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Case study

A failure study of a locking compression plate implant

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ABSTRACT

In this case study a failed locking compression plate was investigated. Such plating systems are used to provide the stability to fractured bone and fixation. The locking compression plate had been separated in two pieces. One of the fracture surfaces from the failed component was investigated for surface topographical features. The visual, optical and scanning electron microscopy results indicated the presence of beach marks, intermetallic inclusions, corrosion pits and striations indicating fatigue crack propagation and overload failure. Some corrosion damage also was documented on the fractography. This case study shows that corrosion may have initiated fatigue crack which grew by the activities of daily living causing the failure.

1. Introduction

Locking compression plates are extensively used to treat the factures of the bones [1–3]. Annual use of such devices is expected to be over 4.5 million in the United States alone. The plate submitted for this investigation is a 10 hole, plate. Each hole was prepared such a way to allow either a non-locking screw or a locked screw placement. In the case of a locked screw, the screw head contains threads and meshes with the screw threads within the plate-hole. Such meshing allows the transfer of forces from the bone to the plate without compressing the bone, thus enhancing the vascular supply to the fracture site [3,4]. Therefore, these devices are very popular and used for fracture fixation, osteotomies, nonunion and fusion of smaller bone fragments [1–4]. Hybrid plating technique [2] combines the use of both locking and non-locking screws in different holes within the same construct depending upon the bone quality to reduce the costs of operation.

The locking compression plate stabilizes the bone fragments by the virtue of the attachment of screws to the plate in a very rigid manner that allows only fixed angle coupling [4]. Non locking screws apply frictional force, see the mechanics of force development in plated constructs in Fig. 1, between the plate and the bone to achieve stabilization of the bone fragments that are generated by the screws which compress the plate and bone together [1–4].

2. Materials and method

The retrieved device is shown in Fig. 2. The device consisted of plate, separated in two pieces from the mid-section. There were 8 screws of the different sizes. Among them two were locking screws and others non-locking screws. Total length of the

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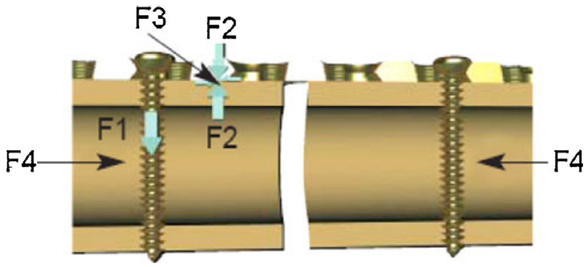

Fig. 1. Mechanics of the locking compression plate technology and forces generated as a result [12] where, F1 = force to tighten the screw into a bone, F2 = reaction force developed because of force F1, F3 = friction force between the plate and bone due to F2, and F4 = axial load [2].

plate was 137.5 mm. The length of the screws were; 16.5, 20.5, 24.5, 28.5, and 30.5 mm, respectively. The plate was 3.5 mm thick, Fig. 2.

2.1. Hardness tests

The average hardness of the plate was 279 HB which was similar to [4]. For this material the tensile strength, empirically converted from hardness value, was 965 MPa and consistent with the specifications for Stainless Steel plate [5]. The chemical composition, microstructure and other properties can be found in ASTM F138-03 [5].

2.2. Visual inspection

Visual inspections revealed scratches on the surface of the plate. Some rusting also was visible.

2.3. Optical microscope analysis

Surface topography of the plate was undertaken using an optical microscope. The fracture surface was removed by making a cut close to the fracture surface. The cut piece was cleaned using ultrasonic cleaning process and air blowing [6]. The eight different locking and non-locking screws were also clamped under the optical microscope to investigate the documentable features. Apart from some scratches, which may have formed after the device removal, the screws did not reveal any quantifiable damage to them. Site from where the crack started was documented in Fig. 3.

2.4. Fractography

After cleaning the surface, the sample was observed under the scanning electron microscope (SEM). The features from the site of crack initiation and propagation were documented at low and high magnifications.

3. Results and discussion

The fatigue crack was initiated from the surface of plate. The plate had undergone some corrosion damage as rust was visible on the plate surface. The corrosion and intermetallic inclusion may have started the crack and it propagated from the

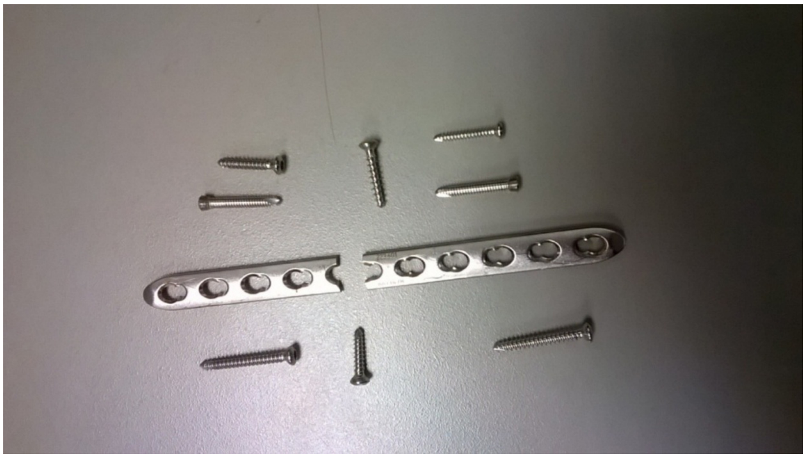

Fig. 2. Locking compression plate and Screws submitted for this study.

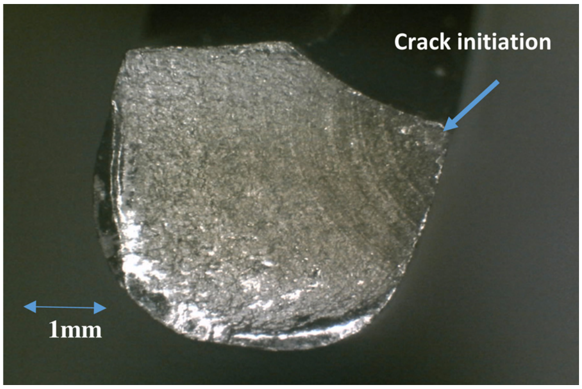

Fig. 3. Fracture surface of the LCP.

Fig. 4. Image observed under SEM.

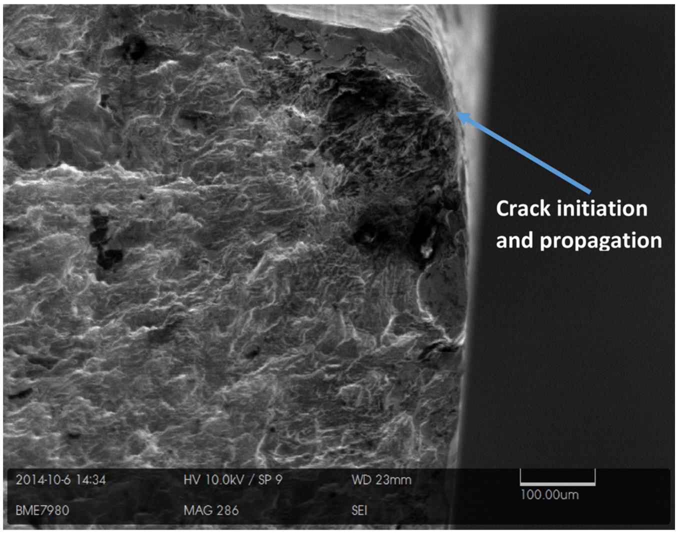

Fig. 5. Inclusions and corrosion on the fracture surface of LCP.

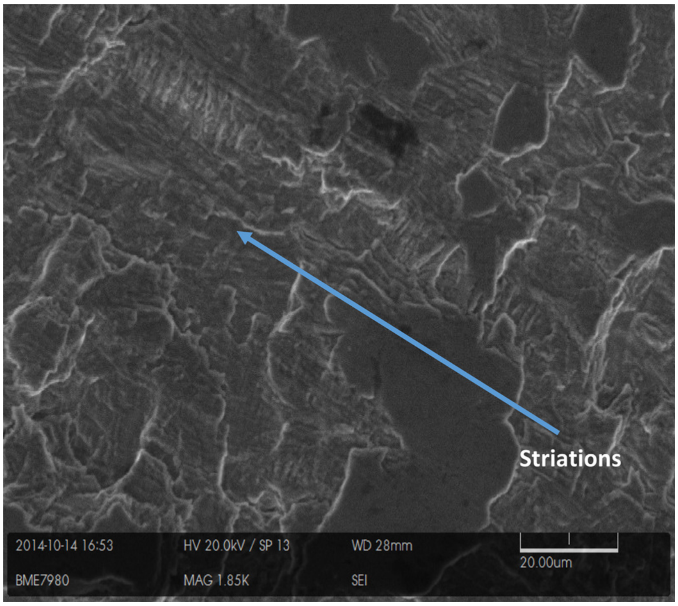

Fig. 6. Fatigue striations and corrosion damage on the fracture surface.

initiation site till it finally led to the failure of the implant. The main composition of the inclusions is known to be of carbon type which not only initiate cracks but also form pits [4]. Once the pit aspect ratio exceeds a certain parameter, the pit then transitions to a crack, investigated by the senior author else-where [7].

At the initiation site beach marks were becoming convex as the crack started to propagate away from the crack origin, Fig. 3. The initiation was a result of interface between the screw, plate with the bony substance. It is well known that biological fluids are corrosive and cause the localized corrosion of implants.

Intermetallic inclusions were observed near the area of crack initiation site as shown in Fig. 4. These particles may have formed during material production, manufacturing and/or other treatment methods used. Machining and cleaning details were not available for this study. Due to the presence of the intermetallic inclusion at the surface, this particular area concentrated stress and may have corroded resulting in pit formation. Corrosion damage is also evident in the fracture surface, Figs. 5 and 6.

Post-surgery, upon load bearing, the construct was subjected to not only the static loads but also the cyclic loading. When the LCP was subjected to the cyclic loading, the crack propagated. Striations were counted where the convex fracture appearance was found, Fig. 3. The striation spacing at the crack initiation site was small, amounting to 0.3 μm and the spacing increases as the crack increases. In the middle of the fracture surface, the striation spacing was 1.72 μm and the

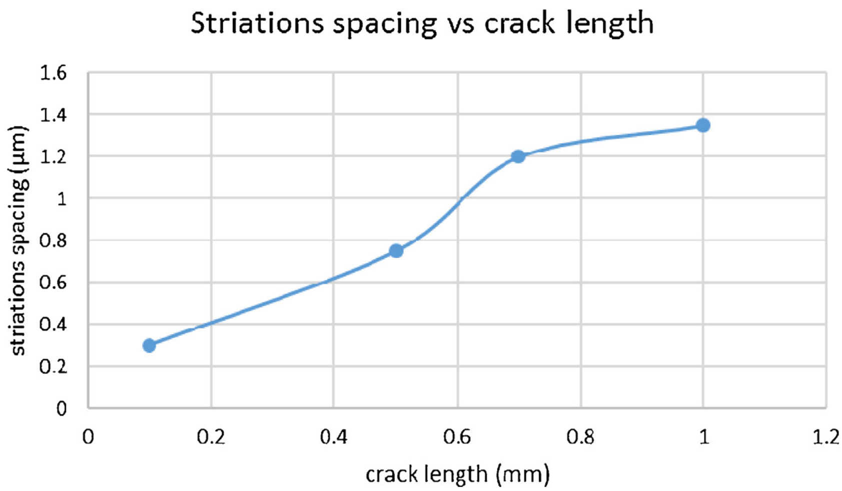

Fig. 7. Striation spacing versus crack length.

thickness of the LCP was 3.5 mm. So from the striation spacing and the thickness of LCP the number of cycles for propagation of fatigue crack was estimated to be approximately 2035 cycles, given that the limited amounts of activities are allowed after surgery. The number of striations was obtained and plotted in Fig. 7. The striation spacing increased as the crack length increased. Since the life of the plate includes both the phases; (1) to crack initiation and (2) propagating the crack to failure, the first phase cannot be quantitatively described. It is well known that the interactive mechanisms between corrosion, which starts a pit, and then transitions to crack, and fatigue which propagates a crack, there may still be interactions between corrosion and fatigue, corrosion fatigue. Therefore, it is not possible to isolate these two phases.

This study only looks into the material features and investigates the observed surface topography. No post-surgery imaging data was available to comment on the placement of the plate and screws, therefore, if improper alignment of the screws caused additional axial, bending and mean stresses. However, the presence of corrosion and fatigue indicate that failure was initiated due to the material defect, corrosion and load cycling due to load bear.

4. Conclusion

The main cause of the failure of the locking compression plate was corrosion-fatigue, within the following steps:

1. The fatigue crack was primarily initiated from the area of the intermetallic inclusion and presence of corrosion
2. The propagation of the crack was by striations mechanisms and corrosion pits, though it is not possible to comment on their interdependence
3. The number of cycles for the construct failure was estimated to be approximately 2035 cycles after the crack was initiated. Since patient file was not available, therefore, it was not possible to comment on the time and/or cycles to failure.

It is therefore recommended that material considerations must be included in the safety, efficacy and longevity assessment of the fracture plating systems.

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