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Comparative Investigation of Mechanical Properties of Ball Attachment Manufactured from Different Alloys and Surface Improvement Processes

Gizem Gulmez[1-a], Oguzhan Gorler[2-b*]

[1] *Specialist, Private Clinic, Sivas, Türkiye.*
[2] *Departments of Prosthodontics, Faculty of Dentistry, Biruni University, Istanbul, Türkiye.*

**Corresponding author*

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ABSTRACT

The retaining system commonly used in overdenture prostheses is the ball attachments, which are deformed over time, which can affect the retention and stability of the prosthesis. The aim of this study is to research the physical properties of the ball attachments which are made of different alloys and used for surface treatment. In our study, ball attachments produced from different alloys (Grade 4, Grade 5, Grade 23, CoCr) and applied various surface treatments (no surface treatment, micro-arc oxidation coating) were used. Samples were prepared in the laboratory environment and exposed to the thermal cycle, which corresponds to a 5-year aging process, by means of chewing simulators. The changes in the surface properties of the ball attachments as a result of the aging process were evaluated with scanning electron microscopy (SEM). Considering that the deformation in the matrix and the patrix would affect the retention resistance, tensile bond strength test was applied in a universal test device to measure this resistance. Values were recorded in Newtons and Megapascals. In order to detect the wear on the patrix, weight measurements were made on precision scales. Values were recorded in milligrams (mg). The data were analyzed using the SPSS program. As a result, loss of retention and wear were observed on all ball attachments and matrix. Retention and weight loss were seen the most in the titanium grade 4 group and the least in the CoCr group. No significant difference was found between the other groups.

Keywords: Ball Attachment; Grade 4 Titanium; Grade 5 Titanium; Grade 23 Titanium; Cocr; SEM, Tensile Strength.

[a] *gzmyyrt@gmail.com* *https://orcid.org/0000-0002-8821-4489* [b] *oguzhangorler@gmail.com* *https://orcid.org/0000-0001-6545-8811*

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Introduction

Aesthetic problems can be solved in a short time with complete dentures. However, time is needed to restore the function. In addition, patients must accept that complete dentures cannot be as stable and retentive as natural teeth. The psychology of the patient is another factor that will affect the result as well as the knowledge and skill of the dentist and dental technician.[1]

In developed countries, it has been reported that the frequency of complete edentulism has decreased with the awareness of the society about oral dental health and preventive dentistry practices. However, as a result of epidemiological studies, an increase in the number of edentulous patients has been observed with the increase in the elderly population.[2-4] According to a study conducted in Turkey, the rate of complete edentulism was reported to be 48% in the 65-74 age range.[5] Therefore, prosthetic rehabilitation of edentulous patients remains up-to-date.

The treatment of edentulous patients has various challenges and many treatment options are available. The traditional treatment method of these patients is to make upper and lower conventional complete dentures. The biggest complaint of patients with conventional complete dentures is that their lower dentures are mobile and their chewing ability is reduced. Conventional complete dentures have some disadvantages. These are; lack of stability and retention, ongoing bone destruction, impaired chewing efficiency, social problems, it requires knowledge, experience and detail.[6]

Retention is the resistance of the prosthesis to move away from the tissues in the vertical direction during function. Stability is the ability of the prosthesis to resist movement or displacement under functional forces. The proof that a complete denture is stable is its resistance to horizontal forces. Compared to other treatment alternatives, patients who use complete dentures are less satisfied because of reduced masticatory function. This is due to the lack of retention and stability especially in the lower complete dentures.[7]

There are also different treatment options where implants are used in complete edentulism. These are hybrid prostheses, fixed prostheses on implants and removable prostheses on implants. It is a common conclusion from long-term studies that implant-supported complete dentures are superior to conventional complete dentures in every respect.[8-13]

One of the most frequently preferred and economical treatment methods in edentulous patients is implant-supported removable prostheses supported by two implants in the upper complete denture and two implants in the lower jaw. In 2002, at a scientific meeting held in Montreal, Canada, a consensus was reached on a common idea based on scientific studies on this subject. This common idea is that lower complete dentures supported by 2 implants should be recommended as the first treatment alternative for edentulous patients. This idea, which was reported to the whole world, is also known as the McGill consensus.[14]

The easiest to use and most popular precision retainer system is the ball attachment (Figure 1-2).

This system consists of an independent ball-shaped patrix of different diameters, usually made of a metal alloy, and a matrix inside the removable prosthesis. The matrix may be all metal or consist of a metal housing with a rubber inside. The metal or rubber part in the base allows rotation between the support and the base against vertical compressive forces. It is a flexible device. When the implants are not placed parallel to each other, situations where the inter-implant angulation is up to 28^{o} can be tolerated by ball attachments. Reduced retention of the ball retainer system can be overcome by changing the tires or activating the clips with special keys.[15,16]

The ball holder system consists of a tire, ball abutment and metal housing. The rubber for the ball attachment can be made of silicone, nitrile fluorocarbon or ethylene propylene. The tire surface is treated with a lubricant to prevent abrasion, rupture and punctures caused by the insertion and removal of the prosthesis. Ball attachments consist of 3 parts: head, neck and body. The metal housing is the part in which the tire is placed. Considering the deformation that may occur, it is not desirable to be made of soft materials such as gold, bronze, aluminum or brass. It is generally preferred to be produced from stainless steel. The circumference of the metal seat should be rounded so that tire deformation does not occur.[17]

In ball attachment systems, tires are generally used for the matrix, but there are also systems that use metal matrices instead of tires. In these systems, the patrix is made of titanium alloy and the matrix is made of gold alloy. It has been reported that better results are obtained with this system in terms of wear among metal matrix systems.[18]

O-ring retainers are matrices made of synthetic polymers in the form of a cyme. O-ring retainers have ability to bend against resistance and then approximately return to their original shape. It consists of a metal housing into which the matrix is inserted and a patrix with a certain anisotropy.

O-ring retainers have ability to move in six different directions. After the abutments are connected to the superstructure, the freedom of movement is restricted. The greater the freedom of movement of a holder, the higher the moment force. Advantages of o-rings; connection change is easy, wide range of movement, the cost is low, it has different retention force values, the time spent for the prosthetic superstructure is less.[19]

In the literature, it is stated that in cases where ball attachments are to be applied, the implants should be placed parallel to each other as much as possible, otherwise their use is not recommended. In such cases, angled abutments, flexible retainers and bar-clip retainers are recommended. When this type of attachment is used on implants that cannot be placed at appropriate angles, serious loss of retention can be seen. Their disadvantage is that they take up too much space in the prosthesis in patients with low inter-arch distance. Their use in the upper jaw is not preferred.[20-23]

Materials and Methods

Our study was carried out in Sivas Cumhuriyet University Faculty of Dentistry Research Laboratory, Sivas Cumhuriyet University Advanced Technology Research and Application Centre, Erciyes University Faculty of Dentistry Research Laboratory, Erciyes University Technology Research and Application Centre with the support of Sivas Cumhuriyet University Scientific Research Project by applying to Sivas Cumhuriyet University Non-Interventional Clinical Research Ethics Committee and obtaining permission with decision number 2019-12/61 and dated 11.12.2019.

Obtaining Blocks to Embed the Specimens and Simulate the Prosthesis

The specimens were prepared in Sivas Cumhuriyet University Faculty of Dentistry Research Laboratory. For our study, 160 implant analogues, 20 ball attachments made of CoCr alloy, 20 ball attachments made of grade 4 titanium, 20 ball attachments made of grade 5 titanium alloy, 20 ball attachments made of grade 23 titanium alloy, 20 ball attachments made of grade 5 titanium alloy with micro arc surface treatment, 20 ball attachments made of grade 5 titanium alloy with anodization surface treatment, 20 ball attachments made of grade 23 titanium alloy with micro arc surface treatment, 20 ball attachments made of grade 23 titanium alloy with anodization surface treatment were used. The diameter of the ball attachments used is 3.5 mm and the step height is 3 mm. (Table 1) (Figure 3)

Draft drawings were made for the preparation of the specimens. It was planned to place the balled attachments on the blocks in pairs with a distance of 22 mm between them to reflect the intraoral situation. PMMA (Polymethylmethacrylate) discs (CAD IVORY Disc, On Dent dental systems, Izmir, Turkey) (Figure 3) with a diameter of 10 cm and a height of 14 mm were used to produce the specimens with CAD-CAM device (Figure 4).

In the CAD CAM device (Redon hybrid, Istanbul, Turkey) available at ESTAŞ EKSANTRİK SANAYİ VE TİCARET A.Ş., PMMA discs with indented edges were obtained from PMMA discs in accordance with the drawn draft in order to fit the chewing simulator with dimensions of 15x35x20 mm to the gods.

A total of 80 blocks were obtained from 20 discs, 4 blocks from each PMMA disc. The slots in these 80 blocks where the implant analogues were to be placed were engraved on a CAD-CAM device (Redon hybrid, Istanbul, Turkey) in a way to be exactly compatible with the analogues.

For the blocks to simulate the prosthesis, 1 master model was produced from PMMA disc. In the block simulating the prosthesis, 2 slots with a distance of 22 mm between them, with a diameter and depth of 6 mm, were opened as a guide for connecting the metal slots of the holders. Measurements were taken from the master model using type A silicone, then cold acrylic was poured into the measurements and rectangular prism shaped blocks were obtained.

Placement of Analogues in Blocks

Two slots in the blocks with a distance of 22 mm between them were prepared by CAD-CAM device in a way to be compatible with the analogues. Implant analogues (Moment, Sivas, Turkey) were placed in the prepared slot and fixed by screwing from the bottom. The analogues were placed at the block level to mimic the crestal placement of the implants.

Connecting the Blocks in which the Ball Attachments are Placed to the Blocks to Simulate the Prosthesis

Ball attachments used in our study were produced from 4 different materials: CoCr, Grade 4 titanium, Grade 5 titanium, Grade 23 titanium. A total of 8 groups were formed by applying micro-arc oxidation and anodization surface treatments to the ball attachments produced from Grade 5 and Grade 23 titanium.

160 ball attachments were placed on the implant analogues and torqued with a torque wrench with a force of 12 N according to the manufacturer's recommendation.

After placing matrices on the abutments to prevent leakage of acrylic resin into the anchor areas, Teflon tapes were placed on the anchor in between. Then, the process of connection to the prosthesis was started. The prosthetic part was tested on the block to which the abutments were connected and contacted with the ball attachments to the acrylic resin. The parts of the prosthetic part where acrylic resin should not come.

Vaseline (Vaseline, Pennsylvania, USA) was applied. Then autopolymerising acrylic resin (Imıcryl, Istanbul, Turkey) was mixed according to the company's recommendations and placed into the prepared cavities and the bonded blocks were placed in a press and kept at 1000 psi pressure to maintain the position until polymerization occurred.

Four different alloys and two different surface treatments were applied to the ball attachments, which were divided into 8 groups in total. After the preparation of the blocks was completed, thermomechanical fatigue, retention measurements, weight measurements, SEM imaging were started to be performed. (Figure 5-11)

Consistency Measurements of Samples

The retention measurements of the specimens were performed by pulling the specimens in a vertical direction at a speed of 5 mm/min using a universal test device (LR 10K Plus, Lloyd Instruments, Farnham, United Kingdom) in the Research Laboratory of Sivas Cumhuriyet University Faculty of Dentistry. With this device, a tension force was applied until the retainers were separated from each other and the maximum retention force required to separate the retainers was recorded. The separation and reattachment of the fully seated patrix and matrix was called 'cycle'. Assuming that the patients wore and removed their prostheses 4 times a day, retention measurements were made in cycles corresponding to 1, 2, 3, 4 and 5 years. Retention measurements were also performed at baseline for the first time without cycle tests. After the 1-year cycles, the tires of the samples were replaced and retention measurements were performed. In this way, the loss of grip on the ball attachments was examined independently of tire wear. A total of 6 grip measurements were performed for each gripper with a universal tester. (Figure 12)

Thermomechanical Fatigue Tests

For this study, thermomechanical fatigue tests were performed using an 8-unit chewing simulator (SD Mechatronic CS-4, Westerham, Germany) (Figure 13) with a thermal cycle in the Research Laboratory of Erciyes University Faculty of Dentistry. The blocks containing the abutments were connected to the godets in the chewing simulator with acrylic, while the blocks containing the metal sockets were connected to the simulator with a connecting apparatus made of brass. After the blocks were connected, the fit of the matrices on the abutments was checked one by one. The device was set to perform 30 cycles per minute. The thermal cycling unit of the device reaches temperatures between 5°C and 55°C degrees, and the aging of the material is carried out during the cycles.

If the patients inserted and removed their prostheses 4 times a day, the insertion, removal and ageing of the specimens corresponding to 1, 2, 3, 4 and 5 years of use were performed by means of a thermal cyclic mastication simulator.

SEM (Scanning Electron Microscopy) Examination of Samples

SEM images of the samples were recorded with the SEM device (TESCAN MIRA3 XMU, Brno-Kohoutovice, Czech Republic) (Figure 15) at Sivas Cumhuriyet University Advanced Technology Research and Application Centre (CUTAM) Laboratory. One ball attachment and one tire holder from each group were randomly imaged from different angles before starting the cycle experiments. After 1, 2, 3, 4 and 5 years of ageing, a randomly selected sample was taken between each year.

SEM imaging of the male and female parts was performed. The ball attachments were imaged without any coating and the tire holders were imaged after 20 nm (nanometer) gold (Au) coating in the Au-Pd (Gold Palladium) coating unit connected to the device.

Statistical Evaluation

The data obtained from our study were analyzed with SPSS 22.0 (Statistical Package for Social Sciences, SPSS for Windows 22.0.0, SPSS Inc, Chicago, USA) and graphs were created with GraphPad Prism V8.0 (GraphPad Software, San Diego, CA). Two-way analysis of variance and Tukey's test were used to compare tensile test data and weight measurements, and the error level was taken as 0.05.

Results

In our study, the first retention force measurements were made before thermomechanical fatigue was applied in the mastication simulator. After the thermomechanical fatigue application started in the chewing simulator, a total of 6 retention force measurements were made at 1440, 2880, 4320, 5760, 7200 cycles.

When the retention measurements of the groups without surface treatment were compared; the least retention force change was observed in the CoCr group during the period corresponding to 5 years of use. The highest retention force loss was observed in the titanium grade 4 group. At the end of the fifth year, the retention values of the CoCr group were statistically significantly higher than the retention values of all other groups ($p<0.05$). While the retention value of the grade 5 group was statistically significantly higher than the retention value of the grade 4 group ($p<0.05$), there was no significant difference between the retention value of the grade 23 group ($p>0.05$). The retention value of the grade 23 group is statistically significantly higher than the retention value of the grade 4 group ($p<0.05$) (Table 2).

When the retention values of titanium samples treated with anodic oxidation and micro arc oxidation surface treatment were compared, at the end of the fifth year, in both grade 5 and grade 23 titanium groups, the retention values of the groups with surface treatment were statistically significantly higher than the retention values of the groups without surface treatment ($p<0.05$). There was no statistically significant difference between the retention values of the micro arc oxidation groups and the retention values of the anodic oxidation groups ($p>0.05$).

Scanning Electron Microscope (SEM) Images Obtained from the Study

When SEM images were analysed, it was observed that while milling marks remaining from the production process of the ball attachments were observed in the control groups, after the thermomechanical fatigue application, as the number of silkus corresponding to the years increased, the amount and depth of abrasion caused by the insertion and removal process increased.

Discussion

In this study, ball attachments manufactured from different alloys and treated with surface improvement processes were subjected to thermomechanical fatigue corresponding to 5 years of use by in vitro experiments.

- To see the changes in the holding force values with the help of tensile test, to investigate which alloy and surface properties of the ball attachment show better mechanical properties against abrasion in the clinic,
- To make qualitative and quantitative analyses at elemental level of the surface treated ball attachments forming the gripper system before and after the experiment.

As a result of the studies, it has been reported that the standard treatment protocol for patients with complete edentulous lower jaw should be 2 implant-supported complete dentures in the lower jaw.[2] In implant-supported complete dentures, mechanisms such as ball attachment, locator attachment, bar or magnet retainer are placed on the implants for retention.[3]

Considering the effect of the type of retention on retention, the ball attachment system, which is frequently used in the clinic, was preferred in our study. The number of samples is very important for obtaining accurate results from the studies. In the literature, it is seen that the number of samples varies between 3-10 in studies examining the retention forces of splinted or non-splinted retainers placed twice on a model.[24-26] In our study, which we started by performing power analysis, the number of samples was determined as 10 (n=10), with 2 grasping attachments in one sample for each group. In studies comparing grasping systems, grasping parts were placed and torqued on implants or analogues in accordance with the recommendations of the companies.

In our study, the retaining parts were torqued to the analogues according to the company's instructions. Implants or analogues were placed in plaster, aluminum bases, acrylic resin or polyvinyl chloride blocks in most of the studies.[27-30] In our study, the analogues were placed in the slots that were opened in PMMA blocks in the CAD-CAM device, which were exactly compatible with the analogues. Overdenture prostheses were simulated using autopolymerising acrylic resin blocks.

When 2 implant-supported removable prostheses were simulated, implants were placed parallel or angled to each other.[25,27,31] For long-term success in overdenture prostheses, the incoming forces should be parallel to the entry path of the implants.[32] This can be achieved by placing the implants parallel to each other. Parallelometers were frequently used to ensure parallelism in studies.[25,33] In our study, the parallelism of the analogues was achieved by opening parallel analogue slots in the CAD-CAM device in accordance with the sketch drawn.

Retention systems used for implant prostheses show wear and loss of retention over time. The amount of wear and loss of retention varies depending on many factors. The complexity of the oral and masticatory system limits the ability to mimic natural conditions by adjusting in-vitro conditions. There are studies reporting that vertical movements caused by the insertion and removal of prostheses are not the main cause of retention loss, and that horizontal forces such as masticatory activity and parafunctional movements are more effective in the wear of abutments.[28,34] Evtimovska et al. reported that in vitro conditions cannot reflect the oral environment. They stated that the absence of saliva and occlusal forces may affect the retention forces due to reasons such as the effect of occlusal forces on the wear of the retaining parts and the ability of soft tissues to transfer more load to the retainers due to their resilience when force is applied on them.[25] Setz *et al.*[35] reported that since the oral environment cannot be fully reflected in in vitro conditions, wear on the retaining parts is seen less and that devices that better reflect the forces in the oral environment are needed to achieve more realistic results.

Ignoring chewing forces in in vitro studies leads to limitations of the studies. This situation can be accepted as a limitation of our study. In in-vitro studies, it is aimed to provide the closest test environment to reality within the framework of the conditions determined.[12,42] Performing the experiments in dry or wet environment affects the friction forces and the amount of wear on the retaining systems. Nagaoka et al. evaluated the retention force in overdenture prostheses and found that the retention force value in wet environment was lower than in dry environment.[36] Different liquids are used for wetting the experimental environment. When the studies in the literature are examined, distilled water, isotonic 0.9% sodium chloride solution and mostly artificial saliva were used.[37,34] In our study, as in the study of Fromentin et al. the denture removal procedure was performed in a wet environment using distilled water. In the study by You et al., the effect of denture cleaning solutions on the retention of locator retainers in a simulated 6-month use was investigated and it was reported that sodium hypochlorite significantly decreased the retention values of locator retainers.[38] It is very difficult to accurately reflect the effect of prosthesis cleaning agents on wear in vitro, and another limitation of our study is the wear caused by prosthesis cleaning agents.

There are many studies assuming that patients remove their implant-retained removable prostheses 3 or 4 times a day.[30,39-41] Kurtulus and Gurbulak[41] applied 720 cycles for 6-month use and 1440 cycles for 1-year use, taking the patients' wearing and removing their implant-retained removable prostheses 4 times a day as a reference. Besimo *et al.*[39], on the other hand, applied 540 cycles corresponding to 6 months of use, assuming that the patients inserted and removed their overdentures 3 times a day. In all of the studies investigating the retention forces of overdenture prostheses, the retention force of the retaining parts was first determined by the pulling force in the axial direction.[42,43] In studies conducted at different times, tensile tests were performed in axial and paraaxial directions and cycles between 540 and 14,600 were performed. Retention force measurements were performed at different time intervals. Retention force measurements were performed by Kobayashi et al.[37] 6 times in total (10, 100, 1000, 5000, 10000 and 14600 cycles), Sultana *et al.*[44] 15 times in total (10.000 cycles, every 500 cycles in the first 4000 cycles and every 1000 cycles in the remaining cycles), Ortegon et al.[45] a total of 36 times (every 100 cycles by applying 3500 cycles), Rodrigues *et al.*[40] a total of 6 times (every 540 cycles by applying 2900 cycles), Pigozzo *et al.*[26] a total of 6 times (0, 1100, 2200, 3300, 4400, 5500 cycles). In our study, as in the studies of Kurtulus and Gurbulak, it was assumed that the implant removable prostheses were inserted and removed 4 times a day (morning, noon, evening and night) and 1 month was accepted as 30 days; 1440 cycles corresponded to 1 year, 2880 cycles to 2 years, 4320 cycles to 3 years, 5760 cycles to 4 years and 7200 cycles to 5 years. Similar to the study of Pigozzo et al.[26], retention force was measured 6 times in total at 0 (before starting the cycles), 1440, 2880, 4320, 5760 and 7200 cycles.

In the studies conducted in the literature, the speeds of the tensile tests performed on the specimens were adjusted at different values. In some studies, the tensile speed of 50 mm/min was considered close to the extraction speed applied in the mouth and the experiments were performed based on this value.[38,42,46] There are studies in which the speed of the tensile test was adjusted as 1 mm/min, 2 mm/min, 3 mm/min.[25,47,43] In a study in which 3 different gripper types were examined, the pulling speed was adjusted as 1 mm/min.[30] Although Rutkunas *et al.* reported that the maximum retention force decreased as the pulling speed increased, there are also studies showing higher retention force despite the higher pulling speed.[39,29] Considering the effect of the pulling speed on the maximum retention force as stated by Rutkunas et al. in their study, the pulling speed was adjusted to 5 mm/min in our study. Since it is easy and reliable to set this speed with the universal tester, tensile tests were performed with this device.

In the studies, locators, ball attachments, bars and their combination retainers were frequently used. In addition to the studies in which un-splinted retainers were placed 1 in the specimens, there were also many studies in which 2 retainers were placed in a specimen with splinted and un-splinted systems in order to mimic the oral environment well.[25,32,37,39,48,49] When the studies in the literature are examined, the distance between implants was adjusted between 20-30 mm when 2 implants were placed in a specimen. In most studies, implants were placed so that the distance between 2 implants was 22 mm.[37,28,50] Taking these studies in the literature as a reference, in our study, the analogues were placed in the models in pairs with a distance of 22 mm between them.

Trakas *et al.*[51] reported that a retention force of 20 N was sufficient for mandibular implant-supported removable prostheses. In studies conducted with retaining attachments of different designs, it was reported that the retention value varied between 10-90 N.[24,32,52,53] However, in terms of patient satisfaction, it is desired that the retention force of overdenture prostheses should be high. Abrasion is the loss of material characterised by the loss of form seen in the abutments under function. Loss of retention caused by abrasion of the abutments is a problem that we observe both in in vitro experiments and in the clinic. The matrix part of the retaining attachment systems is replaced at certain intervals, and in cases where wear is high, the patrix part is also replaced. The wear of the abutments under the function does not occur only as a result of insertion and removal, but many factors affect it. These are; implant angles[45,47], distance between implants[48], abutment and matrix materials[35,39,49], direction of forces separating the prosthesis from the tissue[29], design of the abutments[31,49] and dimensions.[28] Studies directly analysing the abutments are very few. Examination of abrasions on the abutments is performed by SEM imaging, size measurement and weight measurements on a precision balance. In our study, SEM imaging at cycles corresponding to 0, 1, 2, 3, 4 and 5 years and weight measurements of the gripper attachments on a precision balance were performed to observe the wear on the ball attachments and matrices.

In the literature, the holding forces of the ball attachments have been compared with different gripping attachment systems or by changing the materials from which the matrix parts are produced. There is no study in the literature comparing the holding forces of ball attachments produced from different materials and surface treated.

Chung et al.[24] compared the retention forces of 9 different retention systems (ERA white, ERA grey, Locator white, Locator pink, Ball attachment (Spheroflex), Hader bar-metal clip, Magnets (Shiner SR), Magnets (Magnedisc 800), Magnets (Maxi 2)) and reported that the retention values were between 3.68 N and 35.24 N in the retention force measurement performed with a pulling speed of 50 mm/min in axial direction. Titanium nitride coated ball attachment group ranked 3rd in the holding force ranking with 27.34 N. The holding forces of the ball attachments in the study of Chung *et al.*[24] are higher than the holding forces of the ball attachments in our study. It is thought that this may be due to the different surface treatments and pulling speeds applied. In the study by Ortegon *et al.*[45], the retention force measurements of ball attachments on 2 implants placed parallel and angled to each other with a distance of 20 mm between them were performed. The study consisted of 5 groups. A total of 3500 cycles were applied to the specimens and a total of 36 grip force measurements were made every 100 cycles. It was reported that the retention force values were 21.3 N for implants placed in parallel. It is thought that the reason why the retention force values in the study of Ortegon et al. were higher than the retention force values in our study may be due to the fact that fewer insertion and removal cycles were applied. Gulizio *et al.*[47] applied ball attachments on implants placed at 0°, 10°, 20°, 30° angles and titanium and gold matrices were used. They reported a retention force value of 23.8 N for ball attachments using gold matrix placed without angle.[47] It is thought that the difference between the holding force value of the ball attachments in our study and the holding force value in the study of Gulizio et al. may be due to the different matrix materials used. Wolf et al. investigated the retention force values of 6 different ball attachment systems commercially and applied 50.000 cycles under an eccentric force of 100N in a mastication simulator. They reported that the holding force values were between 1 N and 10.4 N at the end of the study.[54] It is thought that the reason why the retention force values in our study are higher than the retention values in the study of Wolf et al. may be since Wolf et al. applied 50,000 cycles to the specimens. The retention values of the ball attachment systems used in our study decreased over time. This may have been caused by the deformation of the matrices and the wear of the patrixes. Although the same matrix system was used in all groups in our study, different degrees of retention loss were observed. This is thought to be since the ball attachments were produced from different alloys and different surface treatments were applied. Our study is not compatible with the studies that reported that the retention force values increased or did not change despite repeated insertion and removal of prostheses under repetitive force. The decrease in retention force values in retention systems over time is a clinical situation that is seen. Matrices need to be replaced when they are broken, damaged and worn. Many factors such as occlusal forces and parafunctional habits cause a decrease in retention force.

SEM images were taken before and after thermomechanical fatigue to observe the wear of 8 different ball attachment systems used in our study. After thermomechanical fatigue application, it was observed that the amount and depth of wear caused by the attachment and removal process increased as the number of cycles corresponding to years increased. In their study, Abi Nader *et al.*[29] examined the SEM images of both patrix and matrix parts of the ball attachment and locator holder system to which they applied 400,000 cycles of fatigue, as well as the holding force values. In the SEM examination, they determined that there was wear on the patrix and matrix in both gripper systems. In the holding force measurements, they reported the holding force values of the ball attachment group as 10.6 N at the beginning and 7.9 N at the end of the experiments. In our study, in parallel with these studies, abrasions were detected in SEM examination in both the ball attachments and matrix parts (Figure 15-26).

In their study, Saito *et al.* used clips produced from the same material on bar holders produced from different materials (CoCr, titanium grade 4, gold alloy with platinum added) and different shapes (round and dolder). After 7200 cycles in the vertical direction, the retention force was measured and SEM images were analyzed to detect surface wear. The Dolder bar made of CoCr alloy and the clips placed on it showed less wear and debris accumulation. It is stated that this result is obtained because the elastic modulus of CoCr alloy is higher than other materials.[55] In a study examining the amount of wear in SEM images, the weights of the matrix parts before and after the experiment were measured on a precision electronic balance. However, no significant change was found.[39] There is no study in the literature in which weight measurement was performed on a precision balance to determine the wear of the abutments. In our study, the weight of the ball attachments was measured with a precision balance before the experiment and after the thermomechanical fatigue application corresponding to each year. The highest weight loss was observed in titanium grade 4 group. The least weight loss was observed in the CoCr group.

It is very important to ensure retention in removable prostheses. The patient's expectation of retention and stabilization may affect their satisfaction, psychological profile and emotional state.[56] Clinical status, performance and initial retention of the retention systems are important indicators for patient acceptance.[52] In clinical practice, the value required for retention strength is the value that the patient is satisfied with. For this reason, the retention force should be at a value that will prevent movement of the prosthesis.[35] At the same time, the retention force should be at certain force levels that will not have a destructive effect on periodontal tissues during insertion and removal of the prosthesis.[57] Therefore, the choice of retention system is very important. Physicians choose the retention system to be used in implant-supported removable prostheses according to the retention values specified by the company and their clinical experience. As stated in the literature, adequate retention for implant-supported removable prostheses is related with the patient's satisfaction level.[58]

Conclusions

- The insertion and removal process caused abrasion in all groups.
- The average holding force was highest in the CoCr group and lowest in the titanium grade 4 group.
- The material with the best wear resistance among the experimental groups is CoC.
- If titanium grade 5 and titanium grade 23 are to be used in the production of ball attachments, it should be preferred that they have anodic oxidation or micro arc oxidation surface treatment.
- It is recommended that the tires should be replaced before 1 year of use, taking into account the deformation of the SEM images.
- The lowest average holding force obtained from the study is within clinically acceptable limits.

Acknowledgment

None

Conflicts of Interest Statement

The authors declare that they have no competing interests.

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Table 1. Study Groups

Study Groups
1. Ball attachment made of CoCr alloy
2. Ball attachment made of Grade 4 titanium
3. Ball attachment made of Grade 5 titanium alloy
4. Ball attachment made of Grade 23 titanium alloy
5. Ball attachment made of Grade 5 titanium alloy with anodized surface treatment
6. Ball attachment made of Grade 23 titanium alloy with micro arc oxidation surface treatment
7. Ball attachment made of Grade 5 titanium alloy with anodized surface treatment
8. Ball attachment made of Grade 23 titanium alloy with micro arc oxidation surface treatment

Table 2 Average Retention of Study Groups in Newton (N) Values. Respectively; Control- 1st year- 2nd year- 3rd year- 4th year- 5th year

CoCr	Mean	17.688	17.601	17.522	17.484	17.402	17.363
	SD	0.842	0.932	1.161	1.030	0.729	1.390
Ti Gr4	Mean	17.687	16.616	15.666	14.652	12.670	10.215
	SD	0.733	1.425	1.246	0.997	0.892	0.927
Ti Gr5	Mean	17.592	15.834	15.638	15.289	14.487	13.336
	SD	0.571	0.781	1.265	1.610	0.744	1.049
Ti Gr23	Mean	17.978	15.876	15.731	15.016	14.484	13.306
	SD	1.121	1.018	0.937	1.028	1.719	1.018
Ti Gr5 AO	Mean	17.894	16.636	15.931	15.486	15.086	14.886
	SD	1.047	1.276	0.965	0.971	1.045	1.014
Ti Gr5 MAO	Mean	17.916	16.711	16.054	15.876	15.101	14.996
	SD	1.264	0.924	1.705	0.993	0.938	1.115
Ti Gr23 AO	Mean	17.783	16.616	15.876	15.183	14.916	14.816
	SD	1.135	1.028	0.993	1.135	1.028	1.028
Ti Gr23 MAO	Mean	17.636	16.691	15.881	15.344	15.074	14.911
	SD	0.874	0.925	0.934	1.777	1.778	0.947

Figure 1. Ball Gripper System

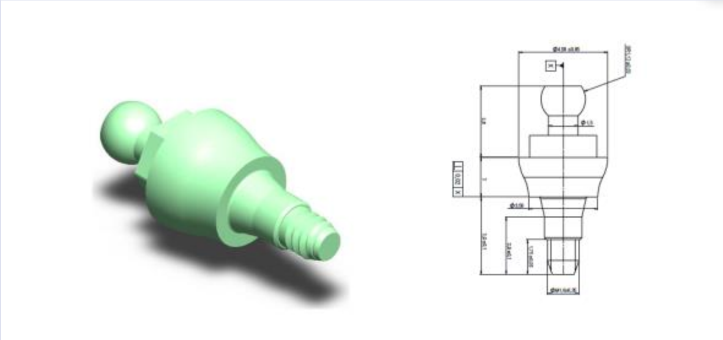

Figure 2. **A**) Three Dimensional View of the Ball Attachment **B)** Draft Drawing of the Ball Attachment

Figure 3. PMMA Disc for Obtaining Rectangular Prism Shaped Blocks

Figure 4. CAD-CAM Device A and B

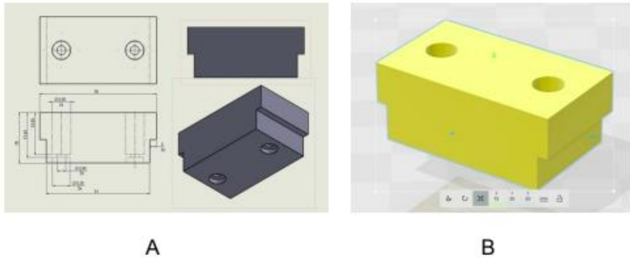

Figure 5. Sketch of the Rectangular Prism Shaped Block in which implants A and B will be placed

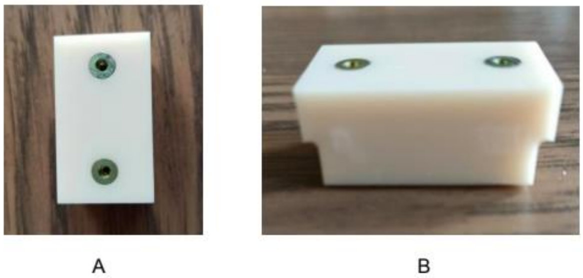

Figure 6. Blocks Prepared in CAD-CAM Device with Implant Analogues A and B

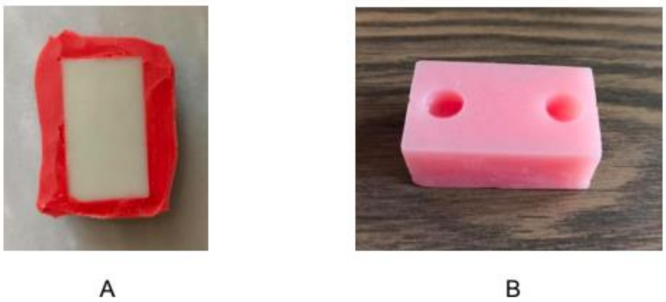

Figure 7. A) Taking Measurements from the Main Model to Simulate the Prosthesis by Using Type A Measuring Item B) Rectangular Prism Shaped Blocks in which the Matrix Simulating the Prosthesis will be Placed

Figure 8. Image Representing the Blocks Where the Ball Attachments are Placed

Figure 9. Pressing of the Ball Attachment System after Fastening

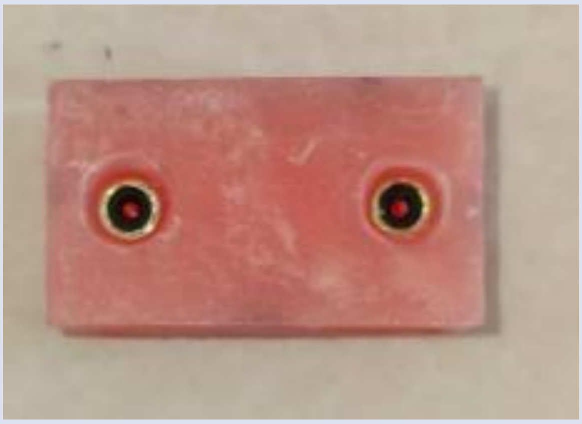

Figure 10. View of the Prosthetic Block after the Pressed Blocks are Separated

Figure 11. Images of Classified and Numbered Blocks

Figure 12. Universal Test Device

Figure 13. Chewing Simulator with Thermomechanical Fatigue

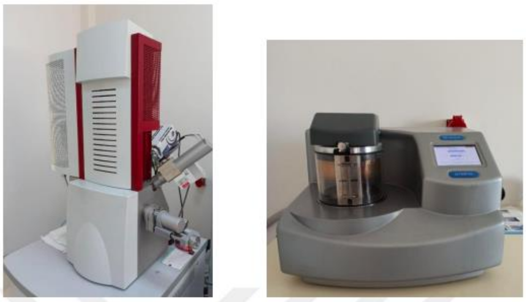

Figure 14. Scanning Electron Microscope (SEM) and Gold Plating Unit Connected to the Device

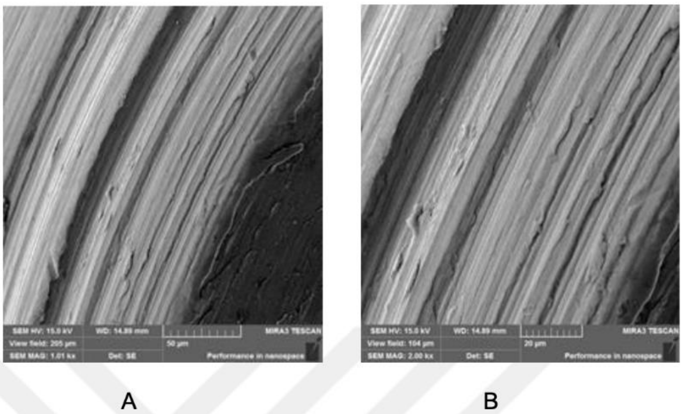

Figure 15. Initial Surface Image of CoCr Ball Attachments at (A) 1000x and (B) 2000x Magnification

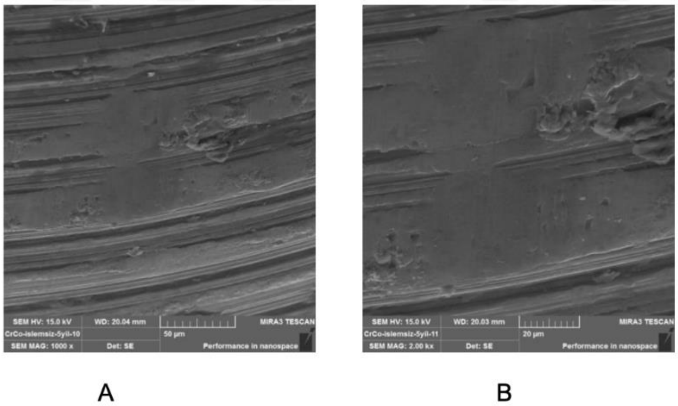

Figure 16. 5-Year Thermomechanical Fatigue of CoCr Ball Attachments at (A) 1000x (B) 2000x Magnification

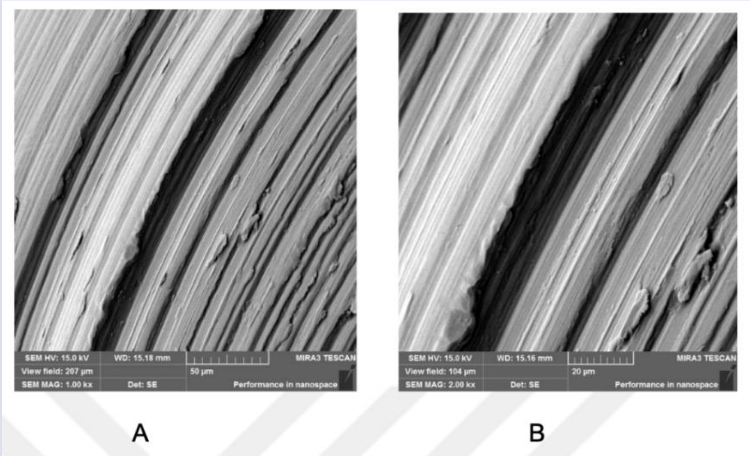

Figure 17. Initial Surface Image of Titanium Grade 4 Ball Attachments at (A) 1000x and (B) 2000x Magnification

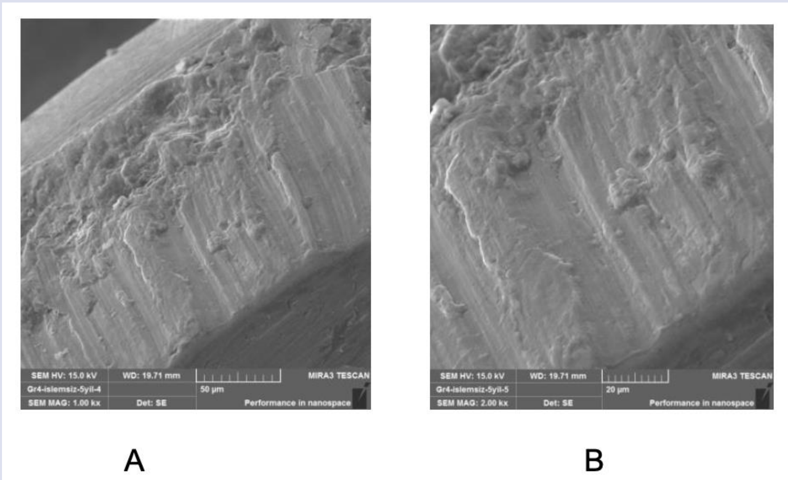

Figure 18. 5-Year Thermomechanical Fatigue of Titanium Grade 4 Ball Attachments at (A) 1000x (B) 2000x Magnification

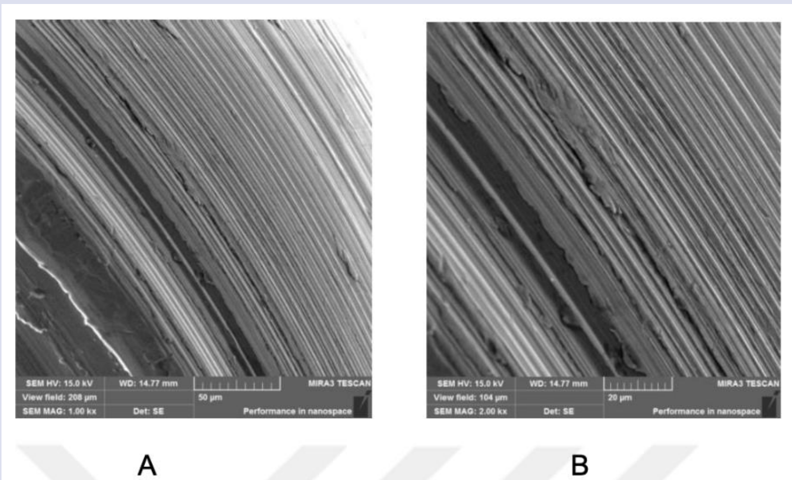

Figure 19. Initial Surface Image of Titanium Grade 5 Ball Attachments at (A) 1000x and (B) 2000x Magnification

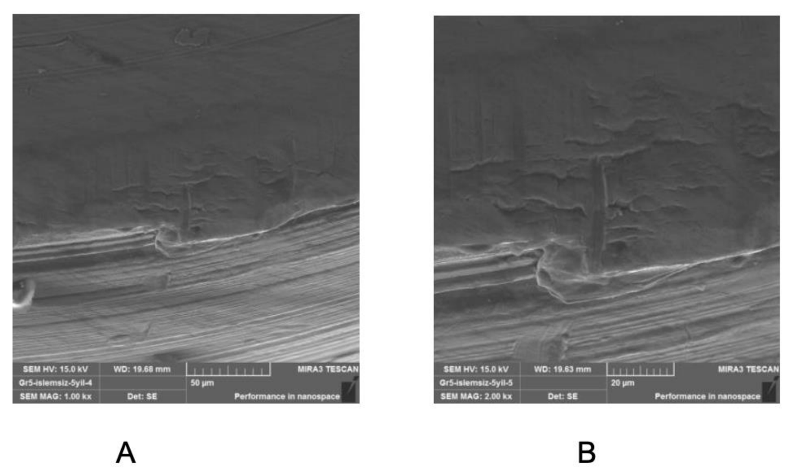

Figure 20. 5-Year Thermomechanical Fatigue of Titanium Grade 5 Ball Attachments at (A) 1000x (B) 2000x Magnification

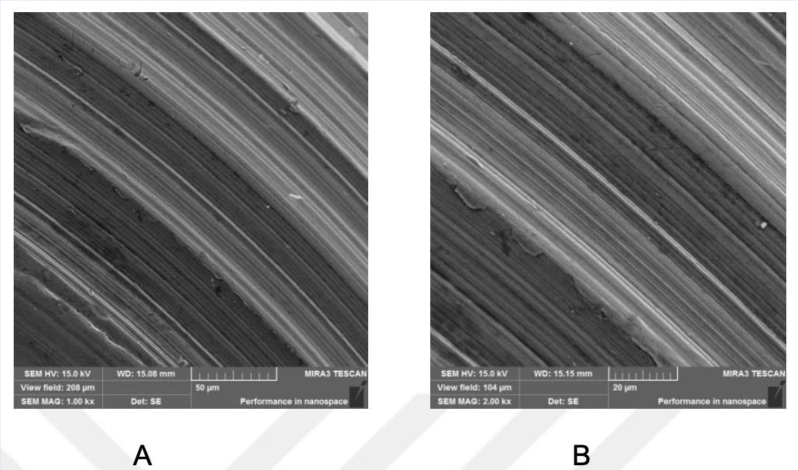

Figure 21. Initial Surface Image of Titanium Grade 23 Ball Attachments at (A) 1000x and (B) 2000x Magnification

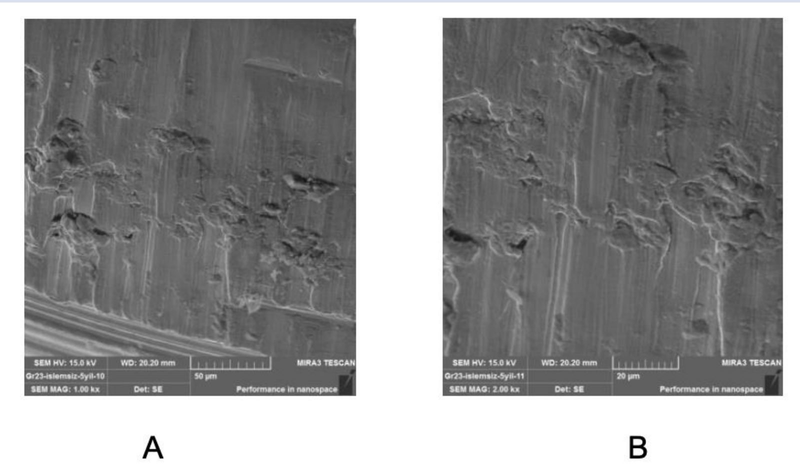

Figure 22. 5-Year Thermomechanical Fatigue of Titanium Grade 23 Ball Attachments at (A) 1000x (B) 2000x Magnification

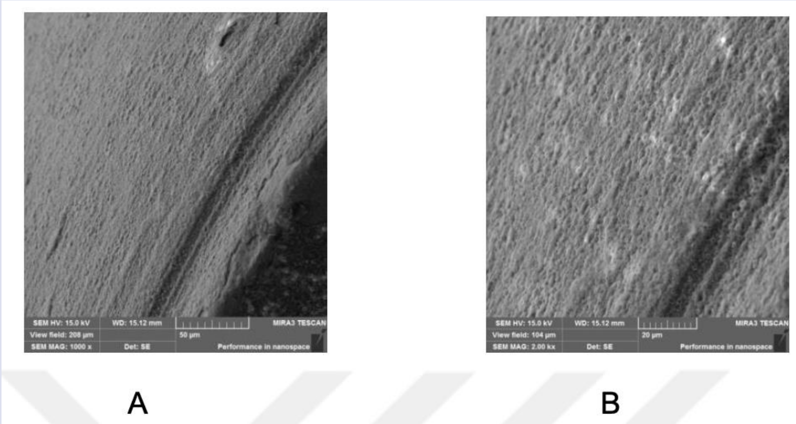

Figure 23. Initial Surface Image of Titanium Grade 5 Ball Attachments with Micro Arc Oxidation Surface Treatment at (A) 1000x and (B) 2000x Magnification

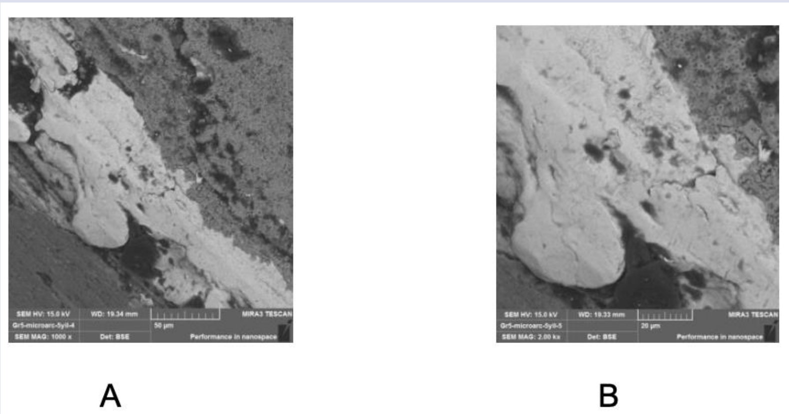

Figure 24. (A) 1000x (B) 2000x Magnification Surface Image of Titanium Grade 5 Ball Attachments with Micro Arc Oxidation Surface Treatment after 5 Years of Thermomechanical Fatigue

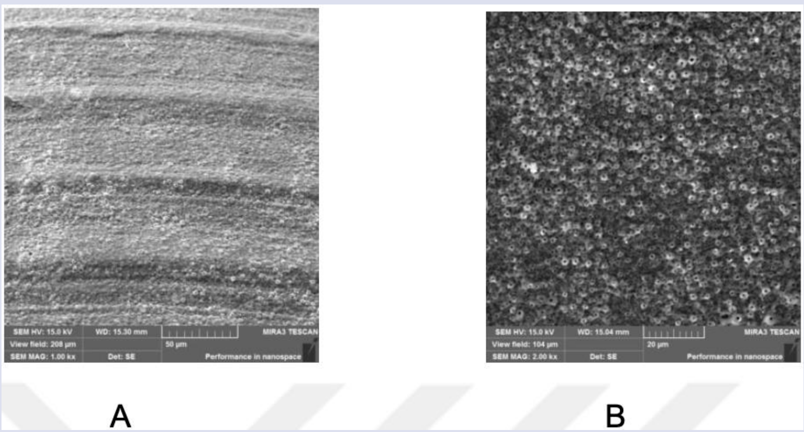

Figure 25. Initial Surface Image of Titanium Grade 5 Ball Attachments with Micro Arc Oxidation Surface Treatment at (A) 1000x and (B) 2000x Magnification

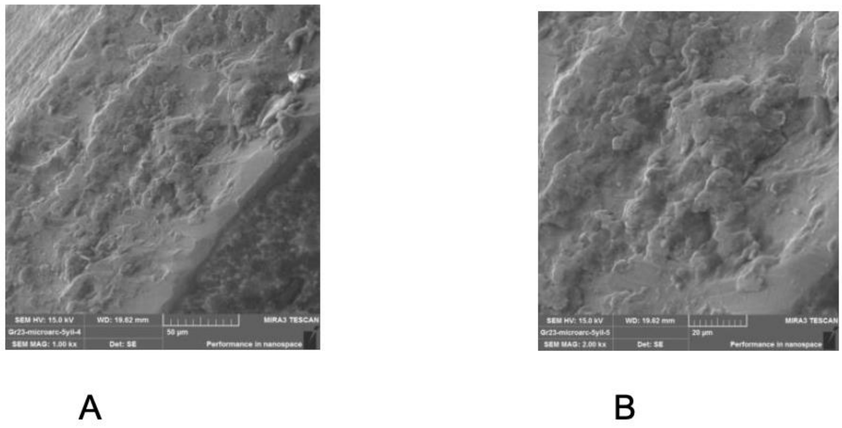

Figure 26. (A) 1000x (B) 2000x Magnification Surface Image of Titanium Grade 5 Ball Attachments with Micro Arc Oxidation Surface Treatment after 5 Years of Thermomechanical Fatigue