Laser Gas Nitriding of Ti-6Al-4V Part 1: Optimization of the Process

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Abstract. A multi-variable test method, known as the Orthogonal Array, was used to optimize the parameters for the laser gas nitriding process (LGNP) to avoid surface cracking. Based on the fundamental requirement of a crack-free condition, the processing parameters were further optimized to improve the surface finish and to obtain a reasonable hardened depth. The effects of processing parameters have also been investigated with respect to the characteristics of the laser nitrided layer. Two types of lasers, i.e., CO₂ and Nd : YAG lasers were used. The CO₂ laser was operated in both the continuous as well as the pulse mode, while the Nd : YAG laser was used only in the pulse mode. A Nd : YAG laser in the pulse mode provided a better surface finish and lower cracking severity.

Keywords: laser gas nitriding, laser applications, laser alloying, nitriding, Ti-6Al-4V, titanium alloys, titanium nitride, processing parameters, carbon dioxide lasers, Nd : YAG lasers

1. Introduction

Titanium alloys are used extensively in the aerospace industry because of an attractive combination of high specific strength and excellent corrosion resistance [1]. However, the principal limitation of titanium alloys is their poor wear resistance which for the most part is due to low surface hardness. For example, severe fretting fatigue problems are frequently observed in the disc/blade fixing regions of fan and compressor components made from titanium alloys for gas turbine engines [2]. The damage results from fretting wear coupled with the fatigue loading conditions, which can dramatically reduce the fatigue life of a component.
The laser gas nitriding process (LGNP) has recently emerged as a new surface modification treatment for titanium alloys. Laser melting of titanium alloys in a nitrogen gas environment forms a hard titanium nitride surface layer. It is attractive because, among other things, there is an excellent metallurgical bond between the hardened surface layer and the substrate [3, 4]. It is well-documented in the literature that laser gas nitriding can substantially improve the wear resistance of titanium alloys [5–7], which, in turn, has the potential for improving the fretting fatigue life.

Laser gas nitriding, however, is at an early stage of development and further research is required to fully understand the process. The principal problem with the laser gas nitriding of titanium alloys is surface cracking. Most work has been carried out by using the CO2 continuous wave laser and surface cracking was observed on treated surfaces [7–12]. For aerospace applications where fatigue or fretting fatigue problems occur, surface macro- and micro-cracks must be eliminated to ensure reliability. Another problem that requires solution is the deterioration in fatigue life. A reduction of the fatigue life of laser nitrided Ti-6Al-4V has been reported [13, 14]. However, there are few details of the experimental conditions in the references. Because the fatigue and the fretting fatigue processes are inter-related, it is necessary to investigate the causes of the reduction in the fatigue life of laser nitried titanium alloys.

This paper will concentrate on the optimization of the LGNP for Ti-6Al-4V to avoid surface cracking. The characteristics of the nitried layers and the effects of the process on the fatigue and fretting fatigue properties will be described in subsequent papers.

2. Experimental procedures

A commercial Ti-6Al-4V plate (6.35 mm thick), supplied as per Aerospace Material Specification (AMS) 4911H, was used as the test material. Since the surface finish can directly affect the absorptivity of the incident laser energy, all test-pieces were polished to 600 grit before laser gas nitriding to provide a consistent surface finish.

Two lasers were used for the gas nitriding tests: (a) a CO2 laser with a rated output power of 3 kW, and (b) a Nd : YAG laser with a rated average output power of 330 W. The CO2 laser was used in either a continuous wave (CW) or a pulse mode with pulse frequency ranging from 5 to 2000 Hz and wavelength of 10.6 μm. The Nd : YAG laser was used only in a pulse mode. The maximum energy output was 55 J/pulse with pulse widths ranging from 0.1 to 20 ms, pulse repetition rates up to 200 Hz and wave length of 1.06 μm. A lens with a focal length of 127 mm was used to focus the beam. During treatment, the laser was focused on the surface of the sample as it was moved under the beam by a CNC x-y table.

Because of its high surface activity, Ti-6Al-4V reacts easily with O2 at high temperature. For the LGNP, it is essential to supply nitrogen gas for nitriding and to shroud the working area to eliminate oxidation. Three kinds of gas supply arrangement were evaluated: (a) a side nozzle, (b) a co-axial nozzle, and (c) a chamber, as illuminated in figures 1(a)–(c).

A side nozzle gas supply, commonly used in the literature [6–8,13], was tested for the LGNP. The advantage of this arrangement was its simplicity (figure 1(a)). However, our experiments indicated that there were two problems associated with this arrangement;