



## Plasma and gaseous nitrocarburizing of C60W steel for tribological applications

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### ABSTRACT

A comparison has been made between plasma and gas nitrocarburizing processes for C60W steel in terms of structural features of the layers and the tribological properties of the specimens. Gaseous treatments were performed in a sealed quench industrial furnace in optimized process cycles. A semi-industrial size unit was operated at a range of process parameters for plasma nitrocarburizing. Experimental results indicate that increasing the treatment time increases the thickness of the compound layer but lowers the wear resistance. Plasma treatment produced a more effective case depth compared with gaseous process, providing a better uniformity. Analysis of X-ray diffraction patterns indicated that the compound layer in gas nitrocarburizing and plasma nitrocarburizing consisted of both  $\epsilon$  and  $\gamma'$  phases.

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**Nitrocarburizing treatments have been** first introduced in the early 1950s; involving the addition of carbon and nitrogen into a steel in order to produce a thin layer of iron carbonitride and nitrides with an underlying diffusion zone containing dissolved nitrogen and nitrides [1,2]. This process is a plasma-activated thermochemical method widely used to increase the fatigue strength, hardness and wear resistance of engineering steels which are used for making dies, tools, automobile parts and machine parts [3–5].

The process consists of generating an electrical discharge in a gas mixture containing nitrogen and carbon under low pressure [6]. It uses glow-discharge plasma to introduce nitrogen and carbon to the surface of the components undergoing treatment. The components are placed on the cathode and the furnace chamber is anode. Application of a voltage of 300–800 V between the two electrodes at a pressure of 1–8 mbar establishes a current-intensive glow discharge [7]. Plasma nitrocarburizing has become an accepted alternative to gas nitrocarburizing as a low distortion diffusion treatment for enhancing the surface wear properties of steels and non-ferrous metals, such as titanium [8].

Until the late 1960s, the only available nitrocarburizing processes used a medium of molten cyanide-based salts as a source for nitrogen and carbon [1]. However, since then, concerns about the environmental aspects of heat treatment processing with cyanide-based salts have been increasing.

Plasma nitrocarburizing involves the introduction of nitrogen and carbon atoms together into the component surface to produce

a hexagonal close-packed (hcp) carbonitride ( $\epsilon$ -Fe<sub>2-3</sub>(N,C)) compound layer 10–20  $\mu\text{m}$  thick on the surface, on top of a relatively thick nitrogen diffusion zone [4]. On the other hand, plasma nitrocarburizing is a process which adds a small amount of carbon-containing gases such as CH<sub>4</sub> and C<sub>3</sub>H<sub>8</sub> to the gas mixture of N<sub>2</sub> and H<sub>2</sub> used at the glow-discharge plasma nitriding method [5,9].

The advantages of the use of the plasma for nitrocarburizing in comparison with conventional gas or salt bath nitrocarburizing are as follows: low emission of toxic gases, minimum distortion of work piece due to low processing temperature, low maintenance costs due to reduced consumption of energy and treatment gas, and formation of a single phase compound layer with a low porosity without mixed  $\gamma'$  and  $\epsilon$  phases [5,10]. Plasma nitrocarburizing is also more economical because it introduces faster diffusion, which in turn allows for lower nitrocarburizing temperatures or shorter treatment times [11–13].

The maturity of plasma nitrocarburizing equipment is reflected by the ability of suppliers to respond to the high reliability requirements of the automotive sector. Following nitrocarburizing, the workpieces are allowed to cool under controlled vacuum conditions; this is in contrast to the gaseous process where the components must be oil quenched directly from the treatment temperature. Another consideration is in respect of the required properties of nitrocarburized steels; research evidences indicate that a monophase structure is preferred for tribological properties and other phases in the compound layer because it will enhance the corrosion resistance [14–16].

In the present paper, a comparative study is performed between plasma and gas nitrocarburized C60W steel specimens. The key elements for comparison are the microstructure of the layers and

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**Table 1**  
Chemical composition of C60W steel.

C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Fe%
0.55	0.27	0.81	0.015	0.017	0.07	0.005	0.05	Bal.

**Table 2**  
Gaseous cycles.

Number	Treatment temperature (°C)	Treatment time (h)	NH <sub>3</sub> amount (m <sup>3</sup> /h)	CO <sub>2</sub> amount (l/h)	Chamber pressure (mbar)
1	570	4	1.5	150	25–30
2	570	8	1.5	150	25–30

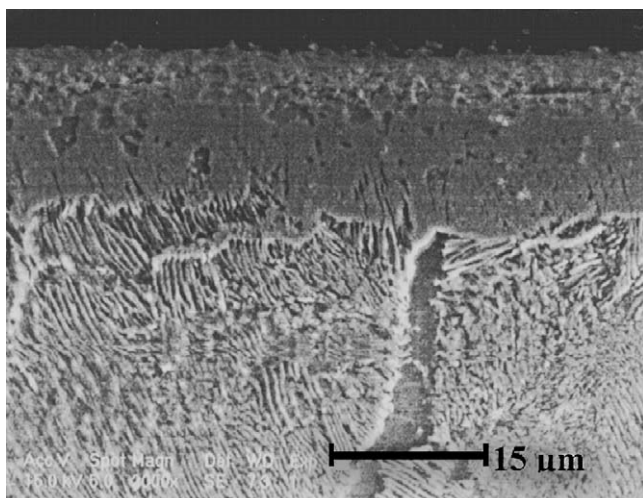
**Table 3**  
Plasma cycles.

Number	Treatment temperature (°C)	Treatment time (h)	N <sub>2</sub> amount (ml/min)	CO <sub>2</sub> amount (ml/min)	H <sub>2</sub> amount (ml/min)	Chamber pressure (mbar)
1	570	4	500	30	60	1.5
2	570	8	500	30	60	1.5

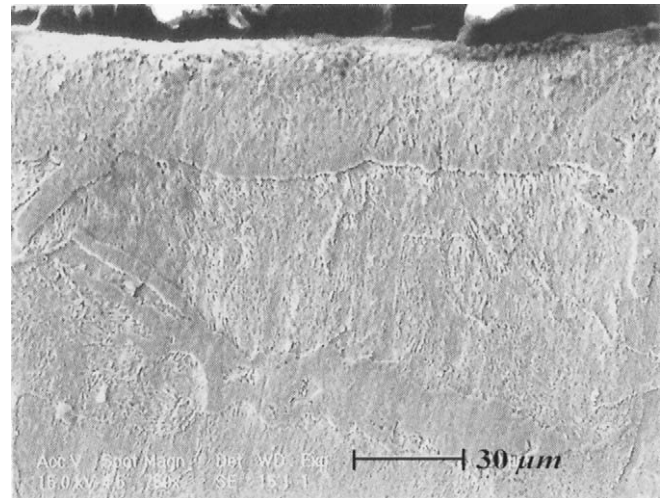
the tribological properties of the treated samples as obtained by pin-on-disc testing.

## 1. Materials and experimental procedure

The base alloy selected for nitrocarburizing treatment was carbon steel C60W (1.1740), the chemical composition is shown in Table 1. The normal structure of this alloy consists of pearlite and some ferrite. Before nitrocarburizing, the samples were ground, degreased and cleaned in suitable solutions. Plasma nitrocarburizing was carried out in a medium size 5 KW furnace operated by DC voltage. After loading, the chamber was evacuated to 0.1 mbar pressure before the power was switched on. The treatment gas, the composition of which was selected based on several preliminary experiments, was gradually introduced at the required pressure. In all experiments a heating time of one hour was used during which sputter cleaning was performed in argon gas. The process cycle was considered from the time the temperature reached the required point. After each treatment the power was switched off to allow the samples to cool below 150 °C before being removed from the chamber. Specimens for gas nitrocarburizing were treated in



**Fig. 1.** SEM microstructure of C60W steel gaseous nitrocarburized at 570 °C for 4 h.



**Fig. 2.** SEM microstructure of C60W steel gaseous nitrocarburized at 570 °C for 8 h.

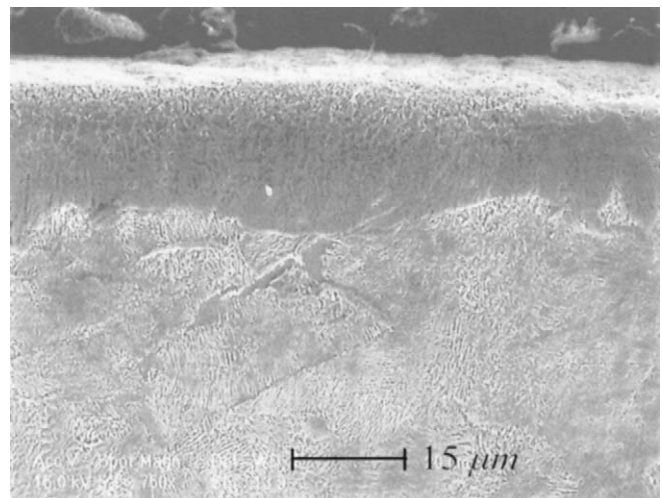
a sealed quenched furnace under industrial conditions. The gaseous and plasma nitrocarburizing experimental cycles are listed in Tables 2 and 3.

The treated samples were sectioned, mounted, and prepared for metallographical examination and the measurement of microhardness gradients. The compound layers produced on the surface were studied by scanning electron microscopy and the phases were identified by X-ray diffraction. The X-ray diffraction was operated at 30 kV and 30 mA with Cu K $\alpha$  radiation and 1.504 Å wave length. The wear behaviour of the specimens was evaluated by a pin-on-disc laboratory tribotester under dry conditions. C60W steel and the nitrocarburized samples were sliding against roller bearing steel (AISI 52100) with hardness of 64 HRC at a range of loads. The amount of wear was determined on a weight loss basis after a fixed sliding distance.

## 2. Results and discussion

### 2.1. Structure of the layers

Optical micrographs of nitrocarburized layers are shown in Figs. 1–4. It is clear that the thickness of the compound layer



**Fig. 3.** SEM microstructure of C60W steel plasma nitrocarburized at 570 °C for 4 h.

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