Characterization and Modification of Surface Integrity by Laser Peening Biodegradable Magnesium-Calcium Alloys

Y.B. Guo, M.P. Sealy
Department of Mechanical Engineering, The University of Alabama, Tuscaloosa, Alabama 35487

Statement of Purpose: Biodegradable implants are a relatively new and emerging form of treatment for common bone ailments. Biodegradable implants are useful to the healing process due to the ability to gradually dissolve and absorb into the human body after implantation. The development of biodegradable implants has had a beneficial effect on in-vivo treatment of patients with various bone ailments.

The materials used to manufacture implants must fulfill specific mechanical and biological roles. Current permanent metal implants made of made of titanium, stainless steel, and cobalt-chromium alloys are often too stiff resulting in a stress shielding effect that can be damaging to the healing process. To minimize the negative effects of stress shielding, magnesium (Mg) alloys are proposed as an ideal biodegradable implant material due to its biocompatibility and superior strength to weight ratio compared to that of other biomaterials. The grand challenge for the successful use of Mg-based implant is to control its corrosion rate.

Laser shock peening (LSP), used in conjunction with Calcium alloying, is a promising surface treatment technique to modify surface and subsurface properties, i.e., surface integrity, of magnesium-calcium (MgCa) implants. Surface integrity can be improved by imparting compressive residual stresses that are beneficial for enhancing corrosion resistance. Furthermore, the compressive residual stresses greatly improve against fatigue crack formation and propagation induced by cyclic loading. LSP also produces surface dents which act as a geometric benefit. Surface dents provide a porous structure that is favorable for cell adhesion and growth to an implant surface. Hence, surface modifications are an effective way to alter the implant/tissue interface in order to improve biocompatibility.

Methods: LSP is a "cold" mechanical process where pressure waves caused by expanding plasma plastically deform the surface of a material as shown in Figure 1.

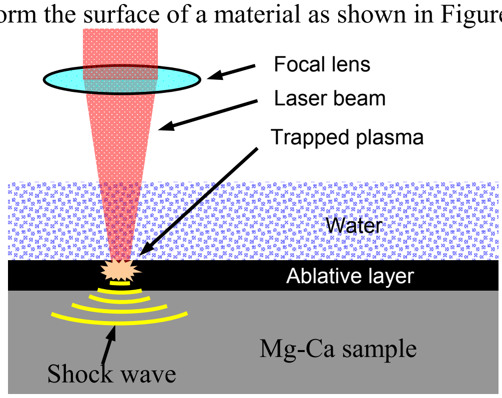

Figure 1. Schematic of Laser Shock Peening

The plasma, confined by a thin layer of water film, expands rapidly resulting in a recoiling pressure wave on the order of GPa. The resulting pressure in confined ablation mode is much larger than the dynamic yield strength. Once the pressure exceeds the dynamic yield stress, plastic deformation occurs and forms a dent. The pressure wave is the mechanical process that plastically deforms the surface and producing high compressive residual stress. The residual stresses can penetrate as deep as 1 mm below the surface. As a result, compressive residual stresses can inhibit corrosion rate of MgCa alloy.

Results: The peening pattern and the surface topography on the polished MgCa surfaces is shown in Figure 2 with peeing overlaps of 25%, 50%, and 75%, respectively.

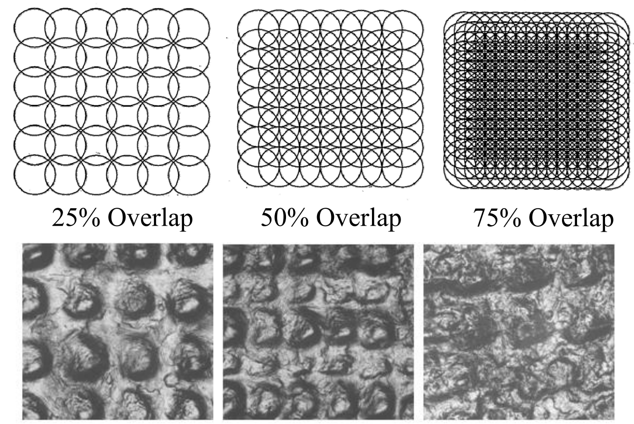

Figure 2. Peening patterns and surface topography

Surface roughness of the peened surfaces increase with laser power and dent overlaps in general as shown in Figure 3. Surface hardness increase up to 200 μm in Figure 4 in the subsurface due to strain and strain rate hardening.

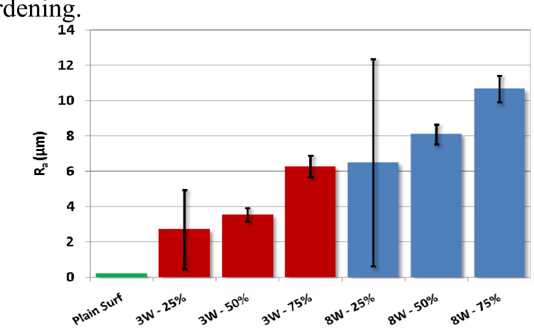

Figure 3. Surface roughness variation

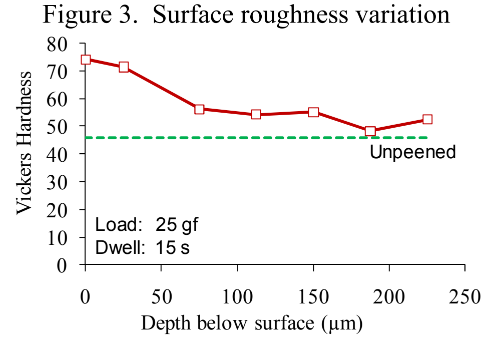

Figure 4. Increased Surface Hardness by LSP

Conclusions: Surface integrity of biodegradable MgCa alloys can be significantly improved by laser shock peening. The increased surface hardness will reduce corrosion rate of the MgCa orthopedic implants. The porous surface will also enhance bone in-growth.