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Effect of shotpeening on sliding wear and tensile behavior of titanium implant alloys

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ABSTRACT

Titanium has good biocompatibility and so its alloys are used as implant materials, but they suffer from having poor wear resistance. This research aims to improve the wear resistance and the tensile strength of titanium alloys potentially for implant applications. Titanium alloys Ti–6Al–4V and Ti–6Al–7Nb were subjected to shotpeening process to study the wear and tensile behavior. An improvement in the wear resistance has been achieved due to surface hardening of these alloys by the process of shotpeening. Surface microhardness of shotpeened Ti–6Al–4V and Ti–6Al–7Nb alloys has increased by 113 and 58 $HV_{(0.5)}$, respectively. After shotpeening, ultimate tensile strength of Ti–6Al–4V increased from 1000 MPa to 1150 MPa, higher than improvement obtained for heat treated titanium specimens. The results confirm that shotpeening pre-treatment improved tensile and sliding wear behavior of Ti–6Al–4V and Ti–6Al–7Nb alloys. In addition, shotpeening increased surface roughness.

1. Introduction

The introduction of compressive residual stress in the surface layer by surface modification technique such as shotpeening can mitigate wear and improve mechanical properties. Shotpeening is a method of cold working in which compressive stresses are induced in the exposed surface layers of metallic parts by the impingement of stream of shots, directed at the metal surface at high velocity under controlled conditions. It differs from blast cleaning (shot blasting), the purpose of which is to clean and remove impurities on the surface. It can also improve the surface roughness to develop the osseointegration of the materials to be implanted. Although shotpeening cleans the surface being peened, this function is incidental. A major purpose of shotpeening is to increase the fatigue life of the components.

The immediate effect of bombarding high velocity shots onto a metallic target is the creation of a thin layer of high magnitude compressive residual stress at or near the metal surface, which is balanced by a small tensile stress in the deeper core, as shown in Fig. 1 [1]. When individual particles of shot in a high velocity stream contact a metal surface, they produce light and rounded depressions in the surface, stretching it radially and causing plastic flow of surface metal at the instant of contact. The effect usually extends to about 0.13–0.25 mm, but may extend as much as 0.5 mm below the surface. The metal beneath the layer is not plastically deformed. In the stress distribution that results, the surface metal has induced residual compressive stress parallel to the surface, while metal beneath has reaction induced tensile stress. This compressive stress offsets any service imposed tensile as encountered in rolling or bending, and improves fatigue life of parts in service markedly.

Peening action improves the distribution of stresses in surfaces that have been caused by grinding, machining, or heat treating. It is particularly effective on ground or machined surfaces, because it changes the undesirable residual tensile stress condition that these processes usually impose in a metal surface to a beneficial compressive stress condition. Shotpeening is especially effective in reducing the harmful stress concentration effects of notches, fillets, forging pits, surface defects, and the low strength effects of decarburization, and the heat affected zones of weldments.

The magnitude of this compressive residual stress is a function of the mechanical properties of the target material and may reach values as high as 50–60% of the material's ultimate tensile strength. Its depth is largely dependent on the peening intensity and the relative hardness of the impinging shots and target material. For a relatively soft target material (230–300 HV), it is feasible to produce a compressive layer of 0.8–1 mm, whilst for a harder material (700 HV), it can be difficult to produce a compressive layer of much more than 0.2–0.25 mm. The introduction of this compressive residual stress at the metal surface layer brings one major benefit. It reduces and can negate any residual or

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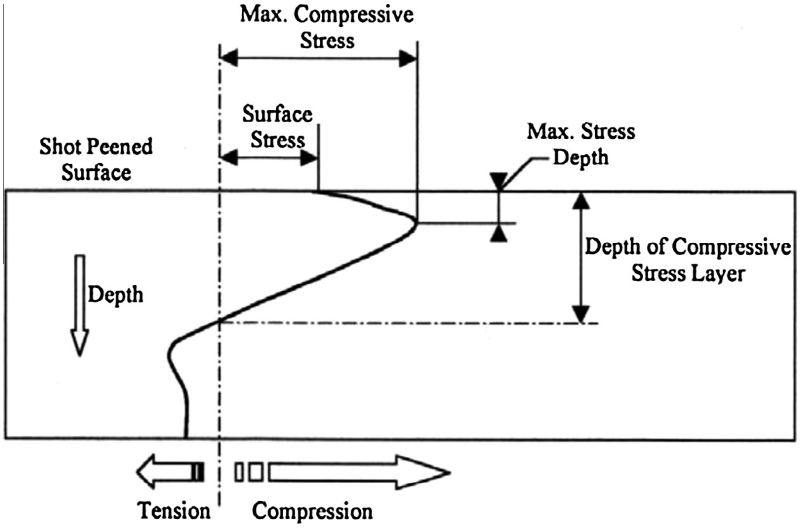

Fig. 1. Effects of shotpeening [1].

subsequently imposed tensile stress at the metal surface. It is well known that most fatigue failures and stress corrosion failures start at or near the surface stressed in tension. Therefore, by reducing the net tensile stresses at and near the surface of the component, fatigue crack initiation and stress corrosion can be delayed, improving the fatigue life of the component treated [1].

Media selection plays an important role to obtain the desired properties by the process. Many kinds of cast steel shots, cut wire shots, glass beads, and zirconium shots are available with various sizes. Depending upon the amount of pressure exerted through the blast nozzle and the surface being processed, each type of media can achieve different results. The resultant properties produced by the application of this process are almost limitless. Change in a few variables can alter various microstructural and mechanical properties of the peened specimens dramatically. It is important therefore to select the optimal variables after the right combination has been found for consistent and high quality results.

There are many ways to deliver the working medium to the surface being treated including compressed air, mechanical and water slurry. The most popular way is compressed air. Air blast is categorized into two methods of media delivery, *suction blast* and *pressure blast*. Suction blast systems are selected for light to medium amounts of production and moderate budgets. Suction is not as efficient as pressure, so the range of applications is more limited, but it often yields comparable results. Suction systems have the ability to blast continuously without stopping for media refills. They are also simpler to use and have fewer wear parts, making them inexpensive and easy to maintain. Suction systems work on the principle that air passing over an orifice will create vacuum at that point. This action takes place in the hand held suction gun, with a media hose connected from the vacuum area to media storage hopper. Compressed air is piped into the back of the gun and causes the lifted media to be blown out of a nozzle on the front of the gun. Energy is expended indirectly to lift the media and then mix it with the compressed air, making suction less efficient than a pressure system.

Pressure blasting feeds media into the compressed air stream at a pressurized storage vessel. The media then accelerates in the air stream as it is routed by a blast hose to the nozzle. Resulting media velocity is often several times that of a suction system, resulting in a common fourfold increase in production. Direct pressure uses force, rather than suction, so it offers much more control at very high and very low operating pressures. Low pressure is used for delicate or fragile substrates, such as removing carbon from aluminum pistons or flash from integrated circuits. Direct pressure systems are especially useful for finishing hard-to-reach recessed areas and odd shapes.

The shotpeening process has to be precisely controlled and repeatable for optimum benefit. To achieve this, all its process variables must be identified and controlled [2]. There are many fundamental parameters affecting the shotpeening processes. The most common are as follows:

(1) Shot density
(2) Hardness and size of the shots
(3) Nozzle characteristics (diameter, deflection angle, length)
(4) Air pressure
(5) Impact angle
(6) Exposure time
(7) Linear and rotational speed of work piece relative to the nozzle.

To specify all these variables, every shotpeening job would require time consuming investigations and industrially impractical procedures. To overcome this problem, a concept was introduced, of peening intensity measurement based on the curvature induced in a thin test strip, by which most of the listed process parameters can automatically be incorporated into one process variable called the Almen peening intensity. With the peening intensity known, one has to only define the shot type and size and peening coverage desired to fully define the peening process. Despite important progress in understanding the process, some areas are not totally mastered yet and difficulties are still hard to avoid. Being able to predict the effect of process in set conditions is indeed the key to gaining complete control over the process and to making it much more reliable.

Surface hardening by shotpeening is one of the upcoming research areas that requires much attention. This process of surface hardening is an important application for improving various mechanical properties which have a poor response to heat treatment process. The application of shotpeening is very vastly studied in terms of improvement of fatigue life for the components working in a cyclic loading environment including biomaterials where the compressive residual stress is induced into the component to prevent crack initiation and propagation. Nowadays this process is also used to improve the microhardness of the peened surfaces.