The Role of Wood Science in Investigating Furniture Failures

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The causes of failure of wood furniture fall into two groups: those due to design and those due to manufacturing errors. Design failures include, but are not limited to, furniture parts that are too small and joints that are incorrectly configured. Manufacturing errors include using the wrong wood species or part, omitting fasteners, and substituting non-approved hardware, fasteners, and adhesives.

In Europe, especially in England and Scandinavia, there are furniture testing laboratories that approve furniture designs and assist manufacturers in making quality control measurements. Furniture is grouped into different categories such as household furniture and office furniture. Each category has its own design criteria based on the furniture’s expected use. Although a few trade organizations in the United States—the Business and Institutional Furniture Manufacturers Association, for example—and some of the larger furniture companies have testing facilities, there is no government testing facility nor any voluntary product standard regulating the strength of furniture purchased by the general public.

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In this article we describe actual furniture failures to illustrate the use of wood science and technology in investigating such failures. It is our hope that the experience gained from these examples will contribute to improved designs and better use of wood in furniture.

**Dowel Joint Failure**

A man was sitting in a wood chair working at a desk. As he pushed the chair away from the desk, the right back post separated from the side rail supporting the seat, causing the man to fall to the floor. Ironically, the man, who is now unable to walk as a result of the fall, had been assigned to this desk job because a previous injury prevented him from doing physical labor.

The man's employer had purchased five identical chairs less than 1 year previous to the accident. Of the four other chairs, two were missing and presumed junked, and two were still in use. The chairs were designed such that there were no stretchers between the legs and no arms. While examining the broken chair it was noted that five different species of wood had been used, and that several indications of sloppy manufacturing were apparent. Inspection of the back post/side rail joint showed that the two 7/16-in.-diameter dowel pins securing the connection had withdrawn from their holes without any wood failure. The holes had been bored to accept 2-1/2-in.-long dowel pins, but 1-1/2-in.-long pins had been used instead. In the bottom of each hole was a considerable amount of adhesive. Under the seat, the screw securing the corner block to the leg had pulled out because it was embedded into the leg less than 3/8 in. When an identical unbroken chair was taken apart, the same situation was found.

In practice, dowel pin joints are assembled by first squinting adhesive into the bored hole, then inserting the pin. Straight flutes or spiral grooves machined along the length of the pin allow glue in the hole to flow upwards and surround the pin as it is forced to the bottom of the hole. If the hole is drilled too deep for the pin's length, the pin simply pushes the glue to the bottom of the hole as it is inserted, leaving a weak, starved joint between the dowel and the sides of the hole.

The diameter and depth of penetration of dowel pins and the distance between them determines the withdrawal (tensile) and bending strengths of doweled joints. The force needed to withdraw a single glued dowel pin from solid wood is (Eckelman 1969):

\[
F = 0.834 DL^{0.89}(0.95S_1 + S_2)abc
\]

where:
- \( F \) = withdrawal strength of dowel loaded in tension (lb.)
- \( D \) = dowel diameter (in.)
- \( L \) = depth of penetration of dowel (in.)
- \( S_1 \) = shear strength parallel to grain of wood being joined (lb.in. \(^{-2}\))
- \( S_2 \) = shear strength parallel to grain of dowel (lb. in. \(^{-2}\))
- \( a \) = adhesive type factor (1 for gap-filling urea formaldehyde (UF) or polyvinylacetate (PVA) with at least 60% solids content; 0.9 for PVA with less than 60% solids content; 0.85 for hide glue)
- \( b \) = dowel/hole clearance factor ([1 - 9.1d] for UF; [1 - 17.1d] for PVA; and [1 - 1.8d] for hide glue, where d is the difference in inches between the diameter of the dowel and the bored hole)
- \( c \) = dowel surface factor (1 for smooth dowels; 0.9 for spiral grooved and fluted dowels)

The bending strength of a two-dowel joint in solid wood is (Eckelman 1971) (Fig. 1):

\[
M = F (d_1 + d_2/2)
\]

where
- \( M \) = ultimate bending moment (in. lb.)
- \( F \) = withdrawal strength of dowel (lb.)
- \( d_1 \) = spacing between dowel hole centers (in.)
- \( d_2 \) = distance from edge of member to center of dowel loaded in compression (in.)

By using pins too short for the depth of the bored holes, the chair's assembler materially reduced the as-designed strength of the joint. Because there was no glue surrounding
the dowels, the joint was bound to fail very early. Use of an
deresize screw in the corner block also reduced the joint’s
strength. Inclusion of arms or stretchers in this chair’s de-
sign would have considerably reduced the stress on the
back post/side rail joint.

Variable Strength of Ring-Porous Hardwoods

Several times a leading manufacturer of wood office fur-

niture had experienced breakage of the same red oak chair
part. Design calculations showed that the wood species and
part dimensions met the strength requirements with a suffi-
cient margin of safety. Examination of several of the failed
parts revealed that their grain was straight and that the
parts had no apparent defects that would reduce their
strength. The red oak was high in quality, but of slow
growth, with a large number of growth rings per inch. The
wood was lighter than usual in weight, indicating low den-
sity. Because the strength of wood decreases as its density
decreases, the actual strength of a piece of wood with
lower-than-average density is much lower than its assumed
strength.

Ring-porous hardwood trees such as red oak lay down a
band of large-diameter, thin-walled cells called earlywood
vessels at the beginning of the growing season. As the sea-
son progresses, small-diameter, thick-walled cells called
latewood fibers are produced. Regardless of how slow or
fast a ring-porous hardwood tree grows, the width of the
earlywood band remains relatively constant from year to
year. The width of the latewood band, however, is narrower
in years of slow growth and wider when growth is fast. As a
consequence, each growth ring in a ring porous hardwood
consists of a band of low-density, low-strength earlywood
of nearly constant width and a band of high-density,
high-strength latewood of variable width. Thus, furniture
parts made from slow-grown ring-porous hardwoods are
lighter in weight, lower in density, and much weaker than
those made from fast-grown wood. That is the opposite
true for softwoods such as southern pine and
Douglas-fir—slow growth results in higher density and
greater strength—often leads to confusion for furniture
manufacturers using ring-porous hardwoods.

The manufacturer of the chairs wanted to know how it
could eliminate the low-strength, slow-grown pieces
through its quality control procedures. The manufacturer
did not want its quality control people to have to count the
growth rings of the thousands of pieces of wood that moved
through the plant daily, but wanted a system that would
positively identify pieces to be culled. It was suggested that
fully machined pieces could be weighed, as long as their
moisture content was well controlled. This way, any piece
below a certain weight could be rejected. The lower thresh-
old of weight would be established by strength-testing fully
machined pieces of known moisture content and weight.
The manufacturer was also advised to specify fast-grown
red oak when purchasing raw material for critical parts
needing greater strength.

Off-The-Wall Kitchen Cabinet

A kitchen cabinet fell off of a wall, injuring a woman. This
new cabinet had been mounted above the sink less than a
year before, and although filled with dishes when it fell, was
not overloaded. Past experience with falling wall-hung cabi-

nets indicated that typically, the cabinets are not hung cor-
rectly by the installer. Frequently, the mounting screws do
not hit the studs or are too short or too small in diameter. In
to this case, however, the mounting bracket was still attached
to the wall with 3-1/2-in.-long by 1/2-in.-diameter lag
bolts. Every bolt was embedded in a stud.

The kitchen contained five wall-hung cabinets, including
the one that fell. A cabinet adjacent to the fallen unit was
still in place. Contrary to the manufacturer’s instructions,
the installer had not screwed the two together. Another cabi-

inet, holding a microwave oven, had begun to separate from
the wall as early as the manufacturer. An examination of the fallen cabinet’s mounting bracket showed
that it originally had been factory-fastened to the cabinet
with staples and hot melt adhesive. In the assembly process,
the staples are used to hold the mounting bracket and cabi-

net together until the hot melt adhesive cools, solidifies,
and gains strength. After a few moisture content cycles, the
wood loosens its grip on the staples, and they provide little
additional strength to the joint.

Some hot melt adhesives have inadequate resistance to
moisture; all re-soften when exposed to high temperature.
Analysis indicated that the cabinet fell off of the wall be-
cause the high humidity and relatively high temperature in
this southern house caused the hot melt adhesive to debond
from the wood. The shipping box in which the fallen cabinet
came was labeled “above the sink cabinet.” Certainly, any
 cabinet located above a sink should be expected to be sub-
ject to high humidity. Screwing the mounting bracket to the
rear of these cabinets would greatly improve their design
and performance, and would have prevented this injury.

Brash Wood Chair Failure

A woman was sitting on a new chair in a restaurant when
her young son climbed up to hug her. One of its legs abruptly
broke, and the woman was injured when she hit the floor.
The chair, made of beech, was imported from eastern Eu-

rope and was of a bent wood design common to the region.
The leg failed where a screw used to attach a brace entered
it. The failed leg showed a very brash break, with the frac-
ture almost perpendicular to the grain and no splintering as
would ordinarily be expected. Although the pilot hole
drilled for the screw had removed some of the wood, it did
not cause the failure.

Brashness in wood is easy to recognize, but its cause can
be elusive. Incipient or early decay can lead to brashness, as
can exposure to high temperature. No decay was found. It is
very likely that in steam-bending the parts for this chair the
strength of the wood was reduced because of overheating
for an excessive period of time.
Concluding Remarks

In each of the cases described above, failure could have been avoided through improved product design and engineering, better in-plant quality control, and meaningful performance testing before the product was released. Although some furniture companies diligently practice all three, most do not. Rational product design and engineering in which a product's service requirements are first defined and the product then designed to meet or exceed those requirements has progressed little in practice during the last 35 years. Many furniture manufacturers continue to rely on trial and error procedures in which product design and engineering takes place only in response to problems that arise after the product has been marketed. The problems attending this practice will persist until the furniture industry adopts policies similar to those employed by other industries that manufacture structural products. Such policies must quantitatively define how a furniture item will be loaded in service (load type, magnitude, and duration, for example); legally define allowable design stresses for the materials of construction; and develop rational procedures for designing the joints used in connecting its parts.

Many furniture manufacturers continue to embrace the “every worker is an inspector” concept with respect to quality control. Although there is considerable merit in this approach, there is also a need to define and document furniture quality requirements, if for no other reason than to periodically ensure that product quality is maintained, and in particular, to ensure that the quality of materials does not change. There is an enormous body of literature describing quality control procedures in other industries which, at least in part, can be applied directly to the manufacture of furniture. Thus, implementation of more effective quality control procedures in furniture manufacture need not await further research.

Performance tests should be used as an integral part of furniture product design and engineering. Such tests should not only qualify a product's fitness for use, but also provide quantitative data consistent with the needs of systematic rational design processes. Performance tests that rely on static loading may not be entirely suitable because furniture such as a chair is loaded in a dynamic and cyclic manner in actual use. Furthermore, performance tests should provide a smooth or stepwise path in testing to failure so that the ultimate strength of furniture can be determined. Worldwide, there are few tests today that satisfy these criteria. The method of test developed by the American Library Association (1995) for library chairs is one system that meets these criteria. Methods for upholstered furniture (1981) and intensive use task chairs (1983) developed by the General Services Administration are two others.

Literature Cited


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