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News and Views
Material witness: Pedal power
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If you want an illustration of the challenges and compromises involved in materials selection and design, look to the bicycle.

At face value, the safety factor built into bicycles is ridiculously high: their strength far exceeds what is necessary for road riding. That's why a dozen people can balance on a commercial bike at the circus, and why in China people can load their bikes with seemingly the entire contents of their house.

But breakage from simple overloading is not what bicycle manufacturers worry about. The main danger, excepting high-speed collisions, is not that the tensile strength of the frame will be exceeded but that it will break because of fatigue. David Gordon Wilson, emeritus professor of engineering at MIT whose newly revised *Bicycling Science* (MIT Press, 2004) tells you all you could need to know about this mighty invention, points out that most structural failures in bikes are caused by fatigue brought on by the impact from hundreds or thousands of bumps.

One solution is to simply add more material to the structure. But as Wilson says, "many riders would prefer a lightweight bicycle meant to last only a few years to pushing around something double the weight and meant to endure for millennia". Whereas manufacturers must balance weight against lifetime, they are not always willing to admit to the resultant compromise.

In addition, ductility plays a role in the material's ability to withstand microscopic cracking — a factor that depends on the shape of the components and the time history of the applied stress. And what about stiffness, which seems desirable until you think about the virtues of elastic compliance (particularly in the handlebars) for softening bumps? Although cyclists can become obsessive about the benefits of weight reduction, small savings in an already lightweight frame make very little difference except perhaps at the highest competitive levels.

The earliest bicycle, the pedal-less Draisienne or 'running machine' made by Baron Karl von Drais around 1817, was fashioned primarily from wood, and the wood-framed bicycle has been revived repeatedly, sometimes made from bamboo. Just three years ago a German company was advertising a rather exquisite "hand-crafted wooden Italian bicycle" with a frame of "sturdy oak", which was perhaps more of an exercise in aesthetics than materials optimization.

Fibre-reinforced composites might sound like ideal candidate materials, but their anisotropy and lack of ductility can let them down: fatigue failure of composites has been called 'sudden death', which is not really what one wants in a bicycle.

Once you add in the questions of wheel-spoke and rim elasticity, brake-block friction (dry and wet), and tyre design (they no longer need tubes), the materials challenges of the bicycle are profound. If you neglect cost, of course, the possibilities verge on the bizarre. The American Bicycle Corporation achieved a splendid stiffness-to-weight ratio with a frame made from beryllium, at a cost of $20,000. It was also highly toxic — not to be ridden in cycling shorts.