29679

New versus Old Wood: Differences and Similarities in Physical, Mechanical, and Chemical Properties

David Erhardt,* Marion F. Mecklenburg and Charles S. Tumosa
Conservation Analytical Laboratory, Smithsonian Institution,
Washington, DC 20560, USA

Tone M. Olstad
Norwegian Institute for Cultural Heritage Research,
PB 736, Sentrum, 0101 Oslo, Norway

Abstract

Physical, mechanical and chemical properties of specimens of new and old (17th century) wood (*Pinus sylvestris* L.) from the same locale in Norway were examined. Only slight changes resulted from more than 300 years in an uncontrolled environment. No significant differences were seen in mechanical and physical properties including stress–strain behavior and dimensional moisture isotherms. Chemical changes found in the resin and cellulose were minor. Analysis indicated some hydrolysis of xylan. These results confirm previous work showing that wooden objects of all constructions, including furniture, safely tolerate moderate fluctuations in temperature and relative humidity. Cycling experiments on the present specimens confirmed this. Intact wood is chemically stable over a wide range of environments. The deterioration of furniture and wooden objects is due primarily to other factors, including abuse, extreme changes in temperature or relative humidity (such as hot, dry conditions caused by central heating), biological attack, or liquid water.

Keywords

Furniture, wood, environment, physical properties, mechanical properties, chemical properties, aging, relative humidity

Introduction

In recent studies,[1–8] the authors have examined the effects of the environment on numerous materials, including cellulosic materials such as wood. We have developed methods of using the results to produce environmental guidelines, including allowable fluctuations of relative humidity, for objects such as furniture constructed from these materials. The criterion for these guidelines is not just avoiding failure, such as cracking, but preventing any permanent physical change at all, such as distortion, change in length, or loss of strength or elasticity. We also take other factors, such as chemical stability, into account.[5–6] The results show that moderate ranges of relative humidity and temperature produce no physical damage in materials such as wood under worst-case conditions of full restraint, long-term exposure to the environmental extremes, and full response of the material. Much wider ranges are safe if worst-case conditions are not met. Thus, wood should survive essentially unchanged (except for possible chemical decomposition) under suitable conditions. Indeed, radiocarbon-dated subfossil specimens of wood up to 9,000 years old can be virtually impossible to date by visual inspection.[9] We conducted our research primarily on new or relatively new (19th and 20th century) materials that are readily available for experimentation. The results show that the conclusions are applicable to older materials. Results from older materials, including analyses of chemical differences between old and new samples, would reinforce this applicability. This is especially true for older materials that have been incorporated into objects. In this paper, we examine and discuss the differences and similarities for specimens of 17th century wood and a specimen from a tree of the same species from the same location felled in 1995.

The wood specimens

Three specimens of wood, each approximately 100 mm on each side, were used in this study. All three are Scotch pine (*Pinus sylvestris* L.). All three specimens are from trees grown in Setesdal, an area in southern Norway. One is from a tree felled in early 1995. The other two specimens (A and B) are from a *tvihøgdloft* (storehouse) at Brottveit farm in Valle in Setesdal. The *tvihøgdloft* is of 17th century construction. In 1923, it was placed on the list of historic buildings protected by law. Unfortunately, the building collapsed in 1924. It was disassembled, and the wood stored outside under a barn. In 1995, the building was reconstructed using as much of the old wood as possible, as well as new wood from the same area chosen to match the original. The old specimens are from the leftover original wood. The new specimen is from the wood used in the reconstruction.

The old specimens are weathered, dirty, and discolored on the exterior surfaces. The discoloration extends approximately 1 mm into the interior, as seen from freshly exposed cross sections. Otherwise, the old wood appears to be in remarkable condition. The only immediately noticeable differences between the interiors of the old and new wood are the highly resinous smell of the new wood (the old wood has a similar, but weaker, odor), and the slightly lighter appearance of the cut surfaces of the new wood. We cut samples for testing from the interior of the specimens.

* Author to whom correspondence should be addressed

Local climate

Det Norske Meteorologiske Institutt provided climatological data consisting of average monthly temperatures (T) and relative humidities (RH) from 1957 to the present for Byglandsfjord, a site near Valle. Normal temperatures for the 1961–1990 period range from −3.3°C for January to 15.3°C for July. Extremes for the entire set of monthly averages ranged from −9.3°C (February 1966) to 18.7°C (July 1994). Normal values for RH were not available, but the monthly averages ranged from 47.1% RH (August 1976) to 96.3% RH (November 1959). Ranges for daily and instantaneous values for T and RH would be wider.

Physical, mechanical and chemical properties

Physical and mechanical properties measured in this work include the dimensional moisture isotherms (change in equilibrium length at constant T as a function of RH) measured in the tangential, radial, and longitudinal directions, and stress–strain measurements for the three directions at constant T and RH. The methods have been described previously.[10] The results can be used to calculate minimum safe values of environmental fluctuations.[2–4] The calculations assume worst-case conditions of full restraint, long-term exposure to the environmental extremes, and full response of the material. Such calculations result in safe allowable ranges for objects such as furniture, which often meets the worst-case assumptions of construction. This worst-case construction can include restraint by joints, nails, and screws; responsive materials adhered to unresponsive materials (tangentially cut veneers on longitudinally cut wood, metal boulework adhered with glue); and thick or coated wood in which the rate of response of the interior or one side differs greatly from the rest of the piece.

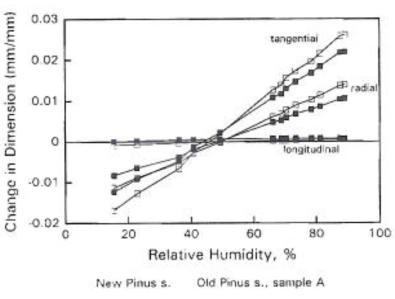

Figure 1. Dimensional moisture isotherms in the tangential, radial, and longitudinal directions for a new specimen of Pinus sylvestris L.*, and old specimen A. The differences are no more than those typically found for different samples of new specimens*

Chemical measurements include analyses of the types and amounts of soluble monomeric and oligomeric saccharides, including cellulose degradation products, and the amount and composition of resin in the specimens. Soluble carbohydrate material was extracted by soaking finely divided wood in water, and analyzed as the *per*-trimethylsilylated oxime derivatives as described previously.[11] The types and amounts of cellulosic degradation products have been used previously to follow the aging of cellulose.[5]

Resin was extracted by soaking in dichloromethane. The extract was methylated and analyzed as described previously.[11] Differences in the distribution of more or less volatile resin components should provide an indication of whether volatilization of resin components in the old wood has occurred. Other changes can be indicators of thermal and/or oxidative reaction processes. In addition, mechanical tests of new samples from which resin has been extracted should show the degree to which any physical differences in old and new specimens could be due to volatilization of resin components.

Response to RH change

Figure 1 shows the dimensional moisture isotherms (change in equilibrium length as a function of RH) in the tangential, radial, and longitudinal directions for the new wood and old specimen A (the results for specimen B are similar to those for specimen A, but are omitted for clarity). The isotherms for the old and new wood are essentially the same, meaning that the responses to RH fluctuations of the old and new wood specimens are the same. The differences are no greater than those typically found for different samples of the same species of new wood. Although the response of the old wood when it was new is not known, it very likely was similar to that of the new specimen. If so, the isotherm has not changed significantly in more than 300 years.

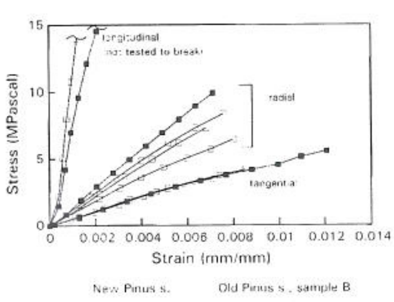

Figure 2. Equilibrium stress–strain curves in the tangential, radial, and longitudinal directions for a new specimen of Pinus sylvestris L.*, and old specimen B. The differences are no more than those typically found for different samples of new specimens*

Stress–strain behavior

Figure 2 shows equilibrium stress–strain curves in the tangential, radial, and longitudinal directions for the new wood and old specimen B. These show the deformation (strain) produced by increasing force (stress), with the curve ending at failure when the sample breaks. Though not identical, the results for the samples vary no more than expected for different samples of new wood of the same species.

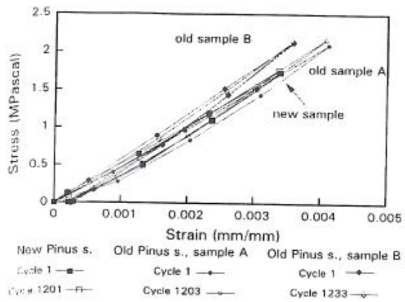

Figure 3. Effect of cyclic straining within the elastic region (strain ≤ ~0.004, or 0.4%) in the tangential direction for a new specimen of Pinus sylvestris *L., and old specimens A and B. The strain is equivalent to that produced in a sample fully restrained at 50% RH and then exposed to a 9% change in RH long enough for full response (worst-case conditions). Even after more than 1,200 cycles, there is no change in the equilibrium length, stiffness, or response to stress*

The stiffness (slope of the curves), elastic limit (reversible stretch, which extends through the initial linear portion of the curve), and strain-to-break values are similar for both specimens. These results suggest that little change in the stress–strain properties of the wood has occurred over time. Most importantly, retention of the strain-to-break values implies that the wood has not been subjected to stresses, either structurally or environmentally produced, that exceeded the elastic limit. This is as expected from earlier work[2–4] that showed that wood tolerates moderate environmental fluctuations with no damage, and quite wide ranges if the wood is not restrained and can expand and contract freely.

Effect of cycling of stress

Samples of old and new wood were subjected to cyclic strains (repeated stretching) of approximately 0.4% in the tangential (weakest) direction. Figure 3 shows stress–strain curves for the initial cycles and after more than 1,200 cycles. The first and last cycles for each sample are essentially identical. Cycling within the elastic region produces no permanent deformation ("damage"). A strain of 0.4% is equivalent to that produced in the tangential (most responsive) direction by restraining a sample at 50% RH and changing the RH by 9% long enough for full response of the sample. (Full response in a 2 mm thick radially cut specimen with end grain exposed took about 48 h. Longitudinally cut specimens can take weeks.) Equivalent strains in the radial and longitudinal directions require even larger RH changes. These cycles thus are equivalent to cycling the RH to equilibrium within a range of 50 ± 9% under worst-case conditions (long exposure to RH extremes, full response, and full restraint in the tangential direction). Cycling will produce no damage for even greater ranges of RH if the worst-case conditions are not met, for example if the sample is not fully restrained. In practice, RH extremes rarely last long enough for materials to reach equilibrium. Extreme conditions generally are of short duration, and surface coatings and the thickness of the materials slow down the response.

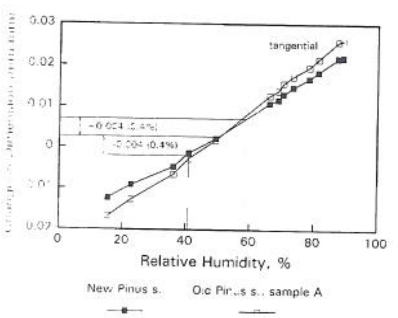

Figure 4. Calculation of the allowable RH fluctuations for a new specimen of Pinus sylvestris L., and old specimen A. A change of ±9% RH from 50% RH is required to produce a change in dimension of 0.4% for either sample. If a sample is restrained in the tangential direction with no stress at 50% RH and not *allowed to respond to an RH change, the result is the same as allowing the sample to shrink or swell and then stretching or compressing it by 0.4% back to the original length. Such changes are within the elastic limit, and are reversible. Because there are no significant differences between the dimensional moisture isotherms or elastic limits of the new and old wood, the minimum safe allowable fluctuations are essentially the same. Allowable fluctuations in the radial and longitudinal directions are at least twice as large, since the response in these directions to RH change is half or less that in the tangential direction*

Effect of age on allowable RH fluctuations

In earlier work, it was shown that allowable RH fluctuations can be calculated from the dimensional moisture isotherm and the strain that materials can tolerate without causing damage by exceeding the elastic limit.[2–4] These calculations assume the worst-case conditions mentioned previously. The resulting allowable fluctuations are extremely conservative, since the worst-case conditions are rarely fulfilled. Since there have been no significant changes in the dimensional moisture isotherms or elastic limits of the old specimens, allowable fluctuations calculated for the new wood also apply to the old wood. Figure 4 shows that an RH change of about ±9% from 50% RH is required to produce a dimensional change of ±0.4% in the tangential direction in samples of the new wood and old specimen A. If the sample is restrained, and *not* allowed to respond to the RH change, however, the result is the same as allowing the sample to shrink or swell, and then stretching or compressing it by 0.4% back to the original length. Such changes are within the elastic limit and are reversible. Permanent distortion, such as compression set, requires larger strains. The cycling data show that the maximum stresses and strains that can be produced within the RH range 50 ± 9%, even under worst-case conditions, cause no damage. In practice, such worst-case conditions are rarely fulfilled. For example, these specimens are from boards cut in a largely radial direction. The RH response in the radial direction is about half that in the tangential direction, and a change of about ±18% RH is required before equivalent strains could ever be produced in a fully restrained radial sample. This can be shown by applying the same approach used in Figure 4 to the plot of radial data in Figure 1 to determine the RH change required for a dimensional change of 0.4%. Unrestrained or partially restrained samples tolerate wider fluctuations.

The allowable fluctuation about a specific equilibrium RH depends on the responsiveness of materials to changes from the starting RH. Most hygroscopic materials do not respond at the same rate throughout the RH range, and are usually more responsive at low RH (below about 30% RH) and even more responsive at

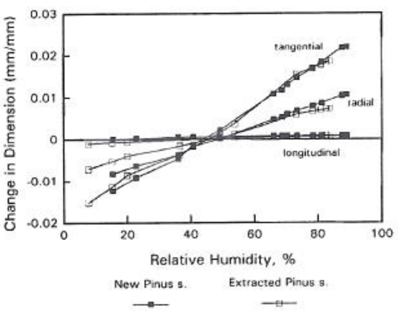

Figure 5. Dimensional moisture isotherms in the tangential, radial, and longitudinal directions for a new specimen of Pinus sylvestris *L., and for samples of the same specimen from which the resin has been extracted. The loss of resin produces no significant difference*

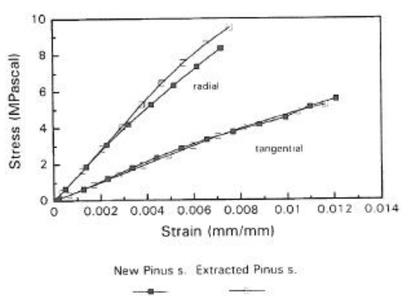

Figure 6. Stress–strain curves in the tangential and radial directions for a new specimen of Pinus sylvestris *L., and for samples of the same specimen from which the resin has been extracted. The differences are within the ranges typically found for different samples of the same specimen. The loss of resin produces no significant difference*

high RH (above about 70% RH). At high and low RH, smaller RH changes are required before excessive strains can occur because the response of materials such as wood and glue to RH changes is greater. Allowable fluctuations for materials and objects equilibrated at high RH can be quite small.[2–4] Furniture can *survive* moderate RH changes at high RH, but only because it is more easily plastically (irreversibly) deformed at high RH. Plastic deformation is not "failure", but does constitute damage. Wood can tolerate only a limited amount of plastic deformation, and each "equilibration" at high RH moves it further through the plastic region and closer to failure. The reversible RH region is still present, but less RH change *beyond* the allowable range is required before failure occurs. Much of the failure seen in furniture exposed to low RH is due not so much to the relatively small changes that occur in going from 50 to 30% RH, as to the stresses, strains, and plastic deformation originally built up by moving furniture equilibrated to high RH (above about 70% RH) to moderate RH environments.

Effect of loss of resin on behavior of new wood

Figures 5 and 6 show the dimensional moisture isotherms and stress–strain curves for new samples and new samples from which the resin was removed by extraction with dichloromethane. No significant difference is observed. Thus, the slow volatilization and loss of resin over the centuries (see below) should not affect the measured physical properties of the wood.

Differences in resin content

The composition of *Pinus sylvestris* L. resin depends on environmental factors rather than on seed origin.[12] Resin extracts from wood grown in the same area should have similar compositions before aging (assuming little change in the average climate). Significant differences among resin samples extracted from old and new wood therefore should be attributable to aging.

A number of old and new wood samples were weighed before and after exhaustive extraction of resin. Weight differences showed that the new wood contained between 12 and 26% by weight of resin, while the old samples contained between 7 and 11%. Though the resin content of even new samples can vary widely (depending, for instance, on the proportion of early and late growth in the specific sample), the generally lower amounts in the old wood indicate that components of the resin can migrate and volatilize from the interior of wood. This is substantiated by the more intense odor of the fresh specimen which indicates both that more volatile resin is present and that it is volatilizing.

Figure 7 consists of gas chromatograms of resin extracted from samples of the three wood specimens. The new resin sample is typical of that expected for this species of wood, consisting primarily of monoterpenes and diterpenes, with abietic acid as the component present in the greatest quantity. One interesting aspect is the presence of the unsaturated fatty acids oleic, linoleic, and linolenic. These compounds are quite reactive. It is the presence and reaction of linoleic and linolenic acid glyceride esters in drying oils that is responsible for the "drying" (polymerization) reactions of these oils. Resin from specimen B of the old wood is similar in composition, though not identical. The differences are typical of those resulting from aging. One indication of change is the lower proportion of monoterpenes compared with diterpenes. The monoterpenes are more volatile, and the lowered proportion is another indication that some loss by volatilization has taken place. The amounts of all but one of the abietane acids are reduced. The amount of dehdyroabietic acid is substantially increased. Dehydroabietic acid is a stable dehydrogenation reaction product of abietic acid, and also of the other abietane isomers, produced by thermal and/or oxidative reaction. Dehydroabietic acid may be the only remaining compound found in analyses of old, thin films of varnish that indicates the original presence of pine resin as a component. That substantial amounts of abietic acid and its isomers, as well as the unsaturated fatty acids and volatile monoterpenes, are still present indicates a remarkable state of preservation of the resin component of the wood. Amounts of the pimarane acids do not vary as much or systematically. Resin from the other old specimen (A)

Table 1. The composition of resin in new and old samples of Pinus sylvestris *L. Amounts reported as percent of total resin components. Amounts do not add to 100% because of unreported components*

Sample	Monoterpenes: α-Pinene	Monoterpenes: Δ-3-Carene	Unsaturated fatty acids: Oleic	Unsaturated fatty acids: Linoleic	Unsaturated fatty acids: Linolenic
New	6.1	11.4	1.8	1.6	trace
B	3.9	4.1	1.4	1.5	trace
A	1.3	2.6	trace	trace	trace

Diterpene acids

Sample	Pimaranes: Pimaric	Pimaranes: Sandara-copimaric	Pimaranes: Isopimaric	Abietanes: Palustric	Abietanes: Dehydro-abietic	Abietanes: Abietic	Abietanes: Neoabietic
New	7.2	1.1	2.4	15.5	8.7	22.1	13.2
B	8.2	0.8	5.4	13.1	16.6	20.3	6.8
A	6.7	trace	3.0	3.6	22.1	13.0	trace

exhibits more signs of aging. Dehydroabietic acid has become the major component. Smaller amounts of the unsaturated fatty acids and lower proportions of monoterpenes are present. Even this sample, though, is well preserved. Table 1 lists the relative proportions of the major components in the three resin samples.

Chemical degradation of cellulosic and other carbohydrate components

Samples of each wood specimen were finely powdered, weighed, and extracted with water. Gas chromatographic analysis of the saccharides present in the extract of the new wood showed that small amounts of both xylose and glucose are present

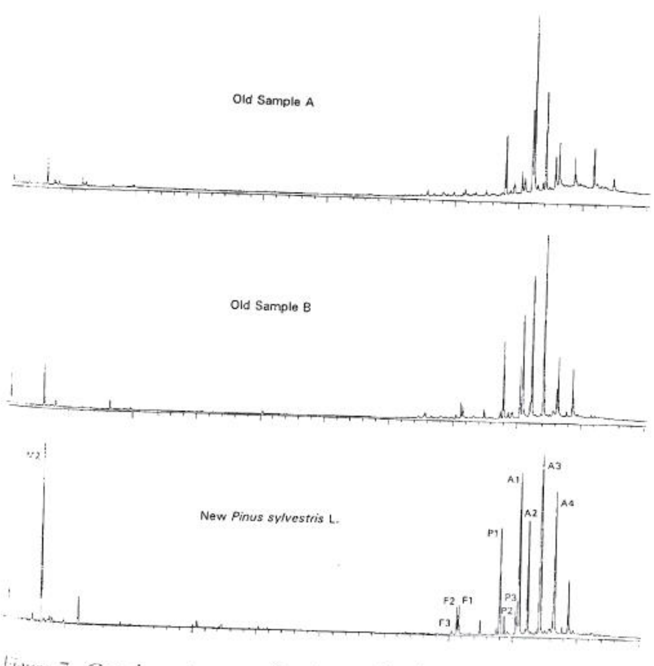

Figure 7. Gas chromatograms of resin samples from a new specimen of Pinus sylvestris *L., and old specimens A and B. The amounts of monoterpenes (M) and unsaturated fatty acids (F) are reduced in the old specimens. The amounts of the pimaranes (P) do not change much or systematically. The abietanes (A) can interconvert and/or dehydrogenate. This results in the more stable dehydroabietic acid (A2) eventually replacing abietic acid (A3) as the major component, as seen in old specimen A. Code: M1 = α-pinene, M2 = Δ-3-carene, F1 = oleic acid, F2 = linoleic acid, F3 = linolenic acid, P1 = pimaric acid, P2 = sandaracopimaric acid, P3 = isopimaric acid, A1 = palustric acid, A2 = dehydroabietic acid, A3 = abietic acid, A4 = neoabietic acid. Acids analyzed as the methyl esters*

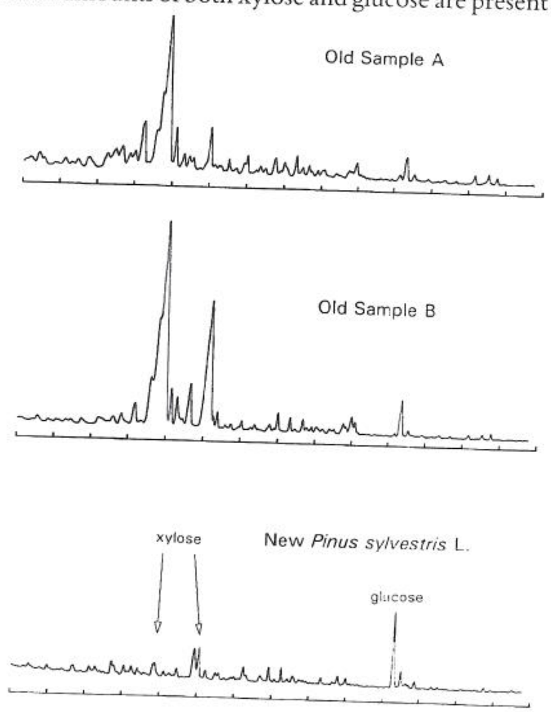

Figure 8. Monosaccharide region of gas chromatograms of aqueous extracts of a new specimen of Pinus sylvestris *L., and old specimens A and B. The amount of glucose is slightly smaller in the old samples, while the amount of xylose is significantly greater. These results, combined with the absence of significant amounts of glucose oligomers in other regions of the chromatograms (not shown), indicate some hydrolysis of xylan, but little or no hydrolysis of cellulose. Saccharides analyzed as the per-trimethylsilylated oximes*

Table 2. Amounts of xylose and glucose in new and old samples of Pinus sylvestris *L.*

Sample	Xylose (μg/g wood)	Glucose (μg/g wood)
New	247	199
B	3254	136
A	1627	93

in their free (monomeric) forms. Though some as yet unidentified peaks complicated the region of the chromatogram where oligosaccharides appear, no peaks were present corresponding to those for glucose oligomers (up through the tetramer) found in chromatograms for aged cellulose.[5] The old samples had increased amounts of xylose and other pentoses, but slightly smaller amounts of glucose and only trace amounts, if any, of oligomers. Figure 8 shows the monosaccharide portion of the gas chromatograms of the samples, and Table 2 lists the amounts of xylose and glucose found in the samples.

Xylose ("wood sugar") is present in wood primarily in the form of xylan, a branched polymer of xylose. The increased amounts of xylose in the old samples probably result from the partial hydrolysis of xylan.

The amounts of glucose and its oligomers can be used to follow the hydrolysis of cellulose during aging.[5] The amounts of glucose in the old samples are in fact smaller than in the new sample. The smaller amounts may be due to the season in which the tree was cut, rather than to any change with aging. This result, combined with the absence of significant amounts of glucose oligomers, shows that little hydrolysis of cellulose has occurred. Thus, though some hydrolysis of xylan has taken place, the less easily hydrolyzed cellulose is essentially intact.

Furniture construction and environmental response

Many furniture construction techniques, such as floating panels, allow for changes due to environmental changes. The preferential use of radial cut boards, which have a response to RH changes about half that of tangentially cut boards, is based on the observation that they respond less to environmental changes, and tolerate more extreme conditions without suffering permanent warping. Unfortunately, a number of furniture construction techniques represent "worst-case" conditions. This worst-case construction can include restraint by joints, nails, and screws; and responsive materials adhered to unresponsive materials (tangentially cut veneers on longitudinally cut wood, metal boulework adhered with glue).

Thick or coated wood in which the rate of response of the interior or one side differs greatly from the exterior or other surfaces can be damaged by large fast fluctuations, although even these fluctuations still must be larger than the allowable range and persist long enough for significant response of the exterior or responsive surface. Large fluctuations which do not last long enough for significant response do no damage. It must be remembered that it is the moisture content of the material, not the relative humidity of the air, that determines whether damage occurs. Even large, long-term fluctuations may be safely tolerated by thick wood if the changes occur gradually (e.g. seasonally). Slow changes reduce the effect of the differing rates of response. Thus, the response of the interior of a thick piece can keep up with the response of the exterior if the change is slow and gradual. This example is not "worst-case" in the sense that large changes can be tolerated under certain circumstances. The problem in this case results from differing rates of response.

True "worst-case" construction includes situations in which responsive materials are combined with non-responsive materials (not just materials which are slow to respond). Metal inlay and wood in the longitudinal direction do not respond more than minimally to relative humidity changes, no matter how long the exposure. Oil paint and gesso layers are also relatively unresponsive. Combining these materials with responsive materials (tangential wood, glue) produces a combination that cannot fully respond to fluctuations much greater than those recommended without permanent change (either plastic deformation, or, if the changes are large enough, failure). The recommended ranges can be calculated from the appropriate properties (dimensional response, allowable strain, modulus or stiffness) of the materials and the construction of the object.[2–3] In general, the allowable RH range is at least as wide as that of the material with the narrowest range. In other words, the allowable range is determined by the most responsive material. It is worth noting that the response of materials is not a constant throughout the RH range. Most materials are least responsive at moderate (approximately 30–60%) RH, and consequently tolerate the widest fluctuations in this range.[2–4]

Summary of results

Analysis and testing of the old and new wood show that little change has taken place in the old specimens. Chemical analyses do show slight changes. The composition of resin in the old specimens has just begun to exhibit some of the changes typical of those which resin varnish films undergo during aging, but the changes are much less extensive than would be found in a resin coating of the same age. Some hydrolysis of xylan has occurred, but no evidence of hydrolysis of cellulose was seen. These slight chemical changes seem so far not to be manifested in measurable physical changes. No significant differences exist between old and new specimens for any physical or mechanical properties measured, including strength, stiffness, elasticity, and response to changes in RH. The lower resin content of the old samples probably is due to volatilization. Extraction of the resin from new samples and testing of the extracted wood shows, however, that the loss of resin does not affect the measured physical or mechanical properties.

Stress–strain cycling of both old and new samples shows that the maximum stresses and strains that could be generated by cycling within the range 50 ± 9% RH produce no permanent change even under worst-case conditions. If worst-case conditions are not met, then no damage would be produced by even wider RH ranges. This is true for more than a thousand cycles, equivalent to many centuries of seasonal fluctuations. That there is no appreciable loss in strain-to-break in the aged samples supports this conclusion. This is especially true since these specimens have been exposed to much wider variations of RH, as well as wide ranges of temperature, as documented in the section on local climate.

These results show that there is no inherent difference between old and new wood, even when the aged wood has been exposed to an uncontrolled environment with quite large short-term and seasonal fluctuations in temperature and RH typical of a temperate climate.

These results, combined with previous work, can be applied as follows: Furniture comprised of any combination of materials in any type of construction can safely tolerate changes of relative humidity within the calculated ranges. The rate and duration of change do not matter within this range. Furniture which is constructed with consideration for environmental effects (floating panels, radial-cut wood, no massive components) can tolerate wider ranges of relative humidity. Furniture containing sections or connected surfaces with differing rates of response (panels coated on one side) also can tolerate wider ranges if the changes occur gradually. Furniture which contains "worst-case" construction (responsive and non-responsive materials joined) is safe within the recommended range, but risks damage outside the recommended range if the exposure is long enough for damaging levels of response to occur. "Equilibration" to RH levels outside the safe range in such cases consists of irreversible plastic deformation. For such construction, the relative humidity should be kept within the recommended ranges, although short excursions outside the range should not be a problem.

Conclusions

Measurements of the physical, mechanical, and chemical state of specimens of *Pinus sylvestris* L. wood from the same location in Norway showed little difference between new and 17th century specimens. Mechanical and physical measurements of strength, stiffness, elasticity, strain-to-break, lack of change resulting from cycling within the elastic region, and the dimensional response to RH changes showed no significant differences. Changes in resin content and composition indicate that some evaporation of volatile resin components has taken place. Only minimal changes in the resin due to thermal and/or oxidative reaction have occurred. Analysis of aqueous extracts of samples showed that some hydrolysis of xylan has occurred in the old specimens, but that the less easily hydrolyzed cellulose is essentially intact. These results show that "old" and "new" wood are not inherently different, and that age alone is not a reliable predictor of condition. The present results combined with previous work on allowable environmental ranges show that the guidelines developed for new materials apply equally well to old objects. In addition, these results were quite predictable based on previous work. The species of wood tested is used extensively in furniture and construction. We expect results for other species of wood to show the same lack of dependence on age. Previously developed environmental guidelines should extend to all old materials.

Earlier work showed that objects incorporating wood, glue, and other materials typically used in the construction of furniture can tolerate moderate fluctuations of temperature and RH with no damage. Safe RH ranges are typically at least ±10% RH for furniture conditioned to moderate RH, although these ranges are smaller for furniture equilibrated to very high or very low RH conditions. Damage (permanent distortion) and failure (fracture) of wood and furniture conditioned to moderate RH occurs under well defined circumstances including restraint and larger fluctuations in RH. That there is no appreciable change in the specimens examined in the present study reinforces the earlier results. There is no perceptible buildup of "damage" due to the temperature and RH fluctuations the old samples have experienced in centuries of exposure to uncontrolled environments. This agrees with results showing that a range exists within which the RH can be safely cycled without producing irreversible changes. Wood can degrade much more than the specimens in this study did, of course, but factors other than those involved here, such as extreme temperatures or dryness due to central heating, biological attack, or liquid water, must be involved. Age and moderate variations in temperature and RH are not important factors in the deterioration of furniture. Moderate and seasonal RH variations within the recommended ranges are not a problem. Funds are much better spent on improving other aspects of collections care and management than on pursuing environmental invariance.

Acknowledgments

The authors would like to thank Anders Haslestad for providing the wood specimens, and Det Norske Meteorologiske Institutt for providing the climatological data.

Notes and references

1. M.F. Mecklenburg and C.S. Tumosa, "The Relationship of Externally Applied Stresses to Environmentally Induced Stresses," in *Fiber Composites in Infrastructure: Proceedings of the First Internatinal Conference on Composites in Infrastructure,* eds. H. Saadatmanesh an M.R. Ehsani (Tucson: University of Arizona, 1996) 956–971.
2. M. Richard, M.F. Mecklenburg and C.S. Tumosa, "Technical Considerations for the Transport of Panel Paintings," *The Structural Conservation of Panel Paintings* (Marina del Rey: The Getty Conservation Institute, 1996, in press).
3. M.F. Mecklenburg, C.S. Tumosa and D. Erhardt, "Structural Response of Wood Panel Paintings to Changes in Ambient Relative Humidity," *Proceedings of the Painted Wood Symposium* (Washington: American Institute for Conservation, 1996, in press).
4. D. Erhardt, M.F. Mecklenburg, C.S. Tumosa, and M. McCormick-Goodhart, "The Determination of Allowable RH Fluctuations," *WAAC Newsletter* 17, no. 1 (1995): 19–23.
5. D. Erhardt and M.F. Mecklenburg, "Accelerated vs Natural Aging: Effect of Aging Conditions on the Aging Process of Paper," *Materials Issues in Art and Archaeology* IV, vol. 352 (Pittsburgh: Materials Research Society, 1995), 247–270.
6. D. Erhardt and M. Mecklenburg, "Relative Humidity Re-examined," *in Preventive Conservation: Practice, Theory and Research*, eds. A. Roy and P. Smith (London: The International Institute for Conservation of Historic and Artistic Works, 1994), 32–38.
7. M.F. Mecklenburg and C.S. Tumosa, "Mechanical Behavior of Paintings Subjected to Changes in Temperature and Relative Humidity," in *Art In Transit: Studies in the Transport of Paintings*, ed. M.F. Mecklenburg (Washington: National Gallery of Art, 1991), 173–216.
8. M.F. Mecklenburg and C.S. Tumosa, "An Introduction into the Mechanical Behavior of Paintings under Rapid Loading Conditions," in *Art In Transit: Studies in the Transport of Paintings*, ed. M.F. Mecklenburg (Washington: National Gallery of Art, 1991), 137–171.
9. L. Kullman, "Palaeoecology of Pine (*Pinus Sylvestris*) in the Swedish Scandes and a Review of the Analysis of Subfossil Wood," *Geografiska Annaler* 76 A, no. 4 (1994): 247–259.
10. M.F. Mecklenburg, "The Role of Water on the Strength of Polymers and Adhesives" (PhD dissertation, University of Maryland, 1984).
11. D. Erhardt, W. Hopwood, M. Baker and D. von Endt, "A Systematic Approach to the Instrumental Analysis of Natural Finishes and Binding Media," (Paper delivered at the 1988 New Orleans conference of the American Institute for Conservation), 67–84.
12. A. Nerg, P. Kainulainen, M. Vuorinen, M. Hanso, J.K. Holopainen and T. Kurkela, "Seasonal and Geographical Variation of Terpenes, Resin Acids, and Total Phenolics in Nursery Grown Seedlings of Scots Pine (*Pinus sylvestris* L.)," *New Phytologist* 128 (1994): 703–713.

ICOM COMMITTEE FOR CONSERVATION

11th Triennial Meeting
Edinburgh, Scotland
1–6 September 1996

Preprints Volume II

JAMES
X
JAMES

Published by James & James (Science Publishers) Ltd, Waterside House, 47 Kentish Town Road, London NW1 8NX, UK

A catalogue record for this book is available from the British Library

ISBN 1 873936 50 8

Printed in the UK by Bell & Bain Ltd, Glasgow

Available from:

James & James (Science Publishers) Ltd.
Waterside House
47 Kentish Town Road
London NW1 8NX
United Kingdom
fax: +44 171 284 3737
email: orders@jxj.com
http://www.jxj.com/

ICOM Committee for Conservation
c/o ICOM Paris
1 rue Miollis
75732 Paris Cedex 15
France
fax: +33 1 43 06 78 62
email: secretariat@icom.org

A NOTE ON THE COVER

The Canongate, Edinburgh, (looking west) from *Modern Athens displayed in a series of views, or, Edinburgh, in the nineteenth century: exhibiting the whole of the new buildings, modern improvements, antiquities & picturesque scenery, of the Scottish metropolis and its environs, from the original drawings by Mr Thomas H. Shepherd, with historical, topographical & critical illustrations.* London. Published by Jones & Co, Temple of the Muses, Finsbury Square 1 January 1829