher treatment temperatures produce deeper cases at five different times (1, 3, 5, 7 and 10) hrs. While the nitrided case depth increased strongly with temperature, the surface hardness decreased at longer nitriding time because of the formation of larger nitride precipitates [31].

## 4 Conclusions

The principal aim of this paper is to the effects of salt bath nitriding process parameters such as treatment time and temperature on the structural surface characteristic of AISI 1045 steel. Based on the results obtained, the most important relationships derived are as follows: The presence of the compound layer and diffusion layer after salt bath nitriding on Samples. The surface hardness, increased with increasing time and temperature of salt bath nitriding treatment, But for extended nitriding periods, a significant loss of surface hardness was observed at high temperatures as a result of the formation of large nitride precipitates. The surface hardness depends on the nitriding time when the temperature is constant.

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