COMPOSITE WOOD MATERIALS IN TWENTIETH CENTURY FURNITURE

by Susan Klim*

Much artistically and historically important 20th century furniture has been made of composite wood materials: plywood, laminated wood, and particleboard. These materials, being not only wood, but wood and glue, have unique properties and unique problems. A review of composite wood materials is presented, including their structure, manufacture, working properties, and the processes of deterioration which are inherent in the material and the technology. Ethical considerations regarding the treatment of these 20th century objects are discussed.

Introduction

Conservators of 20th century furniture are confronted with a broad range of materials that are either new to this century, like plastics, or new in their broad application to furniture, like metals. In addition to these materials is another, a traditional material which has been remade into a new one — composite wood. Plywood, laminated wood, and particleboard retain many of the familiar properties of wood, but their structure and manufacture add dimension and complexity to their usage, and to their deterioration.

Although these materials are unique to the 20th century in the degree to which they have been explored and utilized, their development predates this century, and there are numerous precedents for their use in furniture in the 19th century, and earlier. The Austrian cabinetmaker, Michael Thonet, began experimenting with laminations in the 1830's. He was interested in bending wood to produce fashionable Biedemeier furniture at lower cost than by conventional techniques — fewer parts, less joinery. Thonet abandoned bent laminations by 1850, as he became increasingly involved with the technology of bending solid wood. John Henry Belter, a German cabinetmaker who had emigrated to the U.S. around 1840, experimented with plywood laminations for the dished forms of his elaborately pierced and carved chair backs. The properties for which plywood has been exploited in the 20th century — its strength and dimensional stability, its light weight, its ability to be molded into compound curves — were essential to Belter's furniture, with its massive scale and extensive piercing. Utilitarian uses of the new materials proliferated in the second half of the 19th century, principally for secondary elements like the backs of chests and mirrors, and for prefabricated bent and perforated sheets, commonly used for chair backs and seats. Additionally, there are the isolated examples of more adventuresome use, like a patent model for a side chair (c.1873) by Isaac Cole, which anticipate not only the technology but the aesthetic reach of 20th century composite wood furniture as well.[1]

Definitions and Properties

Plywood is a glued wood panel, composed of relatively thin wood layers, or plies, glued to each other, with the grain of adjacent layers at an angle, usually 90°. There are two major types of plywood: thin panel, or all-veneer construction, and lumbercore.

In its simplest form, **all-veneer plywood** is composed of three layers: face, crossband or core veneer at a right angle, and face (Fig.l). In order that the construction of the panel be balanced, there are usually an odd number of layers — three, five, or seven typically. But plywood can also be made from an even number of veneers, with the two center ones having parallel grain, and in a sense acting as one

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thicker layer (so that the number of *layers* is still odd). In fact, there are any number of variations in the number and arrangement of veneers, depending on the properties of strength and flexibility that are desired. For example, in a bent plywood long chair designed by Marcel Breuer (1902-1981), c.1935, and produced by Isokon (Fig.2), the sequence of veneers in the plywood used for the seat element is, beginning from the front: long grain, cross grain, cross grain (these two are substantially thicker than the others), long grain, and cross grain, which shows at the back of the chair. The grain direction of the majority of the veneers is parallel to the axis of the bend, which facilitates bending. It is an essentially unbalanced construction, but an advantageous one for bending.

Lumbercore is a variety of plywood that has solid strips of lumber, instead of thin veneers, as its core (Fig.3). The strips, which can be narrow or wide, are generally arranged with the grain running alternately left and right, to avoid warping, and then sandwiched between two or four outer veneers. When only one veneer is glued to each face, the expansion and contraction of the core strips can result in splitting or compression of the face veneers; a thick, secondary veneer at each face usually prevents this. Lumbercore is stronger than all-veneer plywood, especially in the direction of its core. It had more extensive earlier use than plywood, typically for elements like desk tops, which required large stable panels. It was apparently commercially available as early as 1860 in Germany. Jean Dunand (1877-1942) appears to have made use of stock lumbercore, for example, in a lacquered wood side chair of 1928 (Fig.4). The chair's sides, which are lumbercore, taper from front to back. The lumbercore is lacquered on the outside face, but on the inside, only visible when the upholstery panels are removed, the lumbercore is exposed. The face veneers have been planed down to accomplish the taper, and the core strips thereby revealed.

The principle behind all of these arrangements is that by gluing sheets of wood to one another at right angles, you can reduce the expansion and contraction of the overall product. As the wood responds to ambient moisture and relative humidity cycles, the very low dimensional change parallel to the grain in one ply restrains the normal swelling and shrinkage across the grain in the adjacent ply. Plywood is, therefore, relatively stable in dimension, with properties along its length which are equivalent to properties along its width. Its weakness is in its third dimension, its thickness. Plywood is non-splitting, however, which allows it to be joined very near its edge, to create flush surfaces, and is quite strong in proportion to its weight, allowing for sturdy, lightweight construction. When wood is converted into plywood, its properties are modified, and its available sizes expanded.

Laminated wood is also a wood/glue composite, but in a laminated construction, the individual pieces of wood are arranged with their fibers running in the same direction. The individual lamina tend to be thicker than the individual veneers of plywood, and unlike plywood, which has equal strength in both directions, laminated wood is stronger in the direction of its grain, more like ordinary timber. It widest applications have been in bending thin members, such as those in the "39" Armchair, designed in 1936 by Alvar Aalto (Fig.5). It is stronger for this purpose than solid bent wood, partly because of the presence of glue (and the shear strength which it imparts to the laminations), and partly because there is less deformation involved in bending thin laminations.

There are hybrids of these materials, as well, laminations which include a cross-ply veneer every 5th or 10th layer, to give laminated wood some of the desirable properties of plywood. The laminated arms of the Breuer long chair (Fig.2), for example, have a crossband laid as the secondary veneer on both faces. Laminated members may have extra thicknesses interlayered into the assembly to increase strength at key points, or removed, to accomplish changes in profile, for example. Plywood and laminated wood may be combined in a single piece of furniture — plywood being employed for the seat and back, where the stresses are the same in all directions, and laminated wood for the arms and legs, where the stresses run parallel to the length of the wood.

Particleboard and fiberboard are reconstituted wood — wood that is first converted to fibers or small particles, then reformed into flat sheets or specific shapes. They constitute a great variety of products, depending on the size, shape, and orientation of the wood particles. Fiberboard is made by reducing wood first to chips, then, by steam or hot water and grinding, into fibers; the fibers are then interfelted by re-establishing their chemical bonds, under pressure, with little or no resin binder. Fiberboards include cardboard or pasteboard, low density fiberboard like Homasote, and hardboards like Masonite; in hardboards, higher heat and pressure serve to reactivate lignin as a binder. Particleboard, a solid wood composite, is manufactured from chips, flakes, or particles of wood that are cut mechanically, then bonded under heat and pressure with a synthetic resin or other suitable binder. Particleboard's properties depend on its particle size and orientation, and on its bonding agent, and to a significant degree on its density, which is a function of its compression during manufacture. Because the particles are randomly arranged, dimensional properties are diminished, so that it does not split or check. In general, though, these boards are not as strong as solid wood, and are especially unstable in their thickness; the density imposed on them by their manufacture can be greater than the wood species own density, resulting in spring-back under moist conditions. Fiberboard and particleboard are especially prone to warping and other moisture damage; despite added sizers, moisture weakens them at least as much as it does solid wood. The reason that particleboard resists water so poorly is that the resin (urea or phenol formaldehyde) does not really coat the particles, but exists as droplets which cover only a fraction of the particle surface. More resin would mean a more water-resistant material, but also a considerably heavier and a more expensive one.

Particleboard and fiberboard are newer materials, present in collections so far to a lesser degree. They have been manufactured only since the early 1950's, though earlier attempts to mold furniture from pressed fibers are known. A notable example is Gerrit Rietveld's (1888-1964) Birza chair from 1928, in the collection of the Stedelijk Museum (Fig.6). Though designed for production — stamped from a single sheet and molded into compound curves — only the prototype exists.

20th Century Technical Developments: Veneer Production

Toward the end of the 19th century, and throughout the 20th, there were a number of critical developments in the production of plywood and bent laminations.

In 1890, the steam-driven rotary lathe was invented. Until that time, veneers were either sawn or sliced radially or tangentially from the stem of the tree. The rotary lathe cuts veneer in a manner analogous to unrolling a roll of paper. The log is first soaked or steamed to make it pliable, then mounted on a lathe and slowly revolved against a stationary knife. As the stem revolves, the knife moves toward the center of the log, and a broad continuous sheet of veneer is produced, peeled from the tree approximately along the lines of the annual rings. This produces the typical figure characteristic of rotary cut veneer.

The seemingly endless sheet of veneer produced by the rotary lathe was the perfect material for the emerging modern aesthetic, with its celebration of clean, undifferentiated surfaces and emphasis on the continuous line. Much like work being done in metals and plastics, plywood found use in the creation of thin, light, fluid, innovative structures. With plywood's drastically reduced dimensional properties, frame and panel construction was no longer required. Plywood's non-splitting character allowed for non-traditional joinery, conceived secondarily to the design, or joinery along edges, using metal fasteners. Politically, the fact that plywood could be mass-produced made the furniture seem democratic, utilitarian — despite that fact that much of it remained highly labor-intensive in its production, and elitist in its appeal. But the forms at least *seemed* machined, and therefore had an appealing philosophical dimension.

20th Century Technical Developments: Adhesives

As plywood and lumbercore were being developed in the 19th century, the only two available adhesives were animal protein glue, derived from collagen, and casein glue, derived from a protein precipitated from skim milk. The lightness and stability of plywood as a construction material made it attractive to the developing aircraft industry, and the need for considerable quantities of plywood during World War I resulted in improvements in machinery and in the development of water-resistant adhesives. Animal and casein glues could be made more water resistant with various additive and treatments, but the water-resistance was limited, and neither were immune to attack by micro-organisms.

Two new protein glues were developed in the early decades of this century. Soybean glues, developed c.1922 from plant protein, had extensive use in bonding softwood plywood. The early plywood industry was, in fact, the principal consumer of soybean adhesives, despite their limited water and microbial resistance, and cellulose staining which resulted from their high alkalinity. The search for improved natural adhesives led to blood albumin glues — blood dried in soluble form, and made strongly adhesive after hydrolyzes with an alkaline. The urgent need for water-resistant plywood for World War I aircraft resulted in increased consumption of blood albumin glues during the period 1910-1925. The cold-press variety of blood glue provided a quick-setting water-resistant bond, and found use in furniture laminates and plywood. The heat-cured blood glues were the most water-resistance glues available until about 1935, when the phenol formaldehyde glue films became available in Europe; their heat-curing requirement, however, generally precluded their use in furniture.

In 1872, Adolf Bayer first obtained a resinous mass when he reacted phenol and formaldehyde in the presence of an acid catalyst. In 1909, Leo Baekeland (the inventor of Bakelite, a phenolic resin) started controlled reactions producing phenol formaldehyde. By 1930, a resin film — paper impregnated with a waterproof resin — was produced in Germany. But it wasn't until 1935 in Europe (and 1939 in the U.S.) that phenol formaldehyde adhesives — in film form, which could be interleafed with wood veneers and bonded in a hot press — came into widescale production and use. They were considerably more expensive than the traditional natural adhesives, but had excellent water-resistance, so they replaced protein adhesives where high performance water-resistance was required.

The second important synthetic resin group used for plywood are the amino resin adhesives — urea or melamine formaldehyde. They were developed between the wars — urea formaldehyde in 1935, and melamine formaldehyde in 1939. Melamine formaldehyde is the more water and heat resistant of the two, and saw wide use in aircraft plywood during the second World War. Amino resin adhesives are widely used in the wood products industry.

Resorcinal resin adhesive is the last important adhesive that was developed for plywood during World War II. It is the most durable of all adhesives for plywood, resistant to climatic changes and to all circumstances to which wood is exposed, except for fire or highly caustic solutions. Resorcinal adhesives cure without heat in the presence of a catalyst, resulting in a high strength, durable bond. Their strength exceeds that of the wood itself.

Furniture makers needing improved adhesives undoubtedly took advantage of the wartime research and developments in these materials, as well as concurrent developments in the buildings industry. There are numerous anecdotes of glue failure in the early days of laminating wood with water-soluble adhesives. Jack Pritchard, the founder of Isokon, which produced Breuer's plywood furniture in the 1930's, includes in his memoirs, *View from a Long Chair,* the story of an order of a dozen of Breuer's Isokon lounges for an indoor swimming pool, where they were placed over warmed tiles. Animal glue had been used, and the chairs soon became "an embarrassing collection of veneers." He goes on to say that they switched to a "new ICI [Imperial Chemicals Industry] product not soluble under Dolphin Square conditions."[2] Unfortunately, he neither identifies the glue nor the extent of its use, so conservators may find the plywood in Isokon furniture glued with animal glues, or with newer synthetic glues. Infrared analysis performed at the Metropolitan Museum on an adhesive sample obtained from the small Isokon nesting table determined that a protein adhesive had been used.

But developments in the adhesives and plywood industries are not necessarily markers for developments in furniture. Some furniture makers incorporated the latest developments, and some did not. In the factories of Artek in Finland, where Aalto's furniture is produced, slow-drying, water-resistant casein is still used for the cold-bending processes of his laminate furniture.[3] Furthermore, designers or manufacturers may have been inconsistent in the use of materials. Plywood may have been produced in-house, or elsewhere, and simply adapted, like Dunand did for his side chair. Much of the plywood used by Isokon, for example, came from a company called Venesta, and was produced in Estonia. What adhesives might they have chosen for producing generic plywood? As with so many things in the 20th century, discoveries came rapidly in many areas, and a great deal of experimentation undoubtedly found its way into furniture-making as well. Archives of 20th century companies, which could be expected to contain a wealth of information, are generally limited in their usefulness because they tend to be organized around a company's needs; the records that they have considered significant are not necessarily the same one's that a conservator would have chosen. In a word, though the technical development of this century's furniture is part of a very recent history, it can be elusive.

Deterioration

Deterioration in plywood is to a large degree inherent in the materials — in the methods of preparing the veneers and in the adhesives. Both sliced and rotary cut veneers emerge from the cutter with knife checks, parallel to grain fracture planes produced in the veneer at the time of manufacture (Fig.7). Sawn veneer does not have these checks. As the knife separates the veneer from the rotating stem, the separated layer of wood is severely bent, and stresses build up in the region of the knife edge. When the strength of the wood is exceeded, the stress is relieved by failure, and the failure is called a knife check or a lathe check.

The most common consequence of knife checking is the pattern of parallel-to-grain cracking of the veneered surface, a pervasive condition of old plywood, almost a patina (Fig.8). The checks, which are introduced into the material as it is peeled or as it is sliced from the log, are worsened by the fact that when the veneers are assembled into plywood, they are glued, restrained. When the check opens to relieve stresses which may be caused by the re-drying of the wood, and subsequent moisture cycles (which, contrary to popular belief, plywood is not immune to) the relief occurs only in the area of the check; the surrounding area remains restrained because it is glued, and so it also checks. That is why the number of checks in plywood is much higher than in lumber: there are no large shrinkage cracks, but many small ones.

The problem of checking is compounded by the fact that the face veneers, the outermost veneers, are glued on one side, and constantly reacting to moisture on the other side. (Because of this, sawn veneers, which do not have knife checks, are liable to split also.) Though the surface of plywood furniture is generally finished, often with nitrocellulose lacquer, the finish succeeds only marginally as a moisture barrier, and the stresses remain decidedly uneven. The lacquer, which generally becomes embrittled with age because of the loss of plasticizers, often cracks and separates from the wood surface; paint may detach as well. As the knife checks deepen, perhaps running completely through the veneer, bleed-through of the glue, and the accumulation of dirt, will further accentuate the cracks.

The second inherent vice in plywood is adhesive failure, and the resulting delamination. There are many different reasons that adhesives might fail. They may lack water-resistance; or the glue may be water-resistant, but of course the wood is not, so that the stresses occurring in the wood as it tries to expand and contract cause the adhesive bond to fail. Cheap extenders can weaken even strong glues; mistakes during production — excessively thick glue layers, premature curing — can compromise the final product. Since many of the synthetic glues were designed to be stronger than the wood, delamination can result in the tearing of fibers. Delamination may result, as well, from the strain of use. The edges of plywood (its third, weak dimension) are particularly vulnerable, which is why they are often filled or coated with a paint or pigmented resin, or finished with a solid wood strip.

In addition to the deterioration which is inherent in the material, there is that which results from its conversion into furniture, i.e., from bending it or molding it, and joining it. The terms “bent” and “molded” tend to be used interchangeably, although “bent” is more often applied to forms that curve in one plane, and “molded” to forms which curve in more than one plane. Technically, however, most of it is accomplished in molds. Laminated members can be bent by hand, and held by means of clamps and jigs until the adhesive sets. And flat plywood, if bonded with a synthetic resin, can be made pliable by heat and moisture. But plywood is usually shaped and glued in one operation, either in customized molds or presses of two or more parts; or by means of fluid pressure — positive (inflatable membrane) or negative (vacuum) — in combination with a single mold.

The molding of plywood into compound curves developed rapidly during World War II; in furniture, the principle experiments were those of the designers Charles and Ray Eames, and Eero Saarinen, whose molded plywood chairs were exhibited in the 1940 Museum of Modern Art “Organic Design in Home Furnishings” competition. Eames gained access to wartime technology in 1942, when he received a contract from the U.S. government to develop a lightweight traction splint and litter for use in transporting wounded soldiers.

For molding compound curves, veneers must be individually shaped and tailored to conform to the curvature. Wood veneers are flexible, but they will stretch very little before splitting. Instead, the flat sheet must be fashioned in a manner similar to that used in converting a flat textile into a 3-dimensional garment. This requires that some material be removed, or notched, and trimmed to accomplish the correct shape. The tailoring may differ with each thickness of the plywood.

Full-sized molds are generally made in wood, plaster or a light alloy. The strips of veneers, cut to size and shape, are laid over the mold, and trimmed, until the mold is completely covered. If multiples are being made, the strips are removed and metal templates are made. Subsequent layers, at an angle to each other, are developed in the same way. When all the veneer has been prepared, it is interleafed with sheets of resin film, and laid in the mold. The assembly is then cured — by traditional heat or high frequency heating — under pressure. Catalysts which will accomplish polymerization at room temperature are sometimes used.

Both bent laminations and molded plywood, while fairly stable constructions, can develop problems with their bent forms. This sometimes occurs because of imperfections in the materials, but climate is probably the most significant factor. Laminated structures, like Aalto's chairs, can become stiff, and lose their spring, when moisture causes the individual laminates to swell: they become thicker, causing the bend to open up slightly. When molded plywood shapes relax due to moisture, glue failure, or faulty production, gaps may develop between laminations. The outermost veneer of the curve is marginally larger than successive inner layers, to accommodate the curved shape without stretching the veneers; when the curve relaxes, this excess material (still glued further down the line) will create a permanent pocket or bubble in the laminations.

Composite woods do not lend themselves to traditional joinery. Plywood, as noted above, renders unnecessary the grooved type of joint which was designed to avoid shrinkage cracks in solid wood. In fact, traditional joinery is hazardous in plywood construction because of plywood's inherent weakness in the plane of its thickness. While dowels have often been used for lumbercore (especially in the early part of the century), plywood is more effectively joined by new methods more suited to its nature. Plywood elements may be slotted and joined like cardboard models. Most frequently, they are joined simply by glue, with metal fasteners, and with rubber shock mounts or plastic components to cushion elements. As a result, the deterioration of this new joinery encompasses the degradation of synthetic glues, rubber and plastic, and the corrosion of metals, rendering the preservation of composite wood furniture even more complex.

Treatment and Ethics

Conservators of 20th century material have a unique responsibility — they are in a rare position to truly conserve — because the objects which come for treatment, for the most part, have not been previously restored. They are virgin in a way that little furniture from previous centuries is. Yet the expectation is that, since they are of this century, and often include among there meanings ideas about modernity, sleekness, machined perfection, they should be made to look new, as the day they were made. This expectation is an insidious one, and will rapidly diminish the number and quality of reliable objects from this century.

New materials with new properties have simply meant new problems. Age, and use, have altered this furniture, despite its promise of providing absolute answers. It must be admitted, as well, that age and use may be partially obscuring the artist's intention, even misrepresenting it. Simply, the object no longer looks like it did when it was made, it no longer fully represents the "newness" which was a part of its meaning.

But returning the object to a new-looking and perhaps correct condition can amount to another, and potentially more harmful kind of misrepresentation. Such an action can serve to nearly completely deny the originality or revolutionary nature of the design. This is especially true for objects which have been in continuous production, or which have spawned numerous knockoffs. But it is true of so many objects within the modern lexicon, because they simply *were* so *avant garde*. So many of the iconic designs of this century – by Aalto, Breuer, Eames and many others — are easily misperceived as being contemporary. But to see a radically modern office chair by Frank Lloyd Wright from 1904 in a worn, slightly rusty state, is to be forced to appreciate just how radical the design was. Though the attempt of a restoration may be to more closely approximate the artist's intention, ironically, when old is made to look new, the artist is rendered a terrible disservice, as is the viewer. The artist is robbed of his prescience, and the viewer is robbed of some of the "information" critical to his understanding of the object.

It is important to begin with a philosophy, though, needless to say, not all objects will conform to it. The needs of any individual object may qualify a philosophy, or require relative values to be assigned to the artistic, technological, and historical data. We can endlessly debate the issue of the integrity of the object — where does it lie? In what the object started out being, or in what it now has become? There is rarely one obvious answer to the questions of treating (and therefore interpreting) these objects. But a bad decision can permanently diminish meaning.

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Notes

1. Two excellent sources for further reading on this extremely interesting topic are *Innovative Furniture in America from 1800 to the Present,* by David Hanks (New York: Horizon Press, 1981) and *Bent Wood and Metal Furniture: 1850-1946,* Derek Ostergard, ed. (New York The American Federation of the Arts, 1987).

2. Jack Pritchard, *View from a Long Chair: the memoirs of Jack Pritchard* (London: Routledge & Kegan Paul, 1984), pp.112-13.

3. Juhani Pallasmaa, ed., Museum of Finnish Architecture, *Alvar Aalto Furniture* (Cambridge, Mass: MIT Press, 1985), p.94. Synthetic resin adhesives were introduced for certain processes in the 1960's.

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Associations
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American Plywood Association
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Hardwood Plywood Manufacturers Association
1825 Michael Faraday Drive
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National Forest Products Association
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National Particleboard Association
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Silver Spring, MD 20910

United States Department of Agriculture
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Particleboard and Panel Products (85-009)
Glues and Glued Products (85-015)

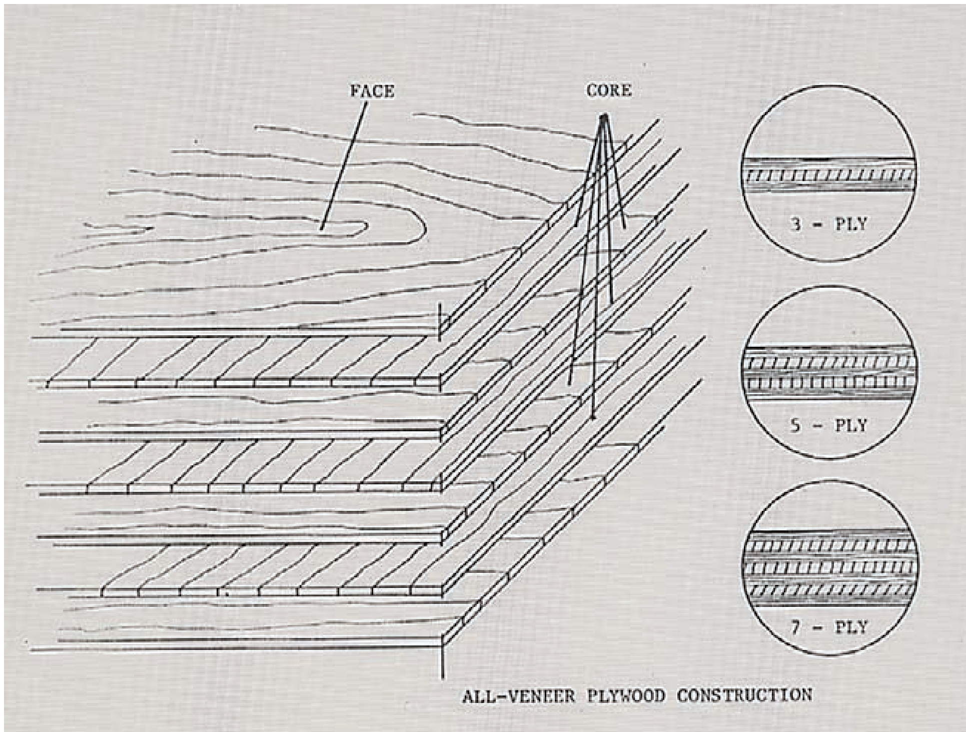

Figure 1

Figure 2 Long chair, c. 1935, Marcel Breuer (MMA Acc. # L. 1985.114)
Manufacturer: Isokon Company, England
Seat Stamped: MADE IN ESTONIA

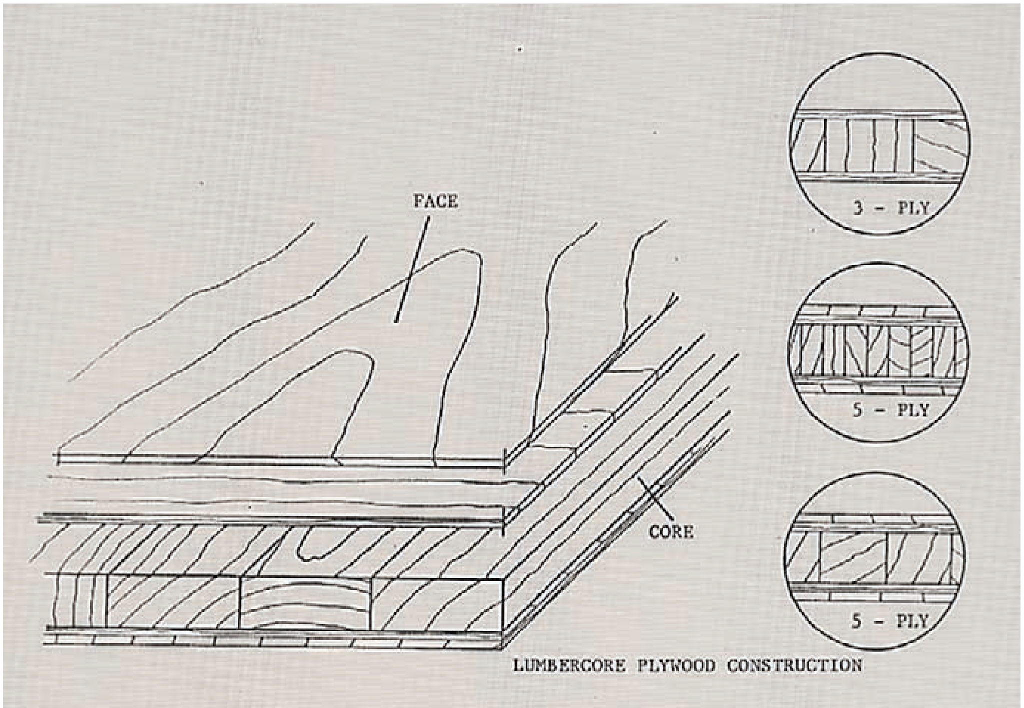

Figure 3

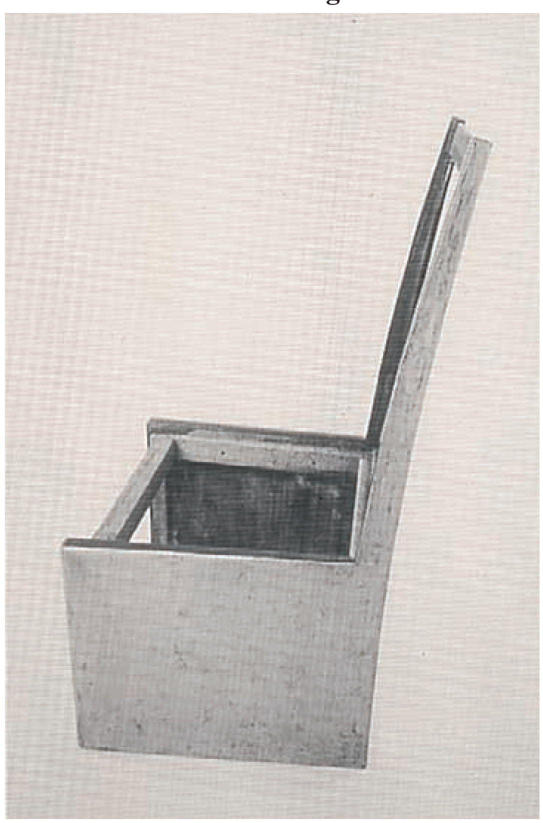

Figure 4 Side chair, 1928, Jean Dunand (MMA Acc. # 1977.226.5)

Figure 5 “39” armchair, c. 1936, Alvar Aalto (MMA Acc. #1985.211)

Figure 6 Birza armchair, 1928, Gerrit Rietveld
(Collection: Stedelijk Museum, Amsterdam)

Figure 7 Veneer slicing/introduction of knife checks (Photo: courtesy of USDA Forest Service, Forest Products Laboratory)

Figure 8 Knife checking of plywood surface veneer