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# Surface morphology and tribological behavior of AlSi10 alloys treated by plasma immersion ion implantation for automotive applications

*Ibrahim Etem Saklakoğlu**

*Ege University, Faculty of Engineering, Mechanical Engineering Department, 35100 Bornova, Izmir, Turkey*

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ABSTRACT

Plasma immersion ion implantation (PIII) was used to implant nitrogen into Al at a temperature in the range of 320–520 °C. AlN phase was observed for temperatures above 450 °C, whereas no AIN detected by XRD diagnosis at temperatures below 380 °C. It was also observed that there was no effective increase in hardness of the material, but some wear resistance due to formation of AlN.



## 1. Introduction

Aluminum sand, die and permanent mold castings are very important in engine construction, e.g., engine blocks, pistons, cylinder heads, intake manifolds, crankcases, carburettors, transmission housings, and rocker arms (ASM Handbook, 1990). However, these materials have inadequate surface hardness and tribological properties. Therefore, modification and improvement of the surface properties are very important for current and future industrial applications. For PIII, high negative voltage pulses are applied to workpieces immersed in plasma. Positive ions from plasma are accelerated towards the workpieces and, in low-pressure collisionless plasmas, bombard the surface with energies equal to the applied voltage. One of the main reasons for interest in PIII is the fact that it can be used as a hybrid treatment together with diffusion process. When the temperature exceeds 250 °C, the diffusion of implanted species (such as nitrogen ions) plays a significant role in certain metals. A nitrogen-strengthened diffusion zone is produced so that it extends well beyond the implantation range. Thus, it gives rise to the increased surface hardness. Fundamentals of PIII technique are described in other articles.

The high potential of utilization of PIII on ferrous and some non-ferrous metals in this field has long been recognized by Möller et al. (1999), Richter et al. (2000) and Sonnleitner et al. (2002). Möller et al. (1999) presented the basic properties of PIII with respect to technological application and some results obtained from PIII-treated stainless steel and aluminum. On the other hand, Richter et al. (2000) showed the wear and corrosion characteristics of austenitic stainless

* Tel.: +90 532 5489359; fax: +90 232 3888562.
E-mail addresses: i.e.saklakoglu@ege.edu.tr, iesaklakoglu@gmail.com.
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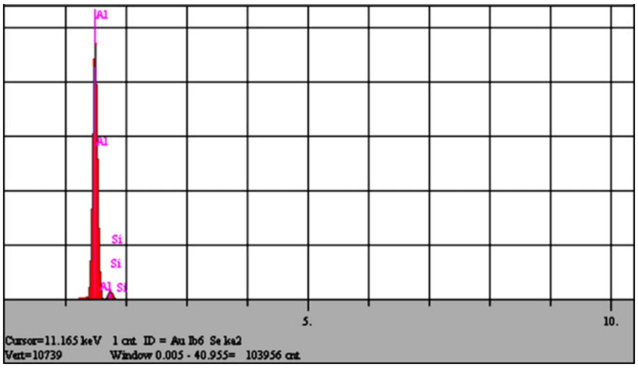


**Fig. 1 – The SEM spectrum for AlSi10.**

steel X5CrNiMo17.12.2 and the aluminum alloy AlMg4.5Mn and AlMgSi1 treated by PIII. Sonnleitner et al. (2002) focused on depth profile, and TEM-investigations of PIII-treated pure aluminum, whereas Zhan et al. (1998) studied the tribological behavior of PIII-treated Al–Cu alloys. Youssef et al. (2005) worked on nitrogen-implanted Al–Cu alloys, whereas Manova et al. (2000) studies surface modifications of aluminum by PIII. The aluminum used in the latter study was 99.99% pure. Surface modification of aluminum alloy 5052 (the main alloying element is 2.2–2.8% magnesium), Ti6Al4V alloy and steels (AISI 304 and H13) by a combination of PIII and plasma nitriding (PN) were investigated by Kostov et al. (2004). Nitrogen ions were implanted by PBII into an aluminum alloy Al–7Si sample, produced by casting by Yamanishi et al. (2001). They presented the depth profiles of nitrogen ions and the friction coefficient, but not detailed surface structure and tribological properties. Blawert and Mordike (1997) showed the effects of PIII treatment on commercially pure aluminum (A199.5). Aluminum alloys AlMgSi1 and AlSi7 were implanted with nitrogen ions using PIII technique by Schoser et al. (1998) along with XPS diagnosis of AlN formation.

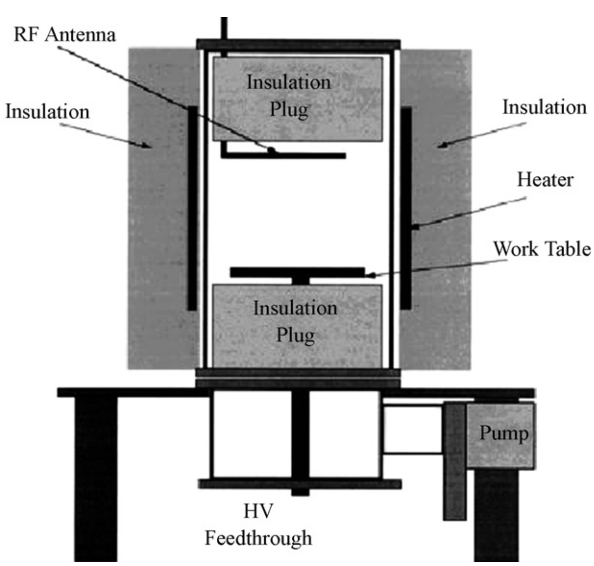


**Fig. 2 – Schematic illustration of the ANSTO Mark 2 PIII system.**

In literature, there is no study on PIII-treated AlSi10 alloy, which is a very important material for automotive industry. In this study, it is aimed to improve the surface properties of AlSi10 alloy applying PIII treatment at different temperatures and investigating the effects of the treatment via hardness tests, wear tests, AFM, SEM, EDS and XRD diagnosis.

## 2. Experimental

The aluminum used in this study was AlSi10 and it was provided by DÖKTAŞ A.Ş.-Manisa/Turkey, where aluminum was used in engine cylinder head manufacturing. A SEM spectrum and analysis of the sample is shown in Fig. 1.

Before running experiments, flat samples were polished to a mirror finish and ultrasonically cleaned. PIII treatment was performed at ANSTO (Australian Nuclear Science and Technology Organisation, NSW, Australia) using their existing PIII system. The sample chamber was pumped to a base pressure of less than $2 \times 10^{-7}$ mbar before each PIII treatment got started. Nitrogen implantations were performed by applying 30 kV negative high voltage pulses. Prior to the implantation, an $Ar/H_2$ preclean at 15 kV/100 Hz HV pulsing during heating up was performed. The implantation time was 5 h and the temperature was in the range of 320–520 °C. In the PIII system, dose rate was $1 \times 10^{14}$ atom/(cm$^2$ s). The calculated dose was $1.8 \times 10^{18}$ atom/cm$^2$ for 5-h PIII treatment and it was $3.24 \times 10^{18}$ atom/cm$^2$ for 9 h PIII treatment.

In a typical PIII treatment, the workpieces are heated to the desired temperature in vacuum by the radiant heating element. Fig. 2 shows schematic illustration of the ANSTO Mark 2 PIII system.

Load-dependent hardness data were obtained using a UMIS-2000 ultra microhardness indenter system at loads of 50, 250 and 1000 mN. For each sample, five indents were made at each load and the average values were calculated.

The wear behavior was determined from wear tests using a standard CSEM pin-on-disc wear machine. A 6-mm rigid ruby ball was pressed onto the samples with a load of 5 N. The velocity of the appliance was 0.3 m/s, and a continuous supply of absolute ethanol was maintained to the disc surface to eliminate any effects due to variations in humidity. The ethanol used provided a mild lubricating regime and removed any loose wear debris. Each disc was tested for 200 m (corresponding to 3183 turns). The quantitative value of wear was

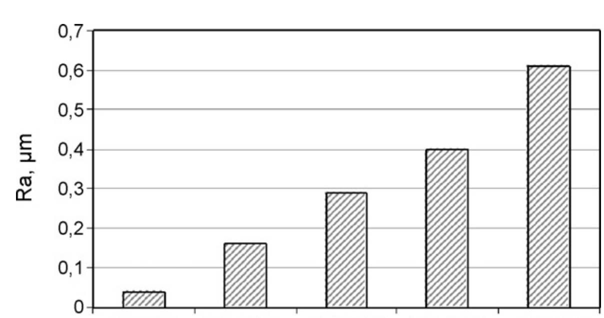


**Fig. 3 – Surface roughness of treated and untreated samples.**