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Rapid communication

A study of the effect of propane addition on plasma nitrocarburizing for AISI 1045 steel

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ABSTRACT

Propane was used as carbon-bearing gas in plasma nitrocarburizing due to its lower ionization energy and the effect of its concentration on the nitrocarburizing rate and phase compositions for AISI 1045 steel was investigated. The surfaces of nitrocarburized samples were analysed by optical microscopy, X-ray diffraction and by using a microhardness tester. The results showed that the case depth increased initially with the increasing concentration of propane, and then decreased when it exceeded a limit of 1.5%. The maximum case depth of 40 μm was achieved at this optimum concentration of 1.5% when nitrocarburizing at 510 °C for 4 h, and a maximum surface hardness of 7.63 GPa and desirable phases of dominant ε nitride with a little cementite were obtained. The amount of cementite increased with the increasing concentration of propane above 1.5%, which hindered the nitrogen and carbon up-take, thus resulting in the decrease of case depth and surface hardness.

Nitrocarburizing is a thermochemical surface engineering process which involves the enrichment of nitrogen and carbon at the surface of a ferrous component [1].The compound layer consists of γ'-$Fe_4(C,N)$ and/or ε-$Fe_{2\text{-}3}(C,N)$ phases, which is desired to increase hardness, wear, corrosion at the material surface and ε-phase which provides better corrosion resistance than γ'-phase [2]. In addition, the fatigue strength and load-bearing capacity are also improved by the formation of a diffusion layer [3], in which nitrogen and carbon atoms are dissolved interstitially in the ferritic lattice and form nitride precipitates [4].

In the past decades, efforts have been made to develop a plasma nitrocarburizing technique since it has many advantages especially in terms of environmental protection [5]. Unfortunately, it was found that, in the glow-discharge of a plasma-containing nitrogen and carbon species, it is rather difficult to produce the desirable single ε-phase compound layer on plain carbon steels. A particular difficulty is to select the type and to control the amount of carbon-bearing species [6]. It has been reported that only single γ'-phase or a mixed phased of γ', ε and Fe_3C can be produced by using CH_4 as a carbon-bearing gas [7]. Carbon generated from ionization of CO_2 or CO is insufficient to produce the single ε-nitride phase [8]. Hence, it is necessary to try a new carbon-bearing gas to get desirable phases on the plain carbon steel.

In this work, propane was selected as the carbon bearing gas and the effect of different additions of propane (from 0.5% to 2.5%) on the nitrocarburizing rate and phase compositions for AISI 1045 steel were investigated. For comparison, methane (1.5%) was also used as carbon bearing gas for a reference.

The material used in this study was AISI 1045 steel with the following chemical compositions: (wt.%), C: 0.46, Si: 0.17, Mn: 0.52, S: 0.031, P: 0.032 and Fe: balance. The specimens were machined to the dimensions of 10 mm × 10 mm × 5 mm, and quenched at 850 °C for 6 min then cooled in water and tempered at 560 °C for 20 min. The specimens were grinded using 240–2000 mesh emery papers and were then cleaned ultrasonically in an ethanol bath before plasma nitrocarburizing.

After cleaning with ethanol, the specimens were placed into a chamber evacuated to 10 Pa. Gases of nitrogen and carbon-bearing gases were introduced into the chamber at a total gas pressure of 290 Pa. The addition of propane was varied from 0.5% to 2.5%. For comparison, 1.5% methane was also used as carbon-bearing gas for a reference. All the samples were treated at the same temperature of 510 °C and the same duration of 4 h.

The cross-sectional microstructure of the treated samples was observed by optical microscopy. Phases were determined by X-ray diffraction (XRD) with Cu-Kα ($\lambda = 1.54$ A) radiation. In addition, the surface hardness was measured by HXD-1000TMC microhardness tester with the test load of 50 g and the holding duration of 15 s, Each hardness value was determined by averaging at least three measurements.

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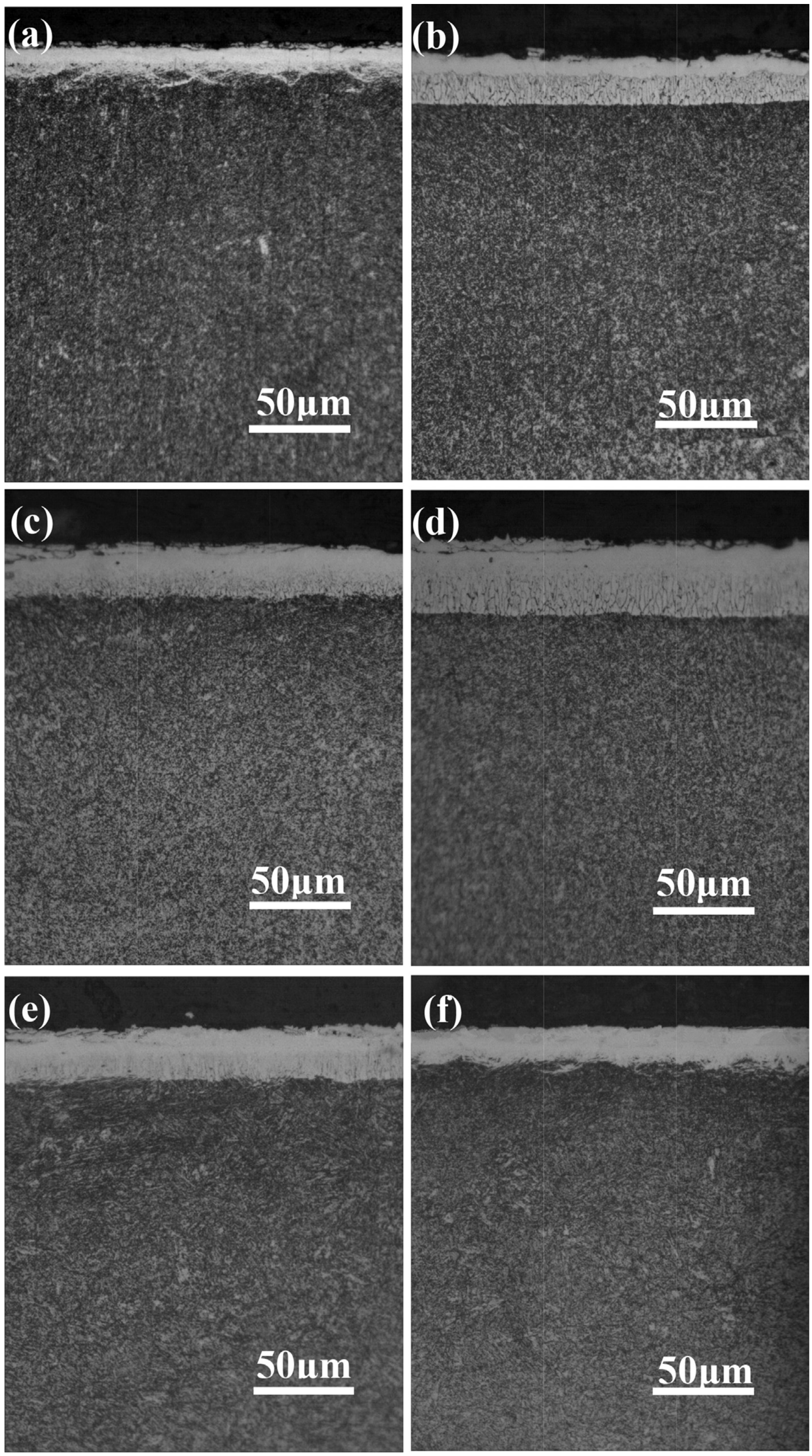

Fig. 1. The typical cross-sectional microstructure of samples treated at 510 °C for 4 h with and without carbon bearing gas addition (a) Without carbon bearing gas; (b) Propane 0.5%; (c) Propane 1%; (d) Propane 1.5%; (e) Propane 2%; (f) Methane 1.5%.