To Repair or Not to Repair Cracked Wood

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If only wood could be defect-free, then the minimum strength of solid-wood beams and other structures could be much higher. Structural failures could be avoided, and-or less material might be required in some applications. Cracks in wooden structures can be filled with adhesives or with thermoplastic composite material. But to approach the intended strength of defect-free wood, it is necessary to use other strategies such as glued rods and surface patches. The ultimate answer may lie in better species selection, tree breeding, forestry strategies, lumber cutting practices, and lumber drying practices to avoid cracks in the first place.

Keywords: Wood defects; Wood adhesives; Reinforcements; Splits in wood

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INTRODUCTION

Wood, for all its positive attributes, can lose much of its value if it develops cracks or other major defects. Defects in wood – either before or after the manufacture of houses, bridges, and furniture, *etc.* – can lower the efficient usage of materials and result in low-strength or even dangerous structures. Wouldn't it be wonderful if there were a convenient way to fix such defects?

When this happens to the wooden chair upon which I sit in my dining room, I am tempted to take the item apart, squirt some wood-glue into the crack, tighten a clamp, let it dry, and hope for the best. What sometimes happens is that another crack, which may already have been present, opens up adjacent to the original crack, and I end up crashing to the floor a second time.

Another problem is that the cracks within wood sometimes had developed already when the tree was standing, or later when the wood was being dried. That means that there has been time for pitch-like materials to migrate to the surface, thereby creating a layer of weak and low-energy material that may be poorly suited to bonding with an adhesive. If I were to squeeze glue into that kind of crack, I would probably get results consistent with my lazy approach: failure of the joint during either the first or a later usage, whichever is the most inconvenient.

At the nano scale, it has been determined that the tensile strength of cellulose crystals can be higher than the bulk tensile strength of steel or Kevlar® (Moon *et al.* 2011). But those super-strong crystals, when obtained from wood, are only about 100 nm long. As a consequence, the strength of anything made out of wood is limited by the strength of whatever is holding those entities together. In natural wood there is a sophisticated hierarchy of structures in which the cellulose crystallites are joined together by amorphous or imperfect crystalline cellulose regions, and there is further involvement with rigid lignin structures and highly bondable hemicellulose chains, all arranged in fibrils, layers, cell walls, fibers, and continuing toward the macroscopic wood that makes up a tree. If only the wood could be defect-free; then one would not need to consider use of formaldehyde-

containing resins to repair it or to bond pieces of it together (Dunky 1998). In principle, the bonding could be done with bio-based adhesives (Pizzi 2006), but it is even better if the natural wood can be used instead.

A literature search did not show much research related to the repair of cracks in wood (Franke *et al.* 2015). Yes, it is possible to squeeze thermoplastic polymers or composite material into the cracks of wood (Dourado *et al.* 2012), but this has not been reported to do much for strength. Glue repairs are of interest to those skilled in woodworking, but they are seldom mentioned in research articles. To approach the original strength of the wood piece, it appears that the most promising strategies are (a) gluing of rods, nails, bolts, or spikes into holes that are drilled perpendicular to the grain of the wood (Akbiyik *et al.* 2007), and (b) attachment of high-tensile-strength "patches" to the side of the wood piece that is expected to be in tension (Clarke *et al.* 1993; Campilho *et al.* 2009; Barreto *et al.* 2010). These types of repairs have been used in many practical cases, including the floor of an ancient building (Metelli *et al.* 2016) and in the repair of timber bridges (Burgers *et al.* 2008; Gutkowski *et al.* 2010).

The principle of overlapping appears to be important when bonding wood together to create a strong joint or repair. Thus it has been shown that "patches" at the surfaces of repaired wood segments are increasingly effective with increasing length (Campilho *et al.* 2010; Carbas *et al.* 2015). At a smaller scale, relatively long finger joints are known to give the best strength. Even at the microscopic scale it has recently been observed that effective frictionally-induced end-grain-to-end-grain welding seems to involve a kind of finger jointing (Zhang *et al.* 2017). In practice, usually it is necessary to cut out damaged material first (Franke *et al.* 2015); then such options as finger-jointing and the use of new wood material become possible.

Repairs after damage has occurred tend to be expensive and inconvenient. So what can be done to prevent such situations? Maybe when ordering a wooden chair I ought to insist that it had been made from a species such as maple or cherry that are not especially prone to splitting. I would not want to trust furniture made from, for instance, *Eucalyptus globulus*, which can yield excellent kraft pulp, but which tends to split or check during drying (Neumann and Saavedra 1992). Also, I would hope that the factory had procedures and technology in place to avoid knots and other strength-decreasing features in the wood pieces they employ when making the chair that I will later buy. Perhaps, in the distant future, wooden furniture will be even better as a result of breeding programs to produce straighter-grain trunks, plantation management done in such a way that most major branches (and the resulting knots) are near the top of the tree, and advances in drying technologies to minimize development of cracks.

So let's return to the topic of the wooden chair in my dining room. Glued bolts can look unsightly. Metal plates or other high-tensile "patches" can call attention to themselves even more. So I did not even start to go down that road. Instead, an experienced woodworker was asked to get involved. The root of the problem was an unfortunate directionality of the grain in the part of the chair that had failed. The best solution was to cut and mill a new piece to replace the broken one.

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