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Investigation on the wear resistance of AISI 316L with micro dimples as a material for human implants' structure

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Abstract Over the past five decades, artificial hip joint materials, such as ceramic, titanium, and cobalt-chromium molybdenum alloy, with significantly improved wear resistance or biocompatibility have been developed and used in medical procedures. The application of AISI 316L, a first-generation artificial joint model, is limited due to its low wear resistance and corrosion resistance. However, AISI 316L is still used in medical procedures. Therefore, improving the wear resistance and corrosion resistance of AISI 316L has attracted research attention. This study aims to improve the wear resistance of AISI 316L for metal on metal (MoM) combination by applying surface texturing technology. Herein, surface work hardening and the generation of the prow of the AISI 316L material were controlled by the dimple effect, the width of the deep groove shown in the profile of the wear surface was reduced by 2 times compared to the surface without dimples.

1. Introduction

AISI 316L is an economic material with good corrosion resistance, and hence, has been adopted as the first-generation artificial femoral head. However, owing to its low yield strength and wear-corrosion properties, parts requiring long-term use, such as artificial femoral head, have gained wide attention [1, 2]. Nevertheless, AISI 316L is still being used for economic reasons in some regions and reportedly accounts for 15 % of the metal head bone material used in medical procedures [3]. Accordingly, improvements in wear resistance and corrosion resistance are required to ensure long-term use of AISI 316L.

Surface texturing technology has been extensively studied to help fluid lubrication of mechanical parts such as journal bearings or sliding bearings [4-8]. Surface texturing creates micro-sized dimples or patterns on the contact friction surface, which improves the load bearing capacity of the internal fluid, acts as a reservoir for lubricant, and lubricates the fluid by trapping wear particles. Furthermore, it lowers abrasion and reduces boundary friction [9-14]. The structure of the femoral head and the aspherical surface of the artificial hip joint are similar to mechanical bearing parts and comprises materials such as metal, ceramic, or polyethylene [15]. Although these parts are designed to be similar to normal joints as much as possible, side effects such as osteolysis occur owing to the generation of wear particles caused by differences in the lubrication of bearing surfaces (femoral head and aspherical surfaces) and normal joints [15, 16]. Therefore, the femoral head requires particularly good wear resistance properties. Therefore, research should be conducted on the application of surface texturing as an alternative for reducing friction and wear between the femoral head and acetabulum, which have structures similar to that of a mechanical bearing part [17-26].

According to a previous study, fine dimples were created on femoral head or liner (or acetabular cup), or a pin on disk friction test piece was created on the disk surface to evaluate the wear characteristics [17]. The combination of friction test specimens is selected based on the actual artificial hip joint bearing combination and studied in the form of ceramic on metal (CoM), metal on metal (MoM), ceramic on ceramic (CoC), metal on polyethylene (MoP), ceramic on polyethylene (CoP), etc. depending on the classification of the bearing materials. Among them, the MoP combination, wherein a polyethylene liner is inserted between the femoral head and the acetabular cup, occupies a large proportion in the study of surface texturing for artificial hip joints, considering the wear particles generated from the polyethylene liner were found to be the main cause of osteolysis in the MoP combination, which was developed in the early days of artificial joints and has been used the most until now [16]. Nishimura et al. [18], López-Cervantes et al. [19], and Zhang et al. [20, 21] experimentally derived the optimal texture aspect ratio and density in a combination of stainless steel and UHMWPE and reported friction and wear reductions of approximately 14 %-25 % and 33 %, respectively.

In contrast, in case of MoM, CoC and other combinations, although they were developed to solve the osteolysis problem of MoP combinations, they are not much applied in medical treatment owing to the generation of fine abrasive particles and other side effects such as edema and breakage. As a result, the study of surface texturing was relatively insufficient. Therefore, it is necessary to conduct surface texturing studies by applying various materials for MoM and CoC combinations with low osteolysis. Roy et al. [22, 23], Choudhury et al. [24], Pratap et al. [25], and Lee et al. [26] carried out a study on surface texturing by extending it to other combinations of the artificial hip joint, such as the CoC and MoM combinations. The results of improved wear resistance were previously reported. The CoC combination was employed for alumina ceramic bearings, and the MoM combination for bearings of a cobalt-chromium-molybdenum alloy or Ti6Al4V-ELI/oxidized Ti6Al4V-ELI alloy. However, for AISI 316L, there are no surface texturing studies for MoM combinations. As mentioned above, AISI 316L material is still being treated in some areas, and it is a material that is continuously used as a biomaterial in various applications as well as artificial joint combinations. Therefore, similar to other biomaterials, it is necessary to study the wear resistance of various material combinations to improve their mechanical and chemical properties.

It is necessary to consider the phase change properties of the austenitic steel series in the wear resistance study of AISI 316L material. This property, commonly referred to as work hardening, has also been reported in previous studies on mechanical cutting of austenitic steels [27]. Zandrahimi et al. [28] reported that the austenite phase transforms into the martensite phase as wear or cutting progresses, and the influence of microhardness changes affects the wear behavior and machinability of the material. Therefore, while analyzing the effect of dimples on the MoM combination, it is necessary to check how the phase change of the wear-progressing region affects the wear resistance of the dimpled surface. In this study, we analyzed the changes in the wear resistance properties in terms of work hardening and dimples for combinations of AISI 316L materials other than MoP. Such efforts may contribute to improving the reliability of the material's service life in the body.

To verify this, a dimple was applied to the MoM combination of AISI 316L material with work hardening properties and we evaluated the changes in the mechanical wear properties in a bovine serum lubrication environment. This showed that the dimples present on the friction surface improved the wear resistance of the MoM combination by delaying the work hardening and generation of the prow of AISI 316L material, which in turn improved the lifespan. Sec. 2 describes the experimental method in detail and Sec. 3 examines the wear reduction effect. Sec. 4 summarizes the study and describes the future research direction.

2. Experimental details

2.1 Specimen preparation

In this study, the pin-on-disk friction test was performed using steel grades produced by POSCO (ASTM-A240M). AISI 316L, a low-carbon austenitic steel with a carbon content of 0.03 % or less, exhibits improved corrosion resistance, and hence, can be used as a biomaterial. The experiment was performed using the same material for both the pin and the plate, and the mechanical properties and chemical composition of the materials are summarized in Tables 1 and 2, respectively. In the pin-on-disk friction experiments, friction pairs were usually made of different materials, given that when a wear test is performed using the same material, materials such as titanium are prone to adhesive wear, which influences the results [29]. However, the MoM combination of the artificial hip joint comprised the head and liner of the same material [30]. The sizes of the cylindrical pin and rectangular plate used in the experiment are Ø5 × 30 mm and 40 mm × 70 mm × 3 mm, respectively. The surface roughness of the flat plate after polishing is Ra 0.04 μm, which satisfies the required roughness of the bearing surface for the artificial hip joint.

2.2 Surface texturing processing

Surface texturing was performed using a 3-axis micro-

Table 1. Mechanical properties of AISI 316L (pin and plate).

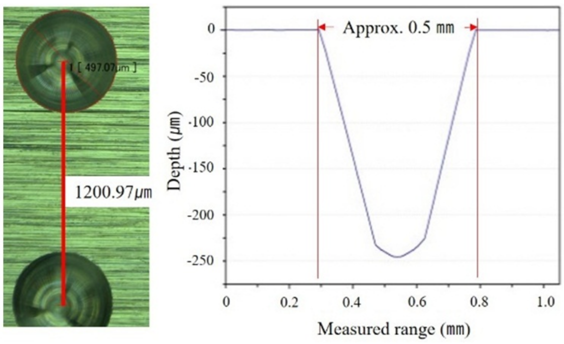
Hardness (HRC)	30
Tensile strength, ultimate (MPa)	580
Tensile strength, yield, 0.2 % (MPa)	290
Elongation (%)	52

Table 2. Chemical composition of AISI 316L (pin and plate, unit: Wt.%).

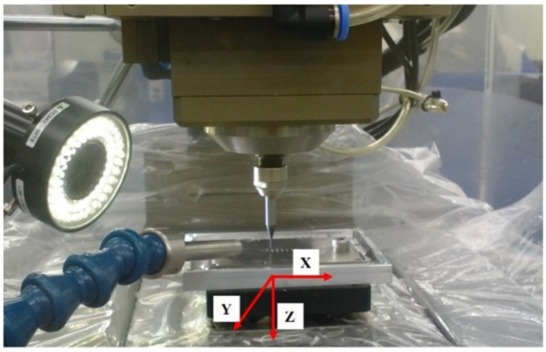
Fe	Cr	Ni	Mo	Mn	C	Si, Cu, P, S
Bal.	16.519	10.079	2.034	1.110	0.0216	0.0019-0.573

Table 3. Machining conditions used in the surface texturing process.

Cutting tool	Ø 0.5 mm, ball-endmill
Machine tool	3-axis micro milling-machine (KIMM)
Spindle speed (RPM)	33,600
Depth of the cut (μm)	80
Lubricant	Oil mist



(a) Profile of the dimples



(b) Three-axis micro-milling-machine

Fig. 1. (a) Profile of the dimples; (b) three-axis micro-milling-machine.

milling-machine (KIMM [31]) as shown in Fig. 1. Micro-milling reduces the occurrence of burrs and damaged layers after processing, and is more advantageous in terms of energy efficiency for machining sub-micro shapes. The fine dimples were 0.5 mm in diameter and 0.25 mm in depth with an aspect ratio of 0.5 (Fig. 1(a)), and the density occupied by the dimples was 16 % (interval 1.2 mm). The surface texturing parameters that affect lubrication, such as the shape, density, and spacing of the micropatterns applied in this study, were selected based on the results of our previous study, the titanium oxide-titanium combination study [26]. The previous study referred to the optimal surface texturing parameters reported by Nishimura [18], which demonstrated that the maximum wear reduction rate could be obtained at a dimple diameter of 0.4–0.5 mm and a spacing of 1.2 mm. Our previous study also showed excellent friction/wear reduction effect on the oxidized titanium surface under the same conditions. A ball-endmill was used for valley shape processing. The processing conditions are summarized in Table 3.

2.3 Pin-on-plate wear test

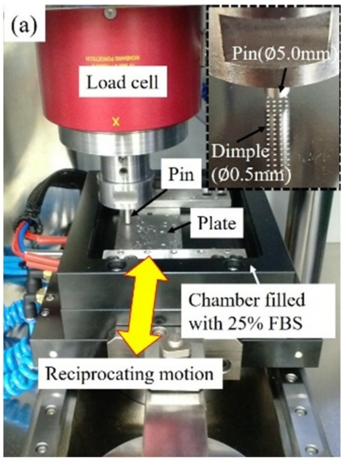
The wear evaluation on the artificial hip bearing surface was typically divided into two methods: the first used a hip joint simulator suggested by international standards, whereas the second used a two-dimensional tribometer device. The hip simulator can continuously applying double peak loads and three-axis motion to the bearing surface through programming. However, it is expensive for application in a small laboratory and cannot provide sufficient friction coefficient in real time [23]. Therefore, several experimental studies have adopted a tribometer as an alternative for evaluating the wear properties in the form of PoD or BoD [17, 23]. Furthermore, wear tests of AISI 316L specimens with fine dimples were performed on a tribometer device (UFW200; Neoplus) in a pin-on-plate method.

The pin-on-plate wear test conditions were selected similar to that in the previous study [26]. In previous studies, conditions were selected by referring to the international wear test standard (ISO14242-1) and previous studies [32-35]. Unlike the simulator, the tribometer device can implement a single load-single motion. Therefore, the sliding speed of the plate was determined by selecting the flexion-extension (FE) motion among the three-axis movements of the hip joint defined in the international standard. The FE motion was selected by many researchers including Dowson [32], and the average angular velocity was 1.5 rad/s, which when converted to a sliding speed for the diameter of the femoral head of 22 mm was ±16.5 mm/s, which can be considered for setting the travel distance for the reciprocating linear motion. The contact pressure applied to the hip joint during the gait cycle of a person weighing 70 kgf varies from 1 to 10 MPa. In both this study and previous studies, we have chosen an average value of 5 MPa as the contact pressure [26, 36].

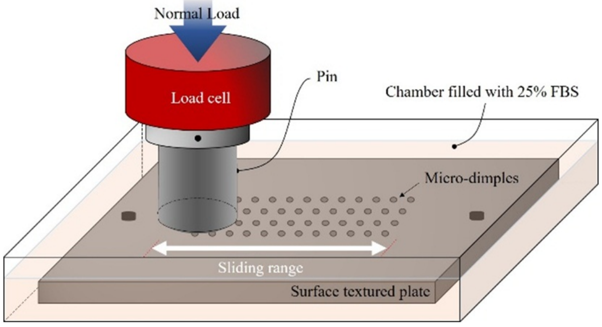
As shown in Fig. 2, a cylindrical pin (Ø5 mm × 30 mm) with a flat contact surface was fixed to the load cell, and the plate was precipitated in 25 % diluted fetal bovine serum (FBS). The behavior of the human body is slower than general mechanical parts, and it behaves in the mixed fluid lubrication area. The synovial fluid has a lower viscosity compared to the lubricating oil of mechanical parts [36]. According to Cakmak et al. [37], the viscosity of FBS at room temperature (25 °C) under atmospheric pressure is 1.105 cP, and at body temperature (37 °C), it is 0.861 cP. Therefore, when body fluid or diluted bovine serum is used as a lubricant when performing abrasion tests on biomaterials, the reliability of wear characteristics evaluation results can be increased. The total wear test time was set to 5×10^3 cycles and 5×10^4 cycles, and the plate was moved back and forth in a straight line at a speed of 1 Hz. Simultaneously, the stroke was 15 mm, load was 100 N, and the contact pressure was 5 MPa. Abrasion tests were performed on specimens with and without dimples.

2.4 Measurement equipment

A scanning electron microscope (SEM) equipment was used



(a) Pin-on-plate test system



(b) A schematic of the wear tests

Fig. 2. (a) The pin-on-plate test system; (b) a schematic used for the wear tests.

to image the dimple shape and surface before and after the wear test. Abrasion depth was measured using a surface roughness tester (PGI 2000S; Tayler Hobson), and surface hardness was measured under a load condition of 4.903 N using a micro-Vickers hardness tester. X-ray diffraction (XRD) equipment was used to analyze the phase change depending on work hardening before and after the wear test. XRD profiles were recorded using CuKα radiation generated at 40 kV, 300 mA conditions. Scans were performed over the range of 2 theta (θ) from 20–80° at a scan rate of 4° per min, changing in 0.01° intervals.

3. Results and discussion

3.1 Effect of phase change on wear behavior

AISI 316L is a typical austenitic steel, which is generally metastable and exhibits a high strain-hardening rate. Therefore, phase change from austenite (γ) to martensite (α) occurs easily when the conditions for plastic deformation of the material are met during cold processing or sliding friction [28]. According to Wei et al. [38], plastic deformation caused by vertical load (compressive stress) and frictional force in a sliding friction environment induces a phase change of the material surface.

Table 4. Results of the micro-Vickers hardness (HV) tests on the AISI 316L samples.

Initial conditions	224
Worn surface (non-dimpled)	322
Worn surface (dimpled)	246

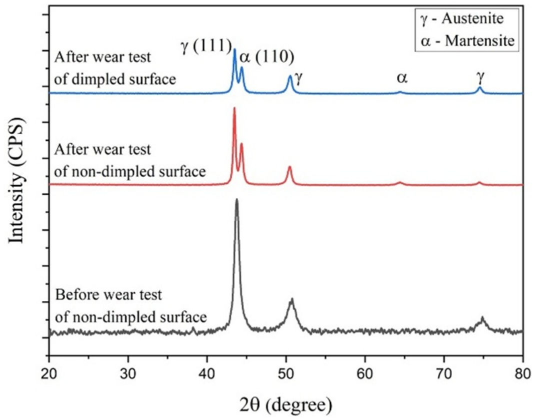


Fig. 3. XRD spectra before and after the wear tests conducted on AISI 316L.

Additionally, the martensite phase generated on the surface increases the surface hardness, and as the ratio increases, the hardness of the surface increases. Furthermore, we adopted the relative motion of the pin and plate as a linear reciprocating friction, that is, a repetitive sliding motion, which reflected the FE behavior of the artificial hip joint. Considering the results of the previous studies, we can conclude that the transformation to the martensite phase can be induced by friction during the wear test.

Fig. 3 shows the XRD analysis result of this study, which reveals the phase change of the surface with and without dimples before and after the wear test. In the XRD analysis results of the specimen without dimples, only the austenite phase (γ) was observed. However, after a wear cycle of 5×104, a peak corresponding to the martensite phase (σ) appeared on both the non-dimpled and dimpled surfaces. Additionally, as a result of measuring the hardness of the wear track with a micro-Vickers hardness tester (Table 4), the hardness increased in both samples compared to before wear, and the hardness of the surface without dimples increased significantly compared to that of the surface with dimples. Therefore, our wear test results show that a phase change to martensite occurred on both surfaces by sliding friction, which increased the surface hardness.

Although the martensitic phase produced during the frictional behavior increased the hardness of the wear surface, opinions are divided on how the occurrence of work hardening affects the wear behavior of austenitic steels. Some researchers [28, 39] reported that the formation of martensite increases the total wear and hardness of the surface. Zandrahimi et al. [28] observed that when a larger load is applied to AISI 304 with sliding friction, the thickness of the deformed layer on the wear surface as well as the amount of wear increases as the martensite phase increased. Furthermore, they analyzed that the increase in wear was due to the higher possibility that the deformed layer was separated as the load increased. Moreover, they confirmed that the microhardness of the two phases with a phase change was lowered than the original microhardness owing to the heat accumulated at the contact point during the wear test caused by the low thermal conductivity of the austenitic steel. This trend was also consistently shown in the experiments of Hsu et al. [36]. They explained the increase in wear rate owing to phase change through friction experiments on AISI 316, AISI 304, and Nitronic60 austenitic steels. Although the hardness of the surface increased according to the amount of martensite generated near the surface, the wear rate increased if the raw matrix supporting the hard and brittle deformed layer was not sufficiently hard. Conversely, Smith at el. [40] stated that the effect of martensite on the wear rate of austenitic steel was unclear in wear tests on AISI 316 at room temperature/no lubrication; instead, martensite contributed to the failure of the multi-layered prow created on the friction surface.

Wear particles are generated from the prow, and in case of a low load, the ductility decreases owing to surface oxidation and high martensite content. Then, the prow is broken by repeated impacts, generating wear particles. As such, there are differing opinions on the relationship between austenite phase transition and wear. Moreover, considering previous studies dealt only with surfaces without dimples, there is no discussion on the effect of martensite phase on wear of surfaces with dimples. Therefore, this study comparatively analyzed the effects of dimples on work hardening while considering the wear of the surface.

3.2 Dimple effect and creation of martensite phase

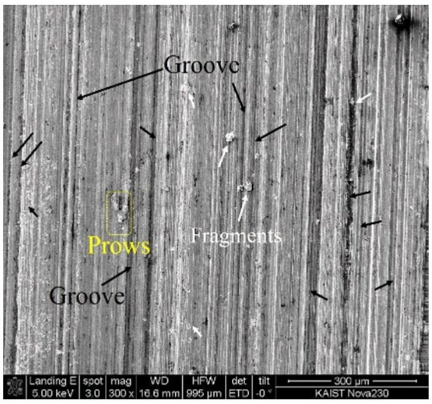
One of the main functions of textured surfaces, also known as the dimple effect, is that dimples increase the load-bearing of the internal fluid (i.e., lubricant) that exists between the two friction surfaces. As the load that can be supported increases, the lubrication regimes of the friction area moves to the fluid lubrication, thereby decreasing the contact between the two surfaces [36]. The artificial hip joint is a mixed fluid region where boundary friction and lubricating friction are mixed; the experimental environment of this study follows this. Therefore, when boundary friction is reduced owing to the dimple effect during sliding friction behavior, the generation of martensite in the surface owing to plastic deformation caused by frictional shear is suppressed.

We considered this assumption from two aspects with the wear test results. First, owing to the dimple effect, less martensite phase was generated on the wear surface with dimples, and the surface hardness increased less compared to the wear of the surface without dimples. This can be explained together with the micro-Vickers hardness measurement results in Table 4, where the hardness of the wear surface with and without dimples increased by approximately 10 % and 44 %, respectively, compared to the non-wear surface. As mentioned earlier, the austenite phase is transformed into a martensite phase as friction-induced deformation, and it is a general opinion that the surface hardness increases as the amount increases [38-40]. Additionally, although the surface hardness increases by work hardening, the wear increases owing to the difference in hardness between the deformed layer and the raw matrix, as well as the damage of the martensite phase. Therefore, through the difference in hardness increase between the two surfaces after the wear test, we derived the following facts. The dimples reduced boundary friction, which in turn reduced the generation of martensite on the friction surface and delayed work hardening, thereby reducing wear compared to the surface without dimples, although the surface hardness was less.

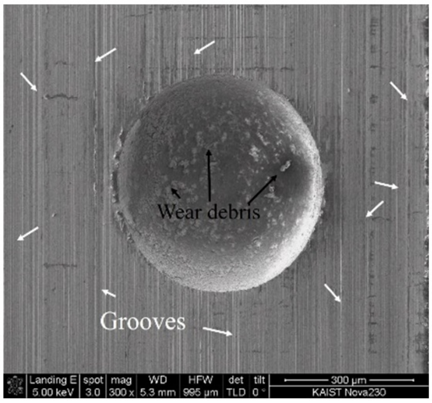
Second, the generation, growth, and breakage of prows on the surface were delayed as boundary friction was reduced by the dimples. Smith et al. [40] reported that a plateau or prow with a groove of 30–40 μm occurred on the wear surface during a non-lubricated, high-load friction test of austenite, a ductile metal. In this study, the generation, growth, and breakage of the prow affected the wear of the friction surface considering hard prow can be generated as fragments by gouging, plowing, or crushing the opposite surface. Furthermore, it can be predicted that if the factors affecting the occurrence of prow are eliminated, the wear caused by prow can be reduced. Moreover, the prow of austenitic steel is produced as the work-hardened material that removes the relative friction surface owing to the interaction of two ductile friction surface protrusions, and the removed materials are then fused and flattened [40]. High load condition and as the wear time increases, the size of the prow increases and forms a multi-layered structure, which then discharges fragments comprising brittle martensite particles.

Therefore, it is important to reduce the load applied to the friction surface and the boundary friction. Therefore, the dimple, which reduces the frequency of boundary friction and introduces bovine serum acting as lubricant into the friction pair, could have a positive effect on the wear of the hip bearing.

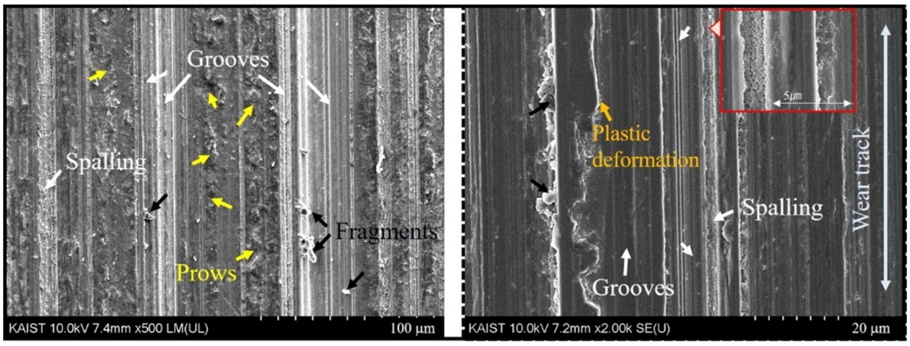
In this study, prow and groove were observed on the wear surfaces of the two specimens. Fig. 4 shows the surface images observed by SEM after 5×10^3 and 5×10^4 cycles of wear tests for surfaces without and with dimples. First, grooves of various sizes and depths were found on both surfaces, however, the clear difference is that deeper and wider grooves were observed on the surface without dimples. The maximum depth and width of this groove ranged from 30 μm and 0.25 to 0.5 mm, respectively, as shown in Fig. 5. Compared to the maximum depth and width of the groove on the dimple surface of 15 μm and 0.15 mm, respectively, the difference had doubled. These grooves were created when the prow created on the pin as a result of abrasive wear removed the plate surface, or wider grooves and prows were created as the scratches on



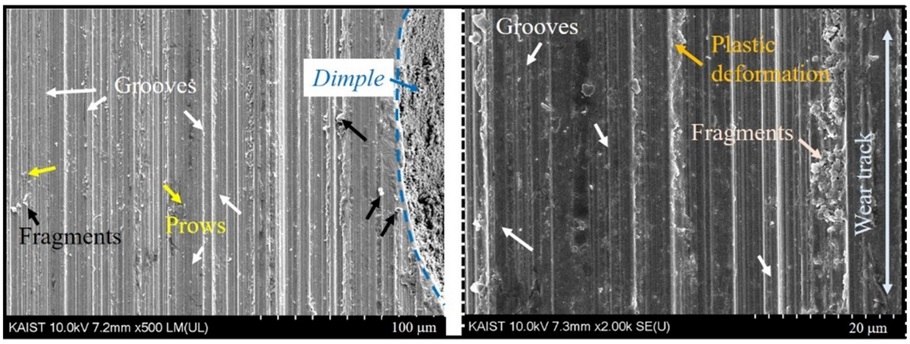
(a) Non-dimpled surface after 5×10^3 cycles



(b) Dimpled surface after 5×10^3 cycles



(c) Non-dimpled surface after 5×10^4 cycles



(d) Dimpled surface after 5×10^4 cycles

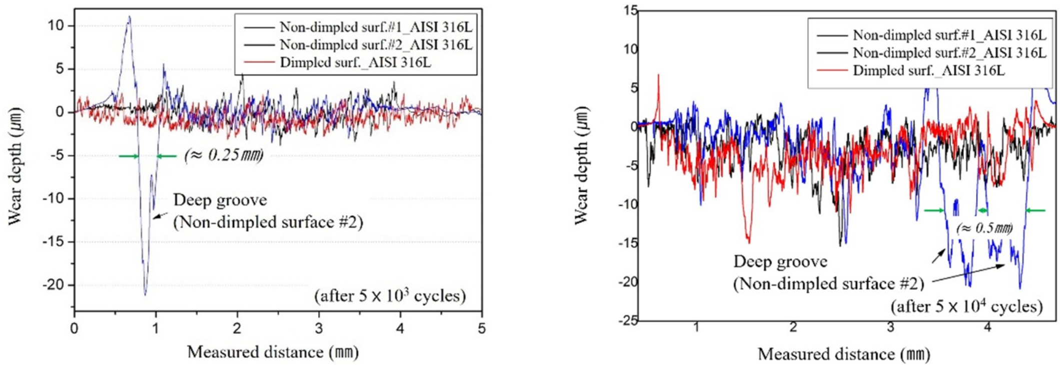
Fig. 4. SEM images of the worn surfaces after wear tests for (a) the non-dimpled surface after 5×10^3 cycles; (b) dimpled surface after 5×10^3 cycles; (c) non-dimpled surface after 5×10^4 cycles; (d) dimpled surface after 5×10^4 cycles.

the surface were merged [40].

Fig. 4(c) shows the wear surface that exposed the subsurface, which was torn off in the sliding direction. Furthermore, severe plastic deformation and many prows were observed. In case of the dimpled surface, the degree of surface grinding and generated prow were relatively small. Additionally, abrasion fragments that fell off on both surfaces were observed, and the size and number of wear particles increased when the wear cycle increased. Considering the wear particles collected inside the dimples as shown in Figs. 6(b) and (d), the fine particles were fused to the plate-like wear particles with a size of 10–30 µm. Hsu et al. [39], and Smith et al. [40] found multi-layered flat wear fragments in sliding wear experiments on 316 austenitic steel and stated that it is reasonable to associate the fine particles with the α' phase and the larger fragments with the γ phase. As a result, as shown in the wear mechanism in Fig. 7, owing to the dimple effect that reduces boundary friction in the mixed fluid lubrication behavior of the artificial hip bearing, the phase transition of the dimpled surface was controlled, and the occurrence of work hardening and prow was reduced. Additionally, wear particles collected in the dimples improved the wear resistance of the dimpled surface.

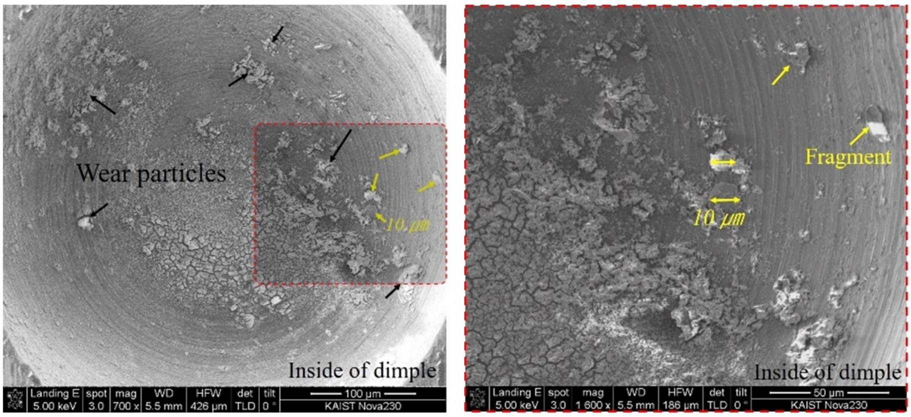
3.3 Friction coefficient

Fig. 8 shows the friction coefficients extracted in real time

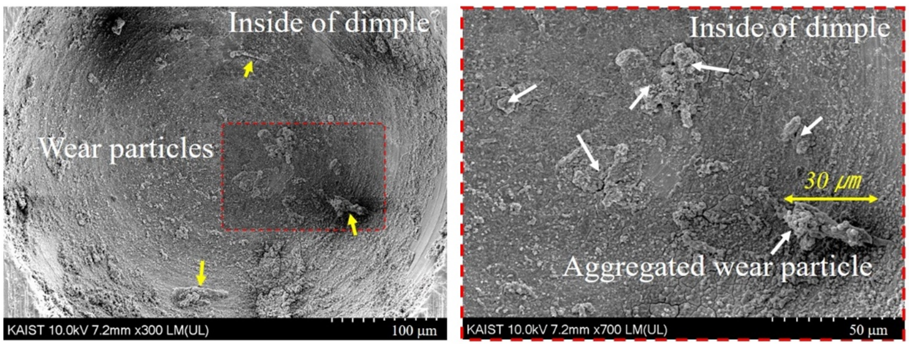


(a) After 5×10^3 cycles (b) After 5×10^4 cycles

Fig. 5. Depths of the wear tracks on AISI 316L in FBS.



(a) For 5×10^3 cycles (b) Magnified view of the red dot area in Fig. 6(a)

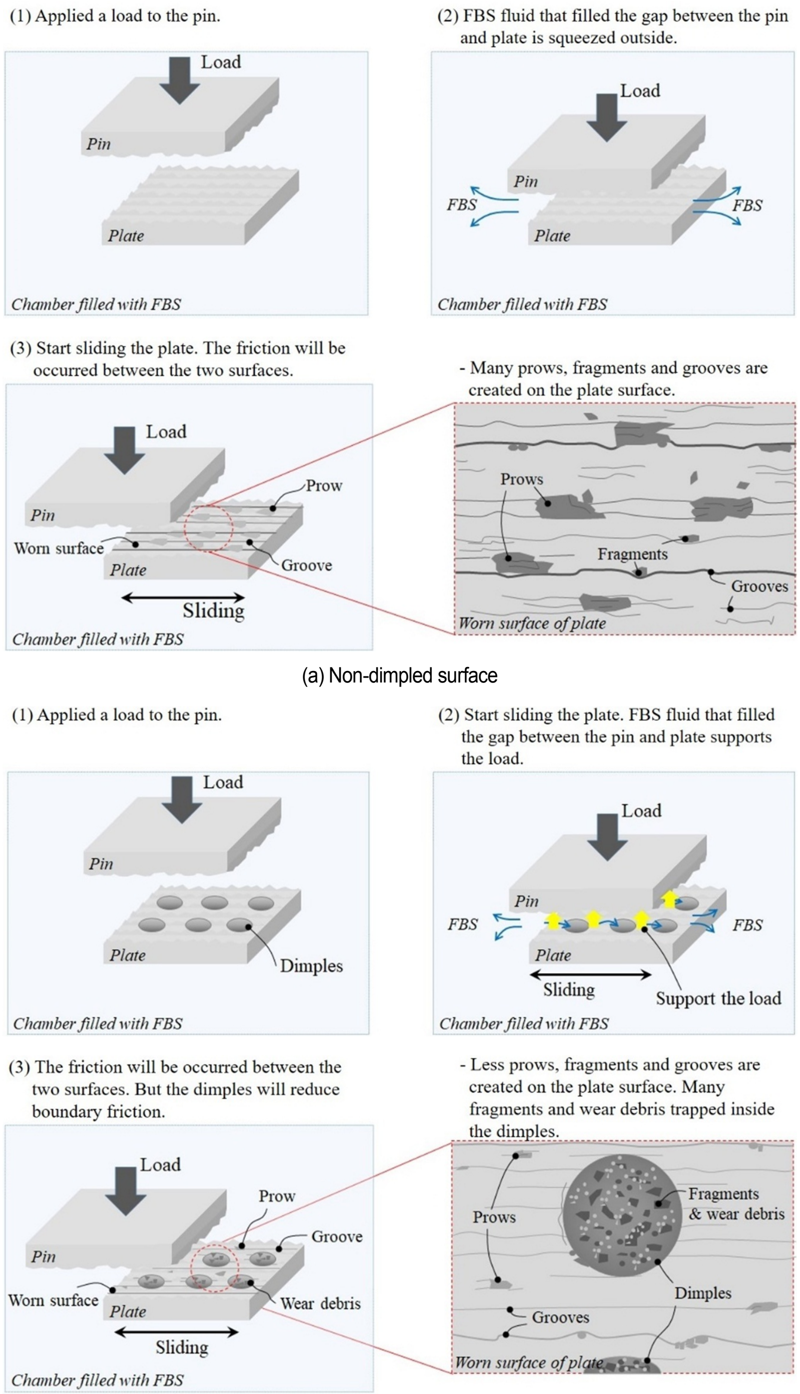


(c) For 5×10^4 cycles (d) Magnified view of the red dot area in Fig. 6(c)

Fig. 6. SEM images of the interior of the dimples: (a) for 5×10^3 cycles; (b) magnified view of the red dot area in Figs. 6(a), (c) for 5×10^4 cycles; (d) magnified view of the red dot area in Fig. 6(c).

during the wear test of 5×10^4 cycles. The friction coefficient of the specimen with fine dimples was changed while maintaining a lower value compared to the specimen without dimples from the initial cycle to the end cycle. On average, the coefficient of friction of the dimple surface decreased by 11 %, and this difference increased as the cycle progressed.

A dimple designed appropriately on the friction surface reduces the friction coefficient considering it avoids contact between the two friction surfaces by increasing the load bearing load of the internal fluid. Similar to the wear results in the previous section, the dimples applied in this study reduce friction well. Additionally, although there was no high-frequency vibration of the friction coefficient in both specimens, a high peak often occurred on the surface without dimples, and the peak widened as it passed the middle part. Moreover, a peak occurred on the surface with dimples, however, the height and width were smaller, and the peak was observed 1×10^4 cycles later compared to the surface without dimples. Vibration of the coefficient of friction in the form of high peaks or wide valleys (indicated by yellow circles), according to Qu [41], reflected



(a) Non-dimpled surface

(b) Dimpled surface

Fig. 7. Schematic of the wear mechanism for (a) the non-dimpled surface; (b) the dimpled surface.

the state and wear phenomenon of the two friction surfaces. The change in the amplitude of the friction coefficient increased as the surface transfer, cracks, and rips occurred. Hsu et al. [39] explained that the occurrence of the peak was related to the generation of large wear particles, which indicates that the particle size generated in the prow, which changes depending on the presence or absence of dimples, and the tendency of the friction coefficient change are related to each other. Overall, when comparing the friction coefficient variation, the wear surfaces, the shapes of wear particles with those of the previous research, similar trends were observed. Moreover, it was confirmed that the wear characteristics of MoM hip bearings applied with AISI 316L material can be improved by controlling the occurrence of boundary friction

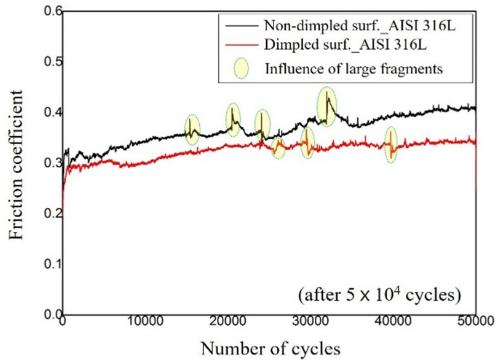


Fig. 8. Friction coefficients of AISI 316L in fetal bovine serum (FBS).

through dimples.

4. Conclusions

In this study, the wear resistance was evaluated using AISI 316L as the material of the artificial hip joint MoM combination bearing. The results confirmed that its performance was improved through surface texturing. In a lubricated condition with a high load, low speed, and little lubricant viscosity, such as an artificial hip joint, plastic deformation and wear of the surface can easily occur owing to boundary friction even in the mixed fluid lubrication area. In particular, austenitic steel undergoes a phase change to martensite owing to friction-induced deformation, which causes work hardening of the surface, which negatively impacts the wear.

In other words, as the load applied to the friction surface increases, the phase change is activated, and as the hardness of the surface increases, the wear increases. This leads to the difference in hardness between the deformed layer on the subsurface and the raw matrix, as well as the occurrence of prow. Therefore, it was confirmed that reducing the boundary friction and the applied load to control work hardening is an important factor in improving the wear resistance of the AISI 316L combination artificial hip bearing. The dimple, which can move the lubricated area on the stribeck curve toward the fluid lubrication by increasing the load bearing capacity of the internal fluid, has the following actions, and this study improved the wear resistance of the MoM combination hip bearing of AISI 316L as follows.

1) Dimples were reduced the phase transition of the wear surface by decreasing boundary friction, thereby delaying the work hardening of the dimpled surface.

2) The reduction in friction and work hardening decreased the formation, growth, and separation into debris particles of prows resulting from the fusion of the work-hardened protrusions on the two friction surfaces.

3) In addition, the surface damage caused by hard particles was avoided by collecting the wear debris generated in the dimple.

In conclusion, it was confirmed that the application of surface texturing technology to AISI 316L material under low-speed-high load-mixed lubrication conditions similar to the lubrication environment of human body structures improves the wear resistance and increases the service life of AISI 316L-based MoM hip bearings. In the future, studies on the corrosion resistance properties of stainless steel and its effects on the body according to long-term use in vivo should be accompanied.

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