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SURFACE PROPERTY OPTIMIZATION WITH LASER GAS NITRIDING

THE TASK

High static and cyclic strength, low density, excellent corrosion resistance and a good biocompatibility make titanium alloys very attractive for a variety of applications, for example for aircraft, biomedical devices, biochemical and offshore equipment. Generally these alloys are not very resistant against abrasive, erosive and cavitation induced wear. Laser gas nitriding is a process to improve the wear resistance of titanium alloys. However, the industrial use of laser gas nitriding is limited or even completely hindered since it can induce cracks and considerably reduces the static and fatigue strength of the nitrided alloys.

Consequently the relationship between structure and material properties needs to be explored. The goal is to identify the structural elements which are responsible for the materials degradation. Process windows need to be established that add improved wear resistance while maintaining the required material strength.

OUR SOLUTION

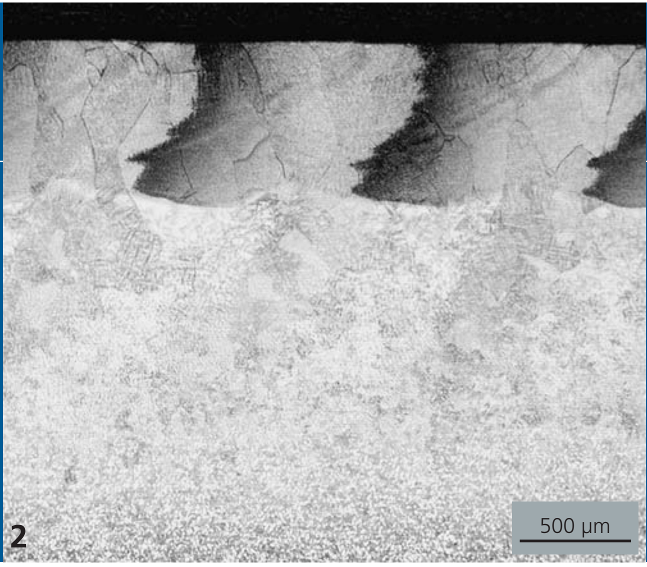
IWS engineers developed equipment and a technology for the laser gas nitriding of three-dimensional components. The system is flexible, productive and suitable for industrial deployment. It consists of a process chamber, a swiveling yoke and a bell shaped cover through which the gas and laser radiation are delivered to the processing zone (Fig. 1).

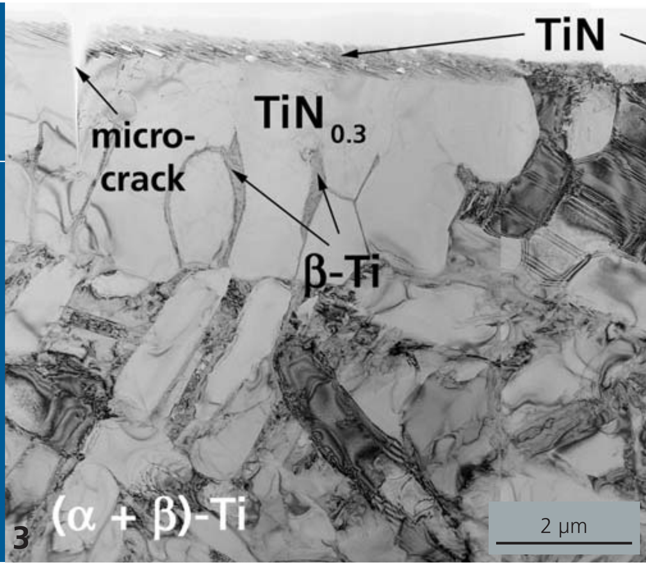
Adjustable process parameters include the amount of nitrogen, the laser power, the track offset and the speed. Several titanium alloys were treated with varied parameter sets. The laser gas nitriding process forms microstructures, which were analyzed in detail using optical and electron microscopic methods. The mechanical properties and the wear behavior of the treated samples were characterized in detail.

RESULTS

By varying the process parameters it was possible to generate wear resistant surface layers with thicknesses ranging from 0.1 - 1 mm (Fig. 2). The hardness ranged from 400 - 1500 HV. Conventional laser gas nitriding reduces the normally high mechanical load bearing capacity of titanium alloys. The material becomes more sensitive to cracks under static bending and loses fatigue strength with increasing nitrogen content. Microstructural elements responsible for the deterioration of these properties were identified. These include coarse titanium nitride phases ($TiN_{0.3}$, TiN) and thin surface layers (Fig. 3). The thin surface layers are formed during cooling when more nitrogen is absorbed, which leads to subsequent solid phase diffusion. They consist of titanium nitride phases and coarse α-Ti grains ("α-case") and contain small pores and cracks.

The fatigue strength of laser nitrided Ti-6Al-4V can reach or even exceed the very high levels of the as delivered state if the formation of coarse and brittle titanium nitrides is prevented



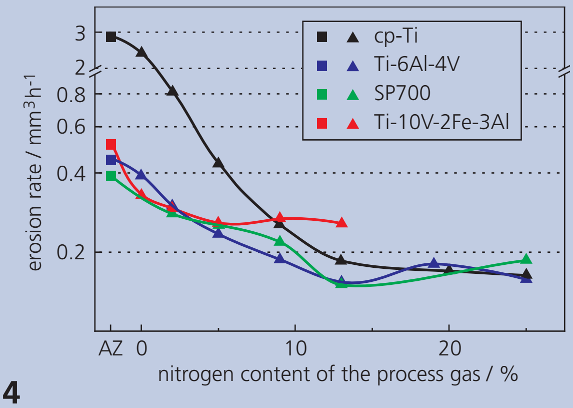


by reducing the nitrogen content of the processing gas and additionally if the thin top layers are removed by grinding or shot peening.

During laser gas nitriding only small quantities of nitrogen are sufficient to increase hardness and erosion resistance of titanium alloys (Fig. 4). The erosion resistance in all titanium alloys is mainly determined by the solid solution hardening due to the nitrogen being dissolved in the hexagonal titanium lattice. The most nitrogen can be interstitially dissolved in cp-Ti. This is also the titanium alloy which exhibits the lowest resistance to induced wear. Therefore the effect is the largest for this titanium alloy.

So far experts agreed that laser gas nitriding of titanium alloy should not be applied to cyclically loaded components. The desired increase in hardness was simultaneously connected with a drastic loss in cyclic strength. However, within the current project we are exploring novel strategies to make it possible to combine high wear resistance with reasonable high static and cyclic strength. This offers new opportunities to use laser gas nitriding in the future for components made of titanium alloys and used under high cyclic loads.

Cavitation erosion resistance of different laser nitride titanium alloys in dependence of the nitrogen content of the processing gas



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1 Systems technology for laser gas nitriding

2 Cross section through Ti-6Al-4V after laser gas nitriding

3 TEM cross section in the surface near region with top layers, fine pores and cracks after laser gas nitriding

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