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Damage Analysis of Broken Orthopedic Implants

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Abstract

Joint implants and fixings are subject to many stresses throughout their life cycle. Despite careful design, material selection, manufacturing technology and proper surgical technology, implant damage and, in extreme cases, fracture can occur. Investigation of injuries is important from the perspective of the patient, the care provider and the manufacturer, among other things, by exploring the cause of the fracture to prevent similar cases. In the present study we performed failure analysis of a hip implant and a bone fixation plate. Fracture surfaces, material composition, material structure and hardness were also investigated. Based on the work done, we determined what might have led to the fracture in both cases.

Keywords*: hip implant, bone fixation, fracture, damage analysis.*

1. Introduction

Joint diseases today are considered to be common diseases. Such diseases include a decrease in bone density with age and abrasion. A decrease in bone density can result in a fracture of the bone, and abrasion disease primarily affects the vertebrae and hip joints due to the vertical position of the body. The femoral head and the inner surface of the acetabulum are the articular cartilage itself, which allows the surfaces of the two bones to slide on each other without injury. The joint is held stable by muscles and tendons **[1, 2]**.

The most effective treatment for advanced hip disease is full joint replacement with a hip implant. These implants can be made of different materials and the way they are implanted can be different. Age and the patient's lifestyle will best determine which technique and implant the doctor chooses for the patient **[1, 2]**.

In the case of the femur suffering a fracture, another device is needed to repair the bone and joint. In this case, a bone fixation plate is used. The plate is fixed to the broken bone fragments with screws, and the screwing method can be compression or neutral **[3]**.

1.1. Failure of hip implants

Orthopedic implants can have a life expectancy of up to 30 years, but hip implants require replacement or revision of the implants every 10-15 years or sooner to prevent or treat abrasion, modular head wear and implant loosening **[4–7]**.

Implants are exposed to various effects after implantation, such as mechanical stress and friction, but even during surgery, there may be factors that reduce the life of the implant. In these cases, the patient can return to the treating doctor with complaints within a few years. Decreased bone density can also be a factor in damage to the prosthesis, as the bone structure is no longer able to maintain the stability of the implant **[5]**.

The success of the implantation is influenced by the surgical technique as to whether the fixation was done at the right angle and extent. In addition to the implant itself and the surgery, the patient also plays an important role in maintaining the condition of the implant, following the instructions of the manufacturer and the physician **[4, 6]**. There are cases where the accident to the patient is the cause of the injury, but even prolonged exposure may be the cause, such as, for

example, the pain of the opposite hip and the consequent incorrect gait pattern [7, 8].

Types of damage are usually fracture, abrasion, loosening, and sprain as well [4–8]. Of these, the most severe case that most affects a patient's quality of life is fracture. To find out what was behind the fracture, failure analysis should be performed on the damaged samples.

1.2. Failure analysis of broken implants

As the impairment can lead to a significant deterioration in the patient's quality of life, all cases should be investigated. Numerous articles in the literature also report case studies [4–8], but they also try to go around the topic as accurately as possible by finite element modelling of the use of hip implants [9]. Most articles focus on the medical side, but article scan also be found on the metallographic and corrosion properties of damaged metal [10, 11].

In recent years, the Department of Materials Science and Technology at Budapest University of Technology and Economics has investigated the damage of several broken hip implants. These measurements were also the basis of our present research.

2. Methods

The aim of our research is to perform failure analysis of two broken implants and to reveal the cause of the damage. One of the implants examined is a hip prosthesis (Figure 1), that has ruptured at the stem, and the other device is a bone fixation plate (Figure 2). In the case of the bone fixation plate, fixation screws were also available, on which no traces of fracture were detected macroscopically, but they were also examined in order to fully evaluate the damage.

Figure 1. *The distal part of the broken hip implant.*

Figure 2. *Distal part of the broken bone fixation plate.*

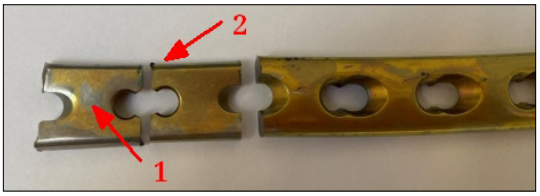

Figure 3. *The distal part of the bone fixation plate after dissection. Slice with fracture surface number 1, number used for metallographic and hardness tests 2.*

2.1. Specimen preparation

Macroscopic images of the damaged implants were taken at the time of receipt, followed by ultrasonic cleaning. In order to properly examine the fracture surfaces of the implant, the implants were dissected at a distance of 10 mm from the fracture line. In order to examine both the hardness and the fabric structure of the material, additional slices were cut parallel to the fracture line (Figure 3).

2.2. Fractography

The removed fractures were imaged with a stereomicroscope (Olympus SZX16) at different magnifications. However, with this method, we have not yet been able to determine the exact cause of the fracture.

Fracture surfaces were then scanned at higher magnifications using a scanning electron microscope (Zeiss EVO MA 10). Scanning the edge of the fracture surfaces along the surface, we looked for crack lines starting from the surface as well as material continuity deficiencies that may have played a role in the damage.

2.3. Metallography

To perform the measurements, the pieces cut from the implants were embedded, then polished. The polished surfaces were imaged with a metallurgical microscope showing the micro-structural features (precipitations, grain size, etc.). By etching the polished patterns, the fabric structure also becomes visible. Kroll's reagent (92 mL H_2O, 6 mL HNO_3, 2 mL HF) was used for the plate and the fixing screw, and hydrochloric acid was used for the hip implant. Microscopic images can also be used to determine the average particle size and the homogeneity of the particle structure.

2.4. Material composition analysis

Material composition analysis was performed on both the fracture surface and the prepared

abrasives by energy dispersive X-ray spectrometry (Edax Metek Elect Plus). Material composition tests can be used to identify the material of the implants and to compare the values with those specified in the standard. The material composition of precipitates and inclusions identified in previous studies can also be analysed with this method.

2.5. Hardness testing

The final step in investigating the damage cases investigated in the current research was the hardness test of the implant material. The specimens prepared for metallographic examination were subjected to HV1 hardness measurements (Bühler 1105) on the surface of the specimens transversely and longitudinally, starting from the edge of the specimen at 1 mm intervals. The hardness results are also comparable to those specified in the standard, and any inhomogeneities can be detected by measuring the entire cross-section.

3. Results

3.1. Visual testing, macro- and micro-fractography

As a result of visual inspection, small and large surface scratches and injuries were clearly visible on the surfaces of the implants. These are presumably generated during removal and are not associated with damage. In the case of the plate, the wear of the anodized layer was conspicuous (**Figures 2**, **3**).

The characteristics of fatigue fracture could be clearly seen on the surface of the samples. Bone cortex remains were not wedged on the fracture surface. In the case of the fixing plate, crack lines starting from the screw thread could be observed (**Figure 4**). From the surface of the stems, it can be assumed that the fracture was a longer process, the two stems did not break at the same time. On the surface of one stem of the plate there is a plastic deformation due to prolonged impact of the material, while on the other part of the stem the crack propagation characteristic of fatigue fracture is not visible, but rather indicates a brittle fracture. (**Figure 5**).

In the case of the prosthesis, several cracks could be observed on the fracture surface that ran to the surface (**Figure 6**). In this case, too, we thought we would discover the characteristics of a fatigue fracture.

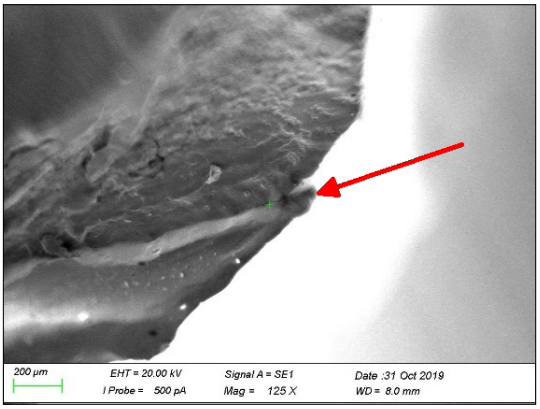

Figure 4. *In this case, too, we thought we would discover the characteristics of a fatigue fracture.*

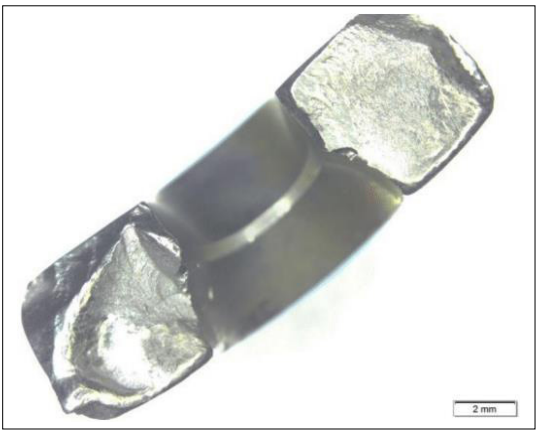

Figure 5. *Stereomicroscopic image of the fracture surfaces of the bone fixation plate.*

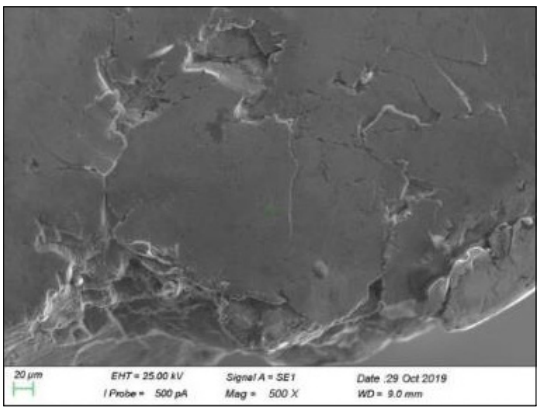

Figure 6. *Electron microscopic image of the fracture surface of the hip implant. Multiple cracks can be observed at the surface edge.*

3.2. Metallography

Metallographic examination of the plate revealed that it had a fine-grained, homogeneous grain structure, containing fine and well-dispersed precipitates, which improve significantly the strength (**Figure 7**). The screw securing the plate was also subjected to metallographic examination. The grain structure was the same as the plate structure.

The granular structure of the hip implant was dendritic, which is not conducive to the propagation of cracks (**Figure 8**). On the electron micrographs, we observed that the fracture lines ran between the dendritic spikes.

In terms of material composition, the fixing plate and the associated screw are made of Ti-Al-Nb alloy and the hip implant is made of cobalt-chromium alloy.

During the hardness measurement, no outliers were obtained for any of the implants. For the plate, the values fell in the 300 HV range. The average of the measurements was 300.5 HV, which corresponds to the value of the relevant standard (ISO 5832-11) (32 HRC = 300 HV). The screw hardness values for the plate ranged from 305.6 to 316.9 HV, averaging 309.62 HV. Hip prosthesis values ranged from 303.2 to 348.9 HV. Its average was 327.75 HV, which also corresponded to the value specified in the standard (ISO 5832-4) (33 HRC = 311 HV).

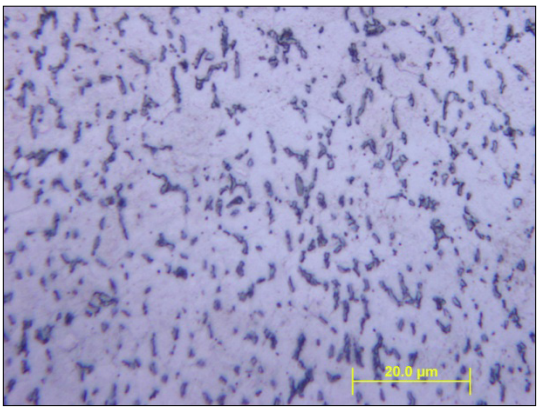

Figure 7. *Microstructure of the bone fixation plate; it shows the fine and dispersed precipitates.*

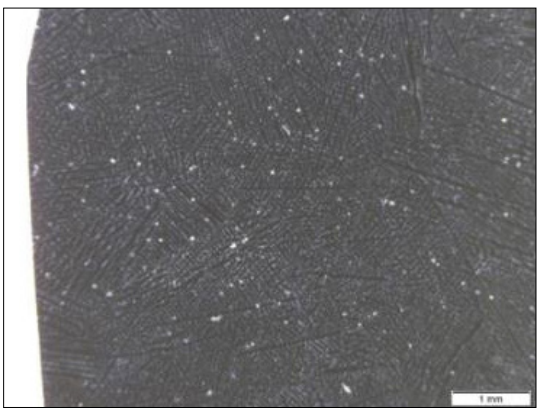

Figure 8. *Dendritic micro-structure of the cast material of the hip implant.*

4. Conclusions

In the case of the fixing plate, the cracks that started the fracture came from the screw surface. From the fracture surface, it can be concluded that the two parts did not break at the same time, as a large amount of plastic deformation could be observed on one of the stems, which can be attributed to the continuous collision of the fracture surfaces. The cause of the fracture may have been a scratch caused by a piece of bone, or even excessive tightening of the screw. In the case of the hip implant, the cause of the fracture is unknown. Cracks running to the surface may have been a possible starting point for the fracture. Even during surgery, the surface may have been damaged, causing the implant to break in the long run.

The material composition and hardness of the tested devices complied with the standards, but our research revealed factors that may have reduced the resistance of the given structure to fracture and could lead to premature damage to the implant.

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