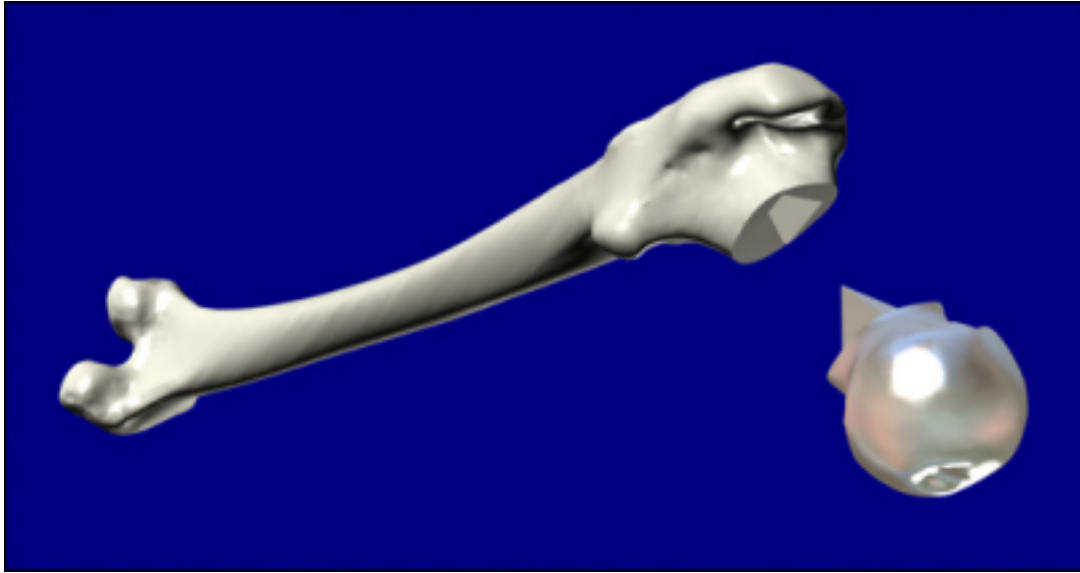


Titanium Bone Implants



Research by
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and
Stewart Veeck (Howmet Research Corporation)

A portion of a human bone was replicated in titanium to demonstrate that the complex surface of an actual bone could be recreated in a structural implant material. Although titanium is currently used for bone replacement, implants are simple geometric approximations of the bone shape. Mismatches between implants and real bone often cause stress concentrations and result in premature implant failure. In this project, an accurate digital model of a bone was sliced into discrete layers. A reproduction of the bone was constructed using Selective Laser Sintering (SLS), a layered manufacturing process developed at The University of Texas at Austin. Rapid prototyping technologies such as SLS are ideal for producing complex parts and prototypes because no specific tooling or patterns are required. Because the titanium piece is an exact duplicate, it will fit the patient's bone structure exactly and have a longer service life.

In this study, an accurate titanium replica of the ball section of a human femur bone was produced. The major limiting factor in titanium processing is the metal's extreme reactivity with many atmospheric elements, particularly at elevated temperature. To avoid titanium contamination a mold for titanium casting, rather than the implant itself, was produced using SLS. Titanium was then cast into the mold using standard methods, thereby maintaining a low level of metal contamination. The key aspect of the project was the selection and development of a mold material system that could withstand the titanium casting process and could be produced using Selective Laser Sintering. Nicole Harlan, a Ph. D. student in the Materials Science & Engineering Program and a member of the Laboratory for Freeform Fabrication, was the principle investigator of the project. She coordinated all aspects of the project and developed the method to make zirconia-based molds for titanium casting.

The complete process was complicated and required the effort of several different entities. Special acknowledgements are given to Professor John Kappelman and the eSkeletons Project in the Department of Anthropology, to Reuben Reyes in the ASE/EM Learning Resource Center, and to Stewart Veeck at the Howmet Research Corporation.

The processing steps included:

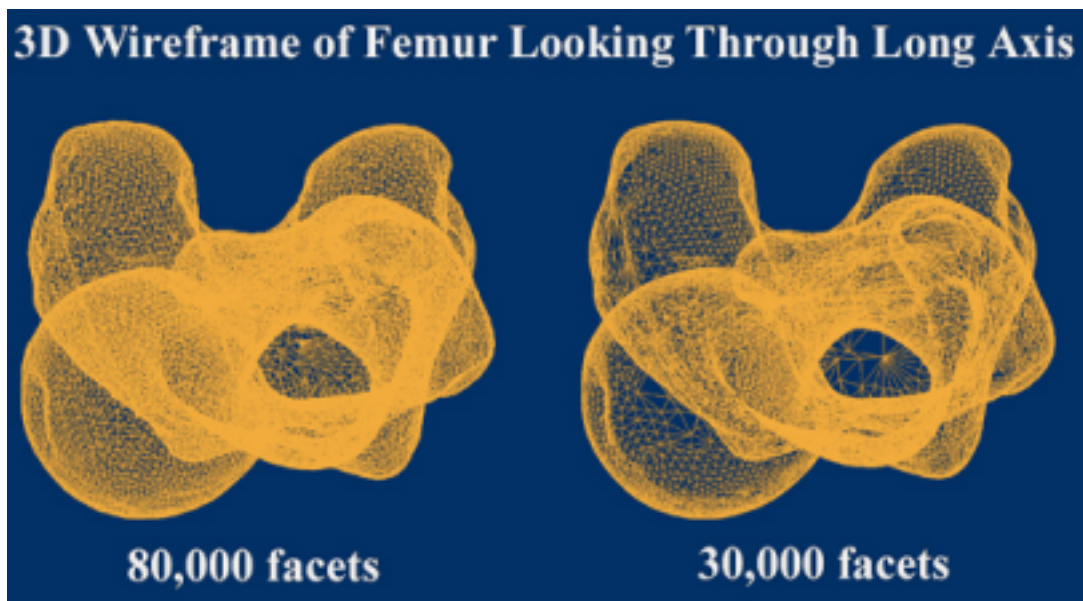
- 1) Acquiring a very detailed 3D representation of the outer surface of a human femur
- 2) Generating a 3D model of the bone that could be manipulated digitally
- 3) Creating and modifying a 3D digital mold of the ball section of the femur
- 4) Constructing and post-processing zirconia mold material
- 5) Characterizing and refining the production process
- 6) Creating a usable bone mold and casting at a titanium foundry
- 7) Evaluating the integrity of the finished titanium pieces

Details of each step involved in the process are in explained below.

1. A human femur bone from the Anthropology Department collection was 3D laser scanned at the Physical Anthropology computer lab. The resulting data was a very accurate representation of the superficial topographic features of the bone. The initial 3D data set contained 80,000 facets and retained a high degree of accuracy. However, a data set of this size is generally too large to work with and had to be reduced. Below is an image of the Digibotics 3D laser scanning machine used to scan the human femur.

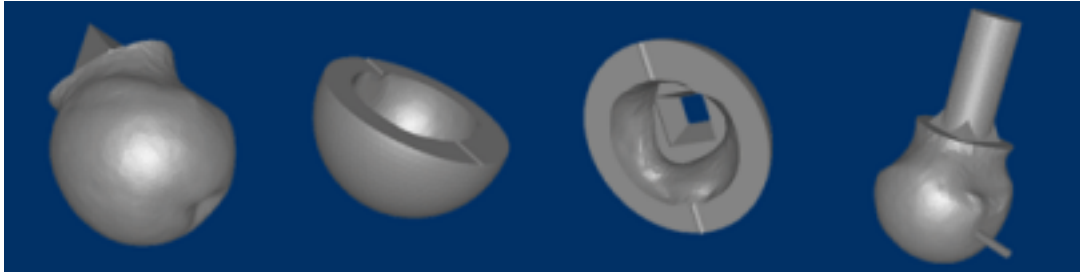


2. The 3D digital data was transferred to the UT ASE/EM LRC to be digitally processed. The original 3D digital model was too complex to manufacture using the laser-sintering machine available at UT. Thus, the first step was to reduce the number of facets representing the femur bone to 30,000 while maintaining part accuracy. The 3D digital model was then sectioned by digitally separating the ball section from the shaft of the femur. A locator peg was added to the ball section to indicate where it would contact the shaft portion of the femur.

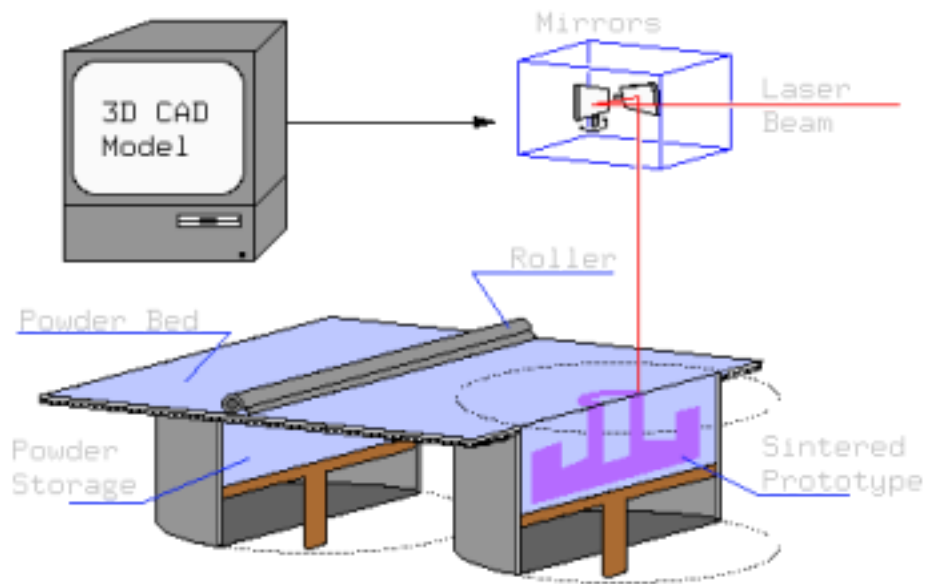


3. The ball section and peg were inverted to create a digital mold. This was a rather complex process because the mold geometry had to meet the specifications of the titanium foundry. The size and shape of the neck, where molten titanium would enter the mold, had to be shaped to prevent pressure build-up and ensure proper metal flow. In addition, a small vent hole was added to allow the titanium to completely fill the mold. Finally, to conserve material, the size of the mold was

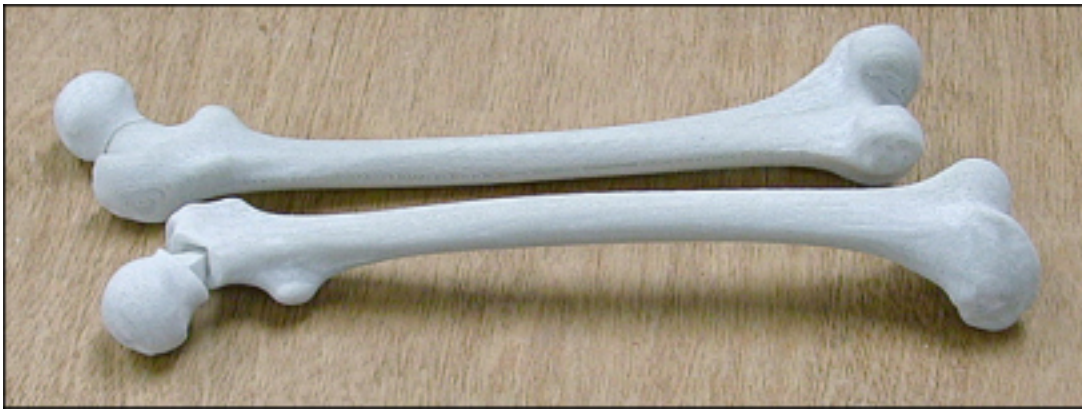
reduced by 50 percent. The finished 3D digital mold was converted to an STL format so it could be constructed in a Selective Laser Sintering workstation. Below are 3D computer images of the making of the digital mold in various stages.



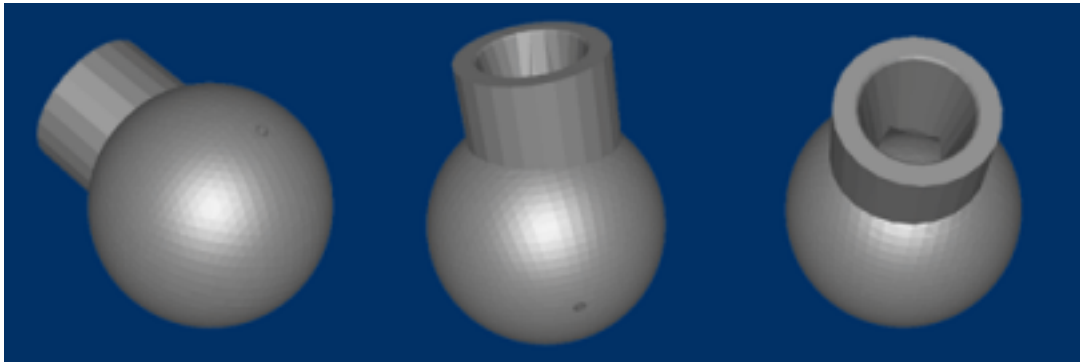
4. Samples of mold material were built on an SLS Model 125 Workstation, located in the Laboratory for Freeform Fabrication (Mechanical Engineering Department). The base material was a mixture of stabilized zirconia powder and a sacrificial polymer binder. During post-processing, the sacrificial polymer binder was replaced by unstabilized zirconia and the material was fired to increase strength. Below is a diagram of the laser sintering machine.



5. Strength, roughness and shrinkage were measured on material samples before and after each processing step. The values obtained were used to refine the process. Shrinkage could be accurately predicted, and roughness and strength were brought to acceptable levels for titanium casting. Below are two sets of femur and ball inserts made in nylon with the Selective Laser Sintering process.



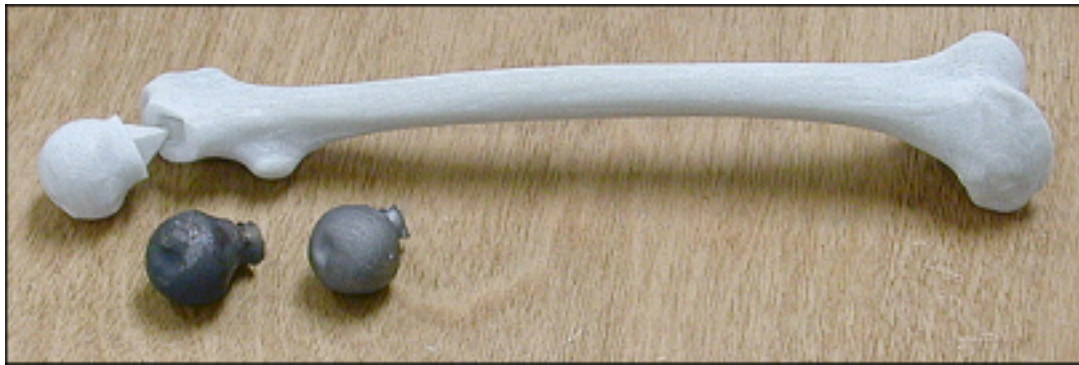
6. A simple test mold and two molds of the bone section were made in the SLS Workstation from the digital models and post-processed. The molds were taken to Howmet Research Corporation, a foundry in Whitehall, Michigan, to be cast with titanium. Below are 3 computer images of the final digital mold.



7. The titanium castings were prepared metallographically. Optical microscopy revealed a thin alpha case on the surface of the casting, typical of as-cast titanium alloys. The thickness of the alpha case was comparable to those obtained using standard mold materials. Roughness measurements indicated an as-cast surface roughness (R_a) of 8 microns. Below are pictures of cast titanium (dark) and broken zirconia molds (white).



It is hoped that a damaged bone can be replaced with a customer-specific titanium implant using the outlined production method. An X-ray, CT or MRI scan of a symmetric, non-damaged bone could be reversed and used to construct the mold for a damaged bone. Essentially any damaged bone (a finger, toe, hand, arm, foot, jaw, or skull) could be replicated in a titanium implant. The high strength to weight ratio and biocompatibility of titanium make it a reliable implant material, and now, using digitally designed zirconia molds, better fitting implants can be produced.



Above pictures of nylon femur with ball insert (white) and 2 titanium casts (dark).



Above pictures of 2 titanium cast (dark) and 1 nylon (white) ball with insert.

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UT Research Web VP for Research

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Nicole Harlan, Reuben Reyes, David L. Bourell, and Joseph J. Beaman
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(TMS 2000)

Nashville Tennessee March 12-16, 2000

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and Manufacturing: Stereolithography and Selective Laser Sintering

Nicole Harlan, Seok-Min Park, Joseph J. Beaman, and David L. Bourell

"Selective Laser Sintering with Meso-Scale Features"

Nicole Harlan, Seok-Min Park, Joseph J. Beaman, and David L. Bourell

"Zirconia Molds for Titanium Casting"

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