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Laser surface micro-drilling and texturing of metals for improvement of adhesion joint strength

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ABSTRACT

The surface texture of a metallic surface plays an important role in its adhesion strength in an adhesion joint. The same applies to medical implants in regard to fixation and tissue integration. To achieve a strong adhesion for a structural joint or a bone tissue fixation for medical implants, the effects of laser drilled micro-holes at the surface of the metals were investigated. The effect of the number of holes per unit area on the adhesion strength of the adhesion joint was evaluated and the results showed that the number of holes per unit area on the adherend surface logarithmically correlated with the bonding strength. Other holes geometries are suggested for enhanced adhesion and bone tissue fixation.

1. Introduction

Joining of metals by adhesion is a popular alternative to welding and mechanical fastening because adhesion joining helps eliminate the risk of local stress concentrations and thermal distortion, and provides the possibility of weight reduction as rivets or screws are not used. However, the success of an adhesion joint largely depends on the joint design, type of adhesive, and most importantly the surface structure of the adherent. Many studies have been carried out to investigate the effect of different types of surface texture on the strength of the joint. This paper attempts to look into the feasibility of using the laser drilling technique to produce different types of surface hole structures on the metal surface, in order to increase the adhesion joint strength.

Nowadays, more and more metallic medical implants are being used for internal fixation. Some of these implants will be removed after the fracture bone is healed. Other implants, such as dental implants and joint replacements, will be left inside the body as long as possible, ideally permanently. As a result, strong and rapid fixation between the metallic implant and bone tissue is of prime importance. Different surface texturing techniques have been investigated [1–10]. There are several common types of fixation methods: (1) to use bone cement or ceramic coating for direct chemical bonding, (2) to use a screw thread for mechanical locking, and (3) to make use of the surface texture on the implant surface to facilitate the attachment of bone cells, and subsequently bone tissue growth on the implant. These methods have their own limitations and disadvantages. For instance, in the case of method (1), it has been frequently reported that de-bonding can occur between the coatings and the implants. For method (2), loosening of the implant occurs when bone loss due to the stress shielding effect takes place. For method (3), conventional surface treatment methods such as surface grinding or sand blasting provide limited anchorage to promote bone cell attachment. To improve the fixation process in terms of speed and attachment strength in method (3), different surface texturing methods have also been intensively researched. Among various surface texturing techniques, producing pits or holes at the surface by pulsed laser drilling seems to be an industrially feasible technique because of the high production rate the laser drilling process can provide.

The advantages for laser micro-drilling, compared with other technologies, can produce highly precise machining and can easily access complex geometries. Ideally the more holes drilled on the adherent surface, the more mechanical locking sites can result. Similarly, the more holes on the medical implant surface, the easier the bone cells attach, resulting in higher adhesion strength.

In this study, the effect of hole density at the surface of the adherent on the adhesion strength was studied. Based on the results, different hole geometries on the metal surface are proposed for the enhancement of the adhesion strength for adhesion joints and fixations in medical implants.

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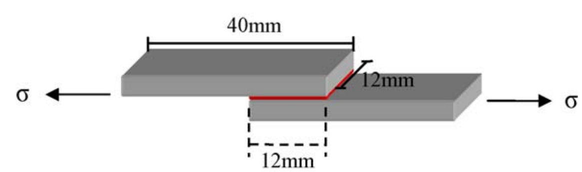

Fig. 1. A schematic diagram showing geometries and dimensions for the lap shear test.

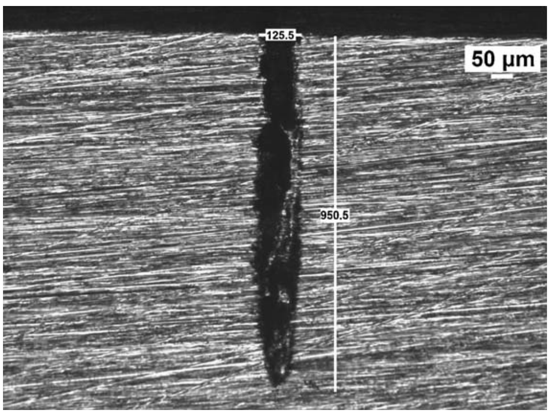

Fig. 2. Optical micrograph showing the shape of the drilled hole.

2. Experiment details

Different materials were used for the different experiments carried out in this work. To study the effect of hole density on the adhesion strength, mild steel plate was used. The samples were spark cut into rectangular plates of size 12 mm × 40 mm × 2 mm. The sample surfaces were ground with SiC paper, successively down to 2400 grit. Three kinds of surface treatments were investigated: (1) sand blasting, (2) grinding with 60 grit SiC paper, and (3) laser surface drilling with different hole densities. The holes on the samples were drilled by a Lumonics Lightwriter SPe 10 W laser system. All holes were produced using the same laser parameters: 10 W, 500 Hz pulse output and 5 s duration. Nitrogen gas was introduced to prevent oxidation and improve the drilling effect in the side nozzle system. The dimensions of the hole were measured by a Lecia DM 4000D microscopy system. Four hole densities were considered, namely 0, 10, 20 and 90 holes per square centimeter. Adhesion strength test ASTM C-633 was used to determine the adhesion strength of the joint. A MIS 810 Material Test System was used for the test. Fig. 1 shows the schematic diagram for the lap shear test. The tensile load was applied at a speed of 0.5 mm/min until fracture. A common epoxy adhesive from Ciba Geigy was used.

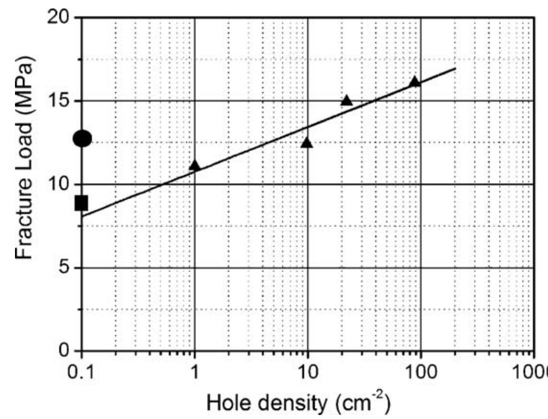

Fig. 4. Fracture loading for adhesion joints with surfaces with different hole density and other surface treatments (▲: hole density; ●: 60 grit grinding; ■: sand blasting).

For the study of different hole geometries, titanium alloy was used because Ti alloys are popular medical implant materials. A SPI 100 W fibre laser was used to drill the special shape holes in the Ti alloy.

3. Results and discussions

3.1. Effect of hole density

Pulsed laser drilling can easily produce holes with controllable depth and width. Fig. 2 shows a typical hole with a large depth to width aspect ratio. The diameter of the hole is approximately 0.15 mm, and the depth is 0.95 mm. Fig. 3a shows an array of laser micro-drilled holes with 1 mm separation between the holes which results in a hole density of approximately 90 holes per square centimeter and Fig. 3b shows the surface structure of a sandblasted surface. Different hole densities upon the adhesive strength were investigated and the results are shown in Fig. 4. It can be seen that the adhesive strength increases logarithmically with the hole density. At 90 holes per square centimeter, an adhesion strength of 16 MPa was obtained. Fig. 4 also shows the adhesion strength of samples subject to other surface treatments, such as grinding and blasting. It is observed that surface treatment by laser micro-drilling with a hole density of 90 holes per square centimeter can increase the adhesion strength by 100%, as compared to that provided by the traditional sandblasting technique. Fig. 5 shows the fractographs of the adhesion joints after the lap shear tests. Fig. 5a shows that the adhesive that penetrated into the hole still remained anchored inside the hole after the joint failed. Cohesive fracture of the adhesive occurred. On the other hand, Fig. 5b shows the adhesive failure between the

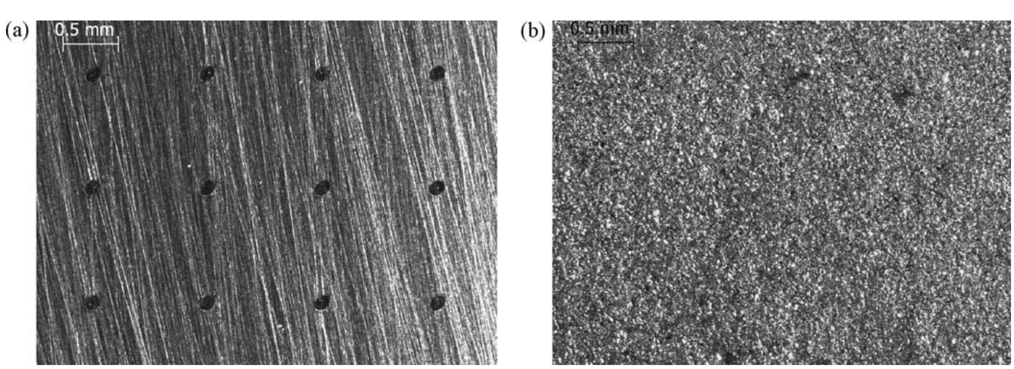

Fig. 3. Optical micrographs showing (a) an array of laser micro-drilled holes and (b) surface morphology after sand blasting.