A body implant made of titanium alloy

TECH FRONTIERS

Fatigue and wear behaviour of Ti-6Al-4V implant alloy

Titanium and its alloys have very attractive properties that enable them to be used in the fields of aero space, biomedical, marine, and also in many corrosive environments. The usage of Ti alloys is more distinct these days in the area of biomedical implants due to superior biocompatibility and corrosion resistance and superior strength. However, due to high coefficient of friction, these alloys have more wear rate. The aim of present study is to examine the tribological and fatigue behaviour of implant alloy Ti-6Al-4V (Ti64) in the field of medical orthopaedics. The tribological behaviour was investigated by conducting wear tests on pin-on-disc tribometer at varying speeds and at a constant normal load. The tests were conducted for a constant sliding distance of 500 metre. The test results indicated that both frictional coefficient and wear volume are decreasing with increase in the sliding velocity of the alloy. Most of the medical elements fails due to fatigue and wear during the operation. Fatigue failure is sudden and happens without any prior intimation under cyclic loading. The lifecycles survived by the Ti-6Al-4V implant alloy were calculated at constant bending moment and at different speeds using RR rotating beam fatigue machine

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TITANIUM alloys used as biomaterials for permanent orthopaedic implants are predominantly subjected to cyclic loading. Among various materials currently employed, the alloy Ti-6Al-4V has found wide biomedical applications due to the better mechanical properties. The usage of Titanium alloys in engineering applications is increasing in the present days because of their superior strength, corrosion resistance, and low density. These alloys find many applications in the areas of aerospace, automotive, nuclear, chemical, marine, and biomedical. Ti64 implant alloy alone covers about half of the total world production of titanium alloys. [1]

Ti-6Al-4V alloy possess less wear resistance that restricts its applications predominantly in tribological area. [2,3] The wear rate of quenched specimen is very low due to the presence of protective oxide coating layer which is formed during heat treatment. [4] The most widely used biomaterial was commercially pure titanium (CP-Ti) [5,6], even though it has low strength, difficulty in polishing and poor wear resistance. Titanium is still insufficient for high-stress applications of long spanned fixed prostheses and the frameworks of removable partial dentures [7,8]. The high biocompatibility of Ti and its alloys has resulted better use over other alloy systems in the medical and dentistry areas. [9-11] The primary characteristics of Ti alloys in the in the field of biomedical include good mechanical properties, excellent corrosion resistance, good biocompatibility, light weight, etc. Hence, Ti and Ti alloys are ideal choices for implantation. The Ti alloys exhibit poor tribological properties due to their low resistance to plastic shearing, low work hardening and low protection exerted by surface oxides. [12] The fatigue limit of a component is usually determined at specified number of cycles. [13]

Based on the fatigue life concept, the metal fatigue can be subdivided into three categories. The first one – low cycle fatigue (LCF) – is up to 10^5 cycles to failure. The second – high cycle fatigue (HCF) – is between 10^5 cycles and 10^8 cycles to failure. The third – very high cycle fatigue (VHCF) – is over 10^8 cycles to failure. [14] Most of the bio materials fail by fatigue and wear during their operation. Fatigue failure comes due to cyclic loading and is sudden, without any prior intimation. So it is a damaging process of components under cyclic loading. The purpose of the present work is to investigate the wear and fatigue behaviour of implant alloy with alloying elements of Al and V. A pin-on-disc type wear and friction monitor was used to study the tribological behaviour of implant alloys. Standard specimens were prepared by machining process and tested on fatigue testing machine under completely reversed bending. The specimens were tested under constant bending moment and at different constant speeds. The lifecycles survived and wear volume of the specimens were calculated from the experimentation.

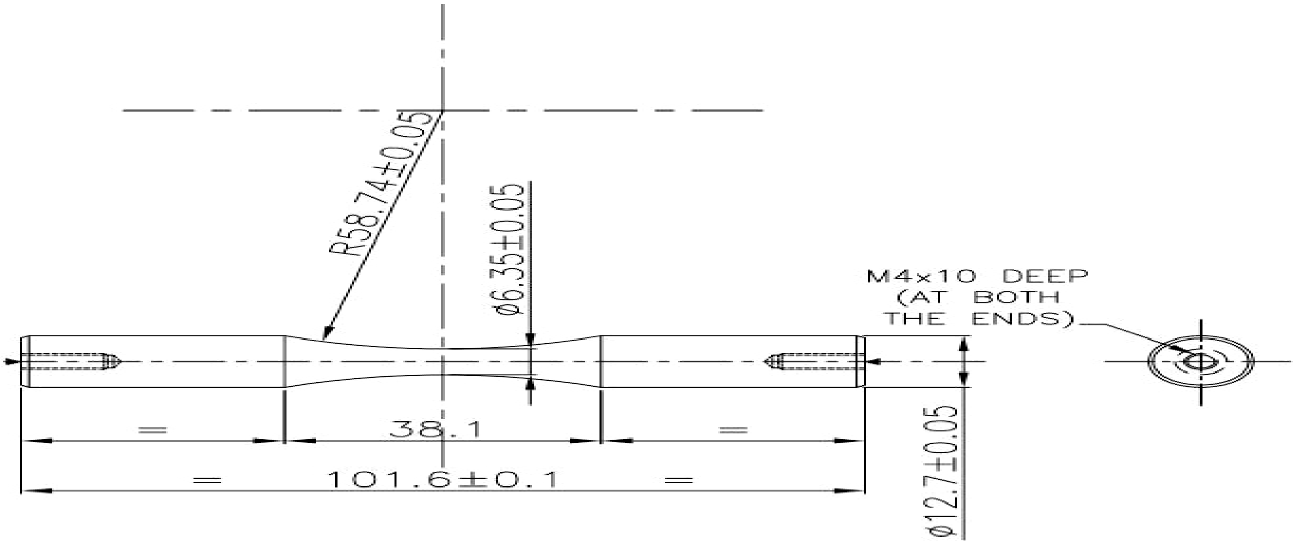
EXPERIMENTAL PROCEDURE

In the present investigation Ti-6Al-4V implant alloy was considered for the fatigue analysis using RR rotating beam fatigue testing machine (Ducom, Bengaluru) shown in **Figure1**.

Figure1: Rotating beam fatigue testing machine

The rotating beam fatigue testing machine involves the preparation of carefully polished test specimens (surface flaws are stress concentrators) which are cycled to failure at stress levels. The fatigue test specimens are machined from test samples with the aid of especially sharp cutting tools to avoid any other additional deformation or over heating during machining. The specimens are ground on precision machine and finally polished in longitudinal direction of the specimen with the finest grade of emery. During machining care must be taken to avoid undercuts at the transition of fillets and cylindrical section. The test specimen must be greased with non-corroding grease to protect against undesirable corrosion. The fatigue test specimens were prepared as per the DIN 50113 standards. **Figures 2 & 3** show the schematic diagram of the fatigue test specimen and sample fatigue test specimens respectively.

Figure2: Schematic diagram of fatigue test specimen



A fatigue rotating beam testing machine was used to compute the lifecycle of Ti-6Al-4V implant alloy. The fatigue machine is used to expose the mechanical behaviour of materials and machine parts subjected to stresses, which continuously or repeatedly alternate about a mean value of zero between positive and negative values of equal magnitude. The test specimen is rotated by means of an AC motor. The specimen is supported on one end and load is applied at the other end by means of loading lever arrangement. The test duration and number of cycles are displayed on the front panel. The motor of the fatigue machine stops immediately when specimen fractures during test. The speed of motor is varied by an AC drive.

The spindle of the fatigue test machine is mounted on double row taper roller bearings. One end of the spindle is a taper to seat collet and the other end is connected to motor shaft through a coupling. Spindle is housed in housing and firmly clamped on to base plate. The specimen for test is clamped on collet and rotated by motor. One end of specimen is clamped on collet and firmly rotated with it, the other end of specimen is subjected

Figure3: Sample fatigue test specimens

Figure4 Controller of fatigue machine

to normal load by suspending a holder on the outer diameter. The specimen rotates inside the holder on bearing and is pulled down to apply load by loading lever. A load cell is connected between the specimen holder and loading lever to measure applied radial load. A part catcher is fixed below the bearing support to collect the specimen after fracture.

The machine operation is controlled by an electronic controller and is placed near the machine at a convenient position for operation. The controller is connected to machine through control cable and signal input cable. For easy operation of machine all switches are mounted on the front panel of controller. The front panel of controller has four displays, namely, normal load, counter, speed, and timer. The potentiometer knob is used for setting the speed of the specimen in rpm. A toggle switch is used for selecting mode of test duration either in time or rev mode. The controller of the fatigue testing machine is shown in **Figure4**.

A pin-on-disc type wear and friction monitor (TR-20LE, Ducom Bengaluru) with data acquisition system shown in **Figure5** was used to measure the wear behaviour of Ti-64 implant alloy.

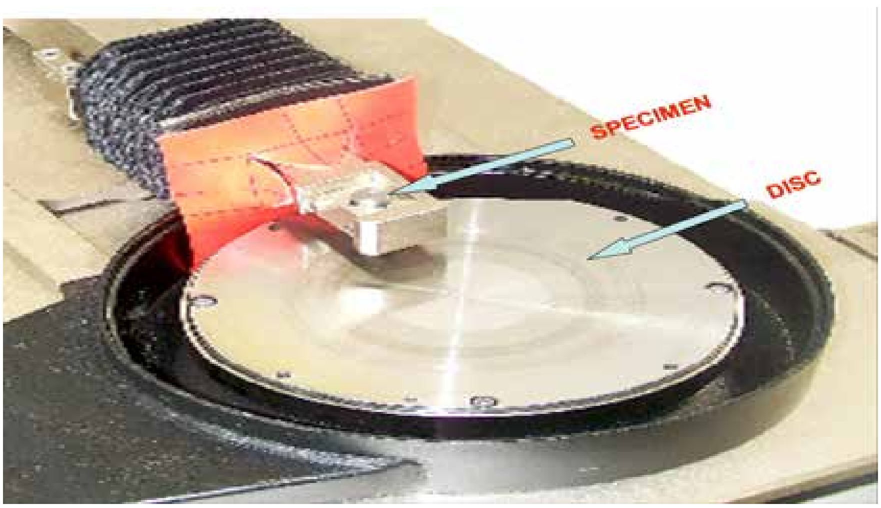
The wear test pins of 8 mm diameter and 25 mm length were prepared as shown in **Figure6**.

The wear and friction monitor consists of hardened ground steel (En-31) disc having hardness of RC62 and surface roughness (Ra) 0.1μm. Track diameter of 100 mm was selected for the wear and friction analysis. During sliding, the change in the height of the specimen was recorded using LVDT (accuracy ±1μm with maximum displacement of ±2 mm). Before the test, the polished pins were cleaned and degreased using ultrasonic cleaner, first with water and soap, followed with ethanol and finally with acetone. Cleaned samples were dried before conducting the wear experiment. **Figure7** shows the photograph of the test specimen on the tribometer disc.

Figure5: Pin-on-disc wear testing machine

Figure6: Wear test specimens

Figure7: Photograph of test specimen on tribometer disc



RESULTS AND DISCUSSION

A fatigue rotating beam testing machine is used to calculate the lifecycle of Ti-6Al-4V implant alloy. When the specimen is rotated about the longitudinal axis, the upper and the lower parts of the specimen gauge length are subjected to tensile and compressive stresses respectively. Therefore, stress varies sinusoidally at any point on the specimen surface. The test proceeds until failure of specimen takes place. The number of cycles survived by the test specimen at constant bending moment and at different constant speed is counted when specimen fractures during the test.

Fatigue test was conducted on the specimens for a constant load of 77.5 kg and at different rotating speeds of 2000 rpm and 2500 rpm under complete reversed bending before fracture occurs. **Figure8** indicates the lifecycles of the test specimen survived under constant load and different speeds before fatigue occurs.

It is observed from the fatigue test that the lifecycles survived by Ti-6Al-4V implant alloy at 2000 rpm is more at a given constant load of 77.5 kg before fatigue failure occurs. But at higher speed of 2500 rpm, it is observed that the lifecycles survived by the test specimen are decreased under the same conditions.

The wear test of the Ti-6Al-4V implant alloy was carried out on wear and friction monitor at the normal load of 20N and at different constant sliding speeds. It was observed that seizure does not take place at this load and speeds. Seizure is a phenomenon of the test specimen becoming welded to the wear disc at high loads and higher sliding speeds of the disc due to wear. At seizure, there will be more noise and vibrations. Tests were stopped at this load and speed. The frictional force and wear volume of the alloys were calculated at varying speeds 0.3 m/s to 1.5 m/s in steps of 0.3 m/s for a sliding distance of 500m are shown in **Figures 9 & 10** respectively.

Figure8: Lifecycles of Ti-6Al-4V alloy

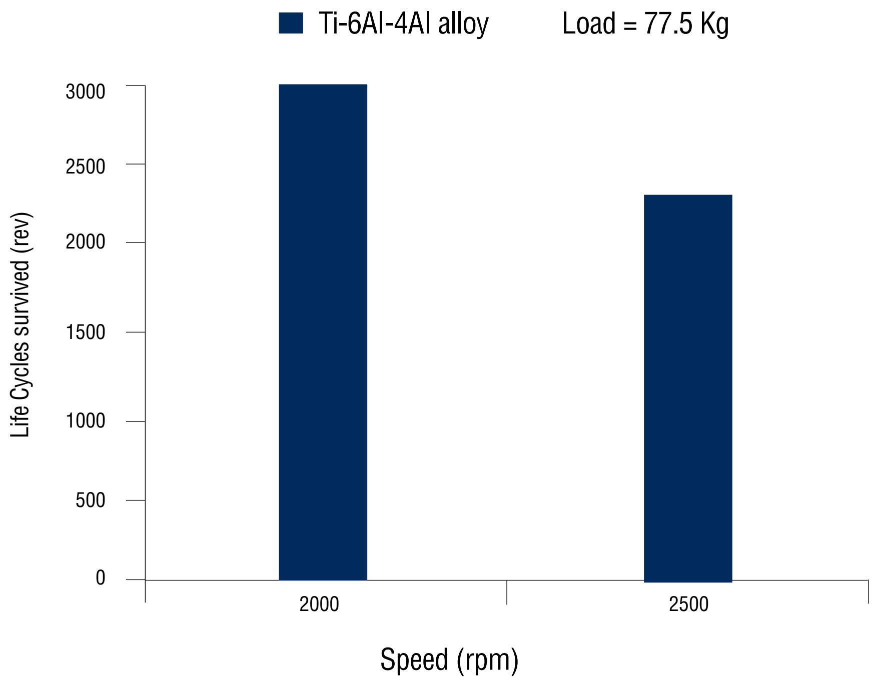
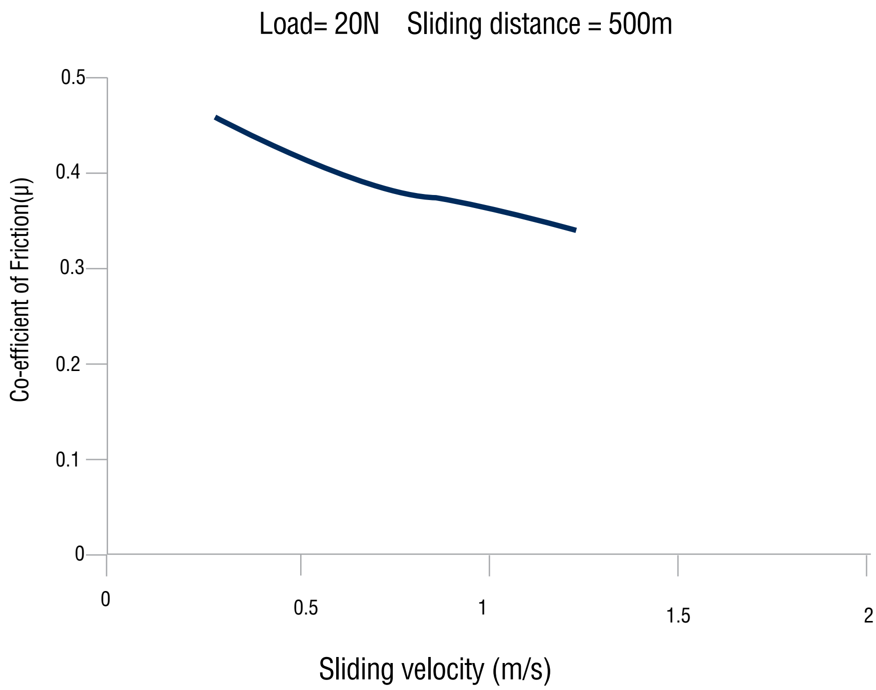


Figure9: Coefficient of friction of Ti-64 alloy



It was observed that the coefficient of friction at low velocity is more and decreases when the sliding velocity increases. Similarly the wear volume is more at lower speeds and decreases with increasing sliding velocity of the Ti-64 implant alloy.

CONCLUSIONS

The variation of the speed on the lifecycles and wear volume of Ti-6Al-4V implant alloy using RR rotating beam fatigue testing machine and tribometer was investigated and the following conclusions were drawn.

• The lifecycles of the Ti-6Al-4V implant alloy depend on the speed.

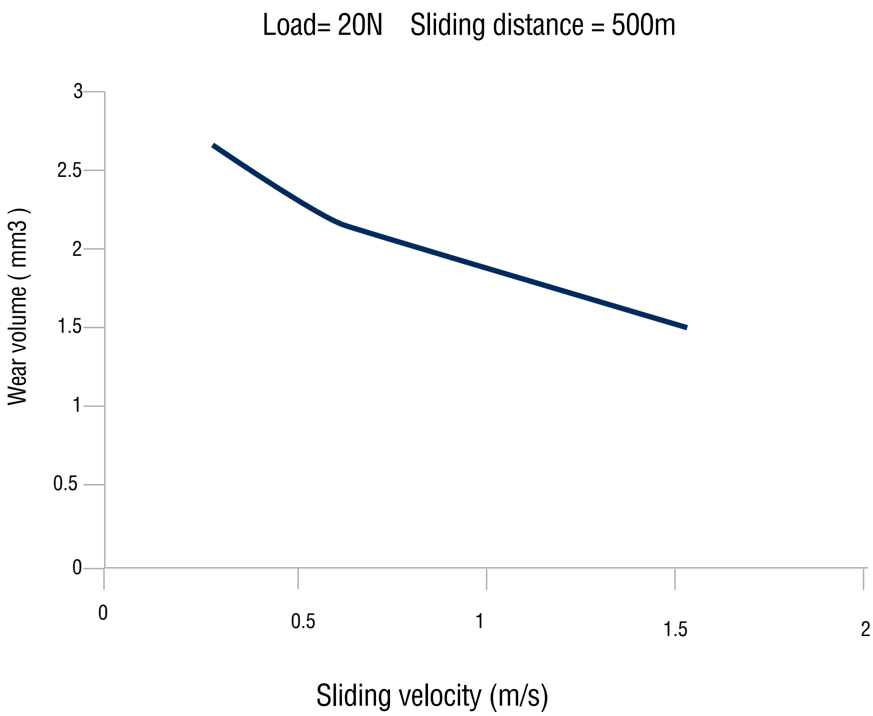
• It was observed that the lifecycles survived decreases when the speed increases.

• It was observed that the coefficient of friction of Ti-6Al-4V implant alloy decreases when the sliding velocity increases.

• It was observed that the wear volume of Ti-6Al-4V implant alloy was more at low sliding speeds.

• It was observed that the wear volume of Ti-6Al-4V implant alloy decreased when the sliding velocity increased.

Figure10: Wear volume of Ti-64 alloy



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