JOURNAL OF THE MECHANICAL BEHAVIOR OF BIOMEDICAL MATERIALS 42 (2015) 274–281

Available online at www.sciencedirect.com
ScienceDirect
www.elsevier.com/locate/jmbbm

Research Paper

Redesign of Indonesian-made osteosynthesis plates to enhance their mechanical behavior

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ARTICLE INFO

Article history:
Received 29 August 2014
Received in revised form 20 November 2014
Accepted 22 November 2014
Available online 1 December 2014

Keywords:
Osteosynthesis plate
Shot peening
Surface mechanical attrition treatment (SMAT)
Mechanical strength

ABSTRACT

Mechanical properties determined by fatigue strength, ductility, and toughness are important measures for osteosynthesis plates in order to tolerate some load-bearing situations caused by muscle contractions and weight-bearing effects. Previous study indicated that Indonesian-made plates showed lower mechanical strength compared to the European AO standard plate. High stress under load-bearing situations often starts from surface of the plate; we therefore refined the grain size of the surface by using shot peening and surface mechanical attrition treatment (SMAT). Single cycle bending tests showed that shot-peened and SMAT-treated plates had significantly higher load limit and bending stress compared to the original plates ($p<0.05$). Weibull analysis confirmed the improvement of proportional load limit of SMAT-treated plates. Fatigue limit also increased upon shot-peening and SMAT treatment (improvement ratio 18% and 27%, respectively). Significant improvement ratio of fatigue tests can be observed in SMAT-treated plates compared to the untreated and shot-peened plates. Fatigue performance demonstrated equivalent results between SMAT-treated and standard plate. These designated that mechanical properties of Indonesian-made plates can be improved upon SMAT treatment leading to significant enhancement of mechanical strength thus is comparable to the standard plate. Our findings highlight the benefits of SMAT treatment to improve mechanical strength of Indonesian-made osteosynthesis plates.

1. Introduction

Osteosynthesis plates used for fracture fixation need to have a high strength, mainly with respect to fatigue, and a high ductility in order to withstand cyclic loading conditions produced by muscle contractions and body weight, until the bone has healed completely (Schneider et al., 2001; Niinomi et al., 2001; Tudor-Locke and Bassett, 2004). Stainless steel

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http://dx.doi.org/10.1016/j.jmbbm.2014.11.025
1751-6161/

316 L is the most widely used material for osteosynthesis plates due to its proven biocompatibility, combined with good strength, ductility, cost effectiveness and ease of fabrication (Disegi and Eschbach, 2000).

The Narrow Dynamic Compression Plate (DCP) is one of the most widely used osteosynthesis plates in Indonesia. However, the result of the fatigue and single cycle strength test showed that those plates were consistently failed at a lower stress than those manufactured in Europe (Dewo et al., 2012). Some possible reasons are:

- The material used; AO-plates (Mathys Medical, Bettlach, Switzerland) are made from stainless steel 316 L implant grade, whereas Indonesian plates are made from a lower quality stainless steel.
- The manufacturing process: In Indonesia, narrow DCPs in Indonesia are produced using simple machinery. Raw material as a form of pipe instead of sheet was cut to get the curvature form of the plate. The manufacturing process of AO plate are kept secret, but most probably they use a flat plate that is forced into a curved shape by cold deformation.
- Poor reproducibility of the manufacturing process. Indonesian plates show a great diversity in dimensions. Fatigue evaluations were adjusted for the overall dimensions, but could not correct the effects for the positioning of the holes. The large eccentricity of the holes will decrease the strength of a plate.

As a consequence, plate failure does happen, either due to malpractice in the rehabilitation process or due to the weakness of the plate (Cook et al., 1985; Cook et al., 1987; Tsaniklidis et al., 2007). In our limited retrieval study on explanted Indonesian-made plates, 14% were found to have failed during service (the study has not been published yet). Therefore, it is necessary to improve the strength and decrease the variance of Indonesian-made plates.

Metals can be strengthened either by mechanical deformation (cold work) or heat treatment. Heavy deformation is one of the conventional ways of cold work which can strengthen the metal through refinement of its microstructure (Gumbsch, 2003). Heat treatment such as annealing can create a more ductile characteristic of a metal (Cook et al., 1985). Due to the presence of large numbers of imperfections on the surface and occurrence of high stresses under loading conditions, failure often starts at the surface. Surface modification by creating a nanostructured surface layer could therefore be expected to improve the mechanical properties of a material, especially the fatigue mode. Refinement of the grain size on the surface, without changing the structure of the coarse-grained matrix, can be done either by using shot peening or a recently developed surface mechanical attrition treatment (SMAT). These treatments basically transform the microstructure of the surface into nano-sized crystallites by introducing a large amount of defects and/or interfaces into the surface layer (Valiev, 2004; Mair and Padipatvuthikul, 2010).

The aim of this study was to test the efficacy of the surface modification techniques, shot peening, and SMAT treatment in improving the mechanical performances of Indonesian Narrow Dynamic Compression Plate within regard to (1) hardness and (2) fatigue limit.

2. Materials and methods

2.1. *Materials*

The following groups of plates were used in the experiments:

1. 20 Narrow DCP 6 hole plates from Indonesian manufacturer A
2. 20 Narrow DCP 6 hole plates from Indonesian manufacturer A, SMAT-treated
3. 20 Narrow DCP 6 hole plates from Indonesian manufacturer B
4. 20 Narrow DCP 6 hole plates from Indonesian manufacturer B, SMAT-treated
5. 20 Narrow DCP 6 hole plates from Indonesian manufacturer B, shot peened
6. 20 Narrow DCP 6 hole plates from Mathys / Synthes as the standard plate (S).

A transverse cut at the minimum cross section was made and used to determine the cross sectional area and the area moment of inertia of each plate from each manufacturer.

2.2. *Geometry of the plates*

A digital sliding caliper was used to measure the following dimensions of the plates: length, thickness, width, the maximum medial and lateral diameter of the holes and the smallest width of the plate material next to a hole (see Fig. 1). A transverse cut at the smallest cross-section was made and used to determine the cross-sectional area and the area moment of inertia.

2.3. *Shot peening*

Ten plates from manufacturer B were sent to the Metal Improvement Company, (Sint-Truiden, Belgium) to undergo shot peening (diameter of the balls 1 mm).

2.4. *Surface mechanical treatment with SMAT method*

A reflecting chamber for SMAT treatment was developed at the Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada, Jogjakarta, Indonesia as shown in Fig. 2.

Ten plates from manufacturer B and twenty plates from manufacturer A were placed in the reflecting chamber together with 3.5 mm diameter spherical steel balls. The chamber was then vibrated with a rotating motor through a cam system with a frequency of 1480 Hz and amplitude of 2 cm for 15 min to each side of the plate. After this mechanical treatment, all plates were mechanically tested with single cycle bending test and a fatigue test in bending mode.