DESIGN OF COMPONENTS WITH ORIENTED MICROSTRUCTURES: A HEXAHEDRAL MESHING PROBLEM

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This paper describes an integration of optimized design and fabrication leading to structural components with complex oriented microstructures. Rather than a solid component with optimized outer shape, for example, this process leads to a component with an inner skeleton – or microstructure – arranged to maximize the stiffness-to-weight ratio. Functional gradients are a natural outcome of this process. We have combined the most advantageous aspects of Solid Freeform Fabrication (SFF) and conventional fabrication techniques into a novel casting process that makes metal components from finely detailed SFF patterns.

Common implementations of topology optimization [1] include means to suppress regions of intermediate density, as these regions are assumed to represent a hindrance to fabrication. In our work, however, variations in density and orientation are used to determine *distortions to the shape and size* of a unit cell to create optimal effective material properties at all locations within the component. Some researchers exploring this concept have permitted the *form* of the unit cell to vary within the component [2], but we submit that manufacturing concerns deserve much greater attention: developing forms for the unit cell so the component can actually be fabricated is the starting point for the current research. Two such forms for the unit cell, and the problems and benefits of each, are pursued in this work.

As one option, we describe a simple unit cell consisting of three orthogonal tapered rods. The rods are oriented, in the simplest case, with the principal stress directions, and the rods' diameters are related to the magnitudes of the principal stresses. Filling a component's volume with this unit cell requires generating a mesh of hexahedra that are oriented with the principal stresses. Some of the well-known difficulties of unstructured hexahedral mesh generation [3] are moot here, as we can accept a rough conformance to the component's outer boundary and smooth it later in a physical machining operation.

As an alternative, we describe a more complex unit cell that has three main orthogonal rods, plus rods in all diagonal directions linking the ends of the main rods. By increasing the diameters of some rods and decreasing others, we can create the effect of orientation in any direction without actually rotating the outer boundary of the unit cell. This implementation requires significantly less work on meshing, but it is more difficult to describe the unit cell itself.

In the paper we present a sample structural component with its optimized distribution of density, and show its microstructure according to both forms of unit cell. We also include examples of cast metal objects made from SFF patterns.

References:

[1] M. P. Bendsoe and O. Sigmund, *Topology Optimization: Theory, Methods and Applications*, Springer Verlag, Berlin, 2003.

[2] H. Rodrigues, J. M. Guedes, and M. P. Bendsoe, "Hierarchical optimization of material and structure," *Struc. Multidisc. Optim.* 24, 1-10, 2002.

[3] Meshing Research Corner. http://www.andrew.cmu.edu/user/sowen/mesh.html (accessed 1/10/06).

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