Multilaminar wood: Manufacturing process and main physical-mechanical properties

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Although not of recent origin, it was only in 1994 that multilaminar wood, also known as ML W (previously called pre-composed or recomposed wood), was officially standardized with the publication of the Italian standard UNI 10396: Multilaminar Wood: Terms and Definitions (UNI 1994). This document defines ML W as a material made of superimposed layers first spread with adhesive and then pressed so as to form a block from which sliced veneers or sawn pieces are obtained, mainly for decorative purposes. Other standards were published later in order to cover further aspects of this product (UNI 1995, 1997a, 1997b). MLW belongs to the broad category of “wood-based materials,” which includes semi-finished products that vary in the type of wood used, the composition, the shape, the surface appearance, the adhesive, and the field of application (Bowyer 1995, Maloney 1996, Bary-Lenger et al. 1999).

MLW first appeared in the 1950s, at a time when there was great market demand for large quantities of sliced veneers with a “rift cut” effect, which were in short supply. In order to fill this gap, a semi-finished product was designed and made by cutting a block of sliced veneers of various kinds of wood (initially faulty sheets of fancy species, in particular mahoganies or rosewoods). To produce this block, these veneers were first glued, then laid one on top of the other, and finally made solid by pressing. Cutting was perpendicular to the gluelines, producing sheets with a striped effect that highlighted the surface appearance with straight lines given by the alternation of different-colored veneers. The resulting sheets were used to overlay wood-based panels. However, the appearance of the resulting product, patented in Great Britain and commercially known as “fineline,” was not comparable to the decorative effect of the fancy veneers it was intended to replace (Giordano 1983).

Subsequently, the evolution of MLW, which took place in Italy, has been...
strictly connected to mass production in the furniture industry. This has led to a search for decorative materials that could be manufactured in large quantities and without waste, discoloration, knots, or other defects due to biodegradation agents, and without the constraints of shape and size of the logs. The result has been a product that can uniformly reproduce the surface appearance, color, and grain of various prized woods through the particular layout of the constituents (sliced veneers, or rather rotary-cut veneers).

Consequently, MLW is now an interesting alternative to traditional types of solid wood, as a material made from the cheapest or plantation wood species, which at the same time offers those working in the sector (including architects and decorators) unlimited varieties of colors and designs for the customizable production of furniture, internal accessories, boiserie, flooring, and several types of articles. The possibility of using the plantation-produced wood to reproduce the decorative effects characteristic of prized species (often to be safeguarded) is extremely important if we want to maintain biodiversity, and is in line with the principles of sustainable management of natural forest resources (Lavisci et al. 1995).

Manufacturing process and uses

The manufacturing process of MLW (Fig. 1) begins by debarking and peeling the best-quality logs of relatively inex- pensive types of wood, such as fast-growing poplar from artificial plantations (Populus x euramericana, especially the clone ‘I-214’) and some African woods such as obeche (Triplochiton scleroxylon), ilomba (Pycnanthus angolensis), or koto (Pterygota spp.) (Anon. 1996). Such wood is light-colored, practically undifferentiated, without too many stains, and therefore easy to bleach and dye. The logs to be worked may be between 230 cm and 350 cm long. The rotary-cut veneer produced, which is generally 0.75 mm or 1 mm thick, is sectioned using a clipper at a width of 72 cm and further selected according to its color and the presence of defects.

If the wood shows marked differences or color variations, it is bleached. This operation, typical of the textile or paper industries, allows the removal of pigmented substances and is aimed at making the rotary-cut veneers more homogeneous in color. Chemically, bleaching is a process that allows the decoloration of some substances contained in wood tissues (main chemical constituents, impregnating or extracting substances) and involves degradation phenomena of the cellulose by oxidation and hydrolysis. According to the shade of color desired, varying dosages of optical bleaches can be added. These act not by dissolving the colored substances, but by converting a portion of ultraviolet rays into blue or bluish-grey light, so as to compensate for the slightly yellow color of the wood.

The manufacturing of MLW normally includes dyeing, which is aimed at giving the veneers a color similar to that of another wood (it should be remembered that one of the primary aims of MLW is to use low-cost wood species instead of others that are more prized or difficult to obtain). The sheets are immersed in open vats containing the dye solutions, or in special autoclaves in which the wood impregnating speed can be regulated by altering the pressure. The dyes used are of the “acids for wool” class at pH 5 to 5.5.¹ In this phase, because of the immersion in the vats, the moisture content of the wood is well above the fiber saturation point; it is subsequently reduced to about 6 percent by passing the sheets in a jet dryer.

The dyed veneers are again examined to check that the dye has been absorbed uniformly and to eliminate any defects, such as knots. These are removed by hand with a cutter but the holes produced do not need to be plugged, as they will be eliminated in the subsequent pressing. Later, the sheets are arranged (by a dry lay-up) to form a block to be glued and pressed. Depending on the features to be obtained (color, pattern, etc.), sheets from different batches or with different dyeing treatments are laid one on top of the other with parallel grain, according to a set sequence.

MLW is glued with a mixture of urea-formaldehyde adhesive and a vegetable flour additive in order to reduce the stiffness of the gluelines and improve their shear resistance. If required, melamine extenders such as melamine-urea-formaldehyde (MUF) or a moisture-resistant adhesive can be added. In some cases, the glue mixture may be colored (producing particular aesthetic effects in the final product); in others, polyurethane adhesives can be used. All the sheets are then passed one by one through a spreader that applies a thin layer of adhesive on both surfaces of the veneers. The amount of adhesive required may vary between 120 and 200 g per square meter of double glueline, depending on the type of wood, the thickness of the veneer, and the pressure used in the subsequent pressing phase.

The pile of sheets is then placed in a special mold in the same sequence as before the gluing operation (i.e., arranging as for the dry lay-up). The resulting block is then kept under a press. With the polymerization of the glue, the block, which is a few meters long and about 70 cm wide and high, becomes solid and ready to be squared, sanded, and sent for slicing or sawing, depending on the type of semi-finished product desired. In this phase, a thermoplastic film is also applied to the head of the block to reinforce the cross edges of the
sliced veneers to be cut later, usually between 0.3 and 3 mm thick.

If a striped, quarter-cut pattern is desired, the pressing is done on a level surface and the block is sliced perpendicular to the gluelines. In order to obtain a flat-cut appearance or varying complexities of different patterns (Fig. 2), the pressing is done with the sheets inserted into a convex mold; the resulting block is then sawn longitudinally at about mid-height and the two complementary pieces obtained are re-glued together (with a two-component adhesive) to form a block, the shape and final appearance of which are determined by the mold used for pressing; 5) when the glue has polymerized, the block can be sliced or sown (using the cutting angles supplied by the computer) to obtain semi-finished products with exactly the same color and grain as the sample whose characteristics were read by the scanner.

The final product has a homogenous decorative appearance with a distinctive pattern (striped, quarter-cut, flat-cut, burr with vertical, parallel vein, abstract, inlaid, etc.) and color range (Fig. 4). The qualitative result achieved in the imitation of the color and morphological features of various fancy woods is very high and gives such a faithful reproduction that only careful examination of the surface of an assortment of MLW makes it possible to see, in some cases, the traces of the large vessels that are typical of the xylem of the tropical wood species used.

MLW can be used to make real wood-based surfaces, available in natural, sanded, treated with modern finishing methods (such as water paints, natural oils, etc.), or pre-finished versions. It can be used both in the form of sliced veneers and uniform sawn pieces or with various inlays, along with other materials, in order to make, for example, sheets on a phenol paper or fabric backing, that are decorative semi-finished products with particular performance characteristics such as greater stiffness or more flexibility and lower radius of curvature.

At present, MLW has a great variety of uses. Its versatility makes it suitable for global marketing, adapting to different cultures and tastes in furniture. It is mainly used as sliced veneers, especially for furniture, ship fittings (a field of application in considerable expansion), and for the hotel sector, where large decorative surfaces with homogenous deco-
rative features are required. In other areas, which can be considered secondary or niche markets, MLW is used as blocks or sawn pieces, for mouldings, gunstocks, skis, skateboards, ping-pong bats, billiard cues, and miscellaneous articles (Anon. 1996). A block of MLW can cost from 1000 to 4000 Euro, according to the complexity of the final pattern. Even if this seems to be expensive, MLW is in increasing demand due to the peculiarities that make it unique and different from both solid wood and the many synthetic imitations of solid wood.

Scope

The lack of technical references on the mechanical properties of MLW is certainly connected with the fact that most of the attention has been focused not on its performance but on its appearance. Recently, however, there has arisen a need to provide further information on the mechanical performance of MLW, particularly regarding its use in the form of sawn pieces, both in the building sector (though not for structural purposes), and in the furniture and window/door frame and shutter industries, as a consequence of the implementation of new European standards on the liability for defective products. With the exception of occasional tests conducted by single producers on few samples or at the specific request of users, no significant testing based on modern methodologies has been performed.

The aim of this investigation was therefore to conduct a preliminary study of the main mechanical features of some of the most common types of MLW. Since various wood grain orientations are possible (e.g., under variation in the final cutting angle of the semi-finished product), and since such changes in orientation may affect its mechanical performance, representative samples of the most common block cutting angles were tested. The study also aimed to characterize MLW from the physical-mechanical point of view, analyzing at the same time the variability that its properties may show within a single block, which is considered the production unit. In addition to the classic physical determinations and bending behavior, we also conducted mechanical tests for the assessment of hardness and footprint and screw-withdrawal resistance, given the importance such properties have in the various sectors of application of MLW (for example, for holding door hinges, etc.).

Materials and methods

For the experimental part of the work, the following semi-finished products of MLW were made according to common industrial parameters:

- 1 multicolored block (3100 by 660 by 660 mm) (henceforth “block W”), made up of 0.75-mm-thick rotary-cut veneers of obeche bleached prior to dyeing and then glued one to another;
- 1 block of the same size and type as above (henceforth “block Z”), made up of 0.75-mm-thick unbleached rotary-cut veneers of obeche;
- 3 “burr type” tables (3100 by 660 by 25 mm) (henceforth “block P”), made up of 0.75-mm-thick rotary-cut veneers of poplar ‘L-214’ from a plantation, pressed in a convex mold.

Gluing for all three types was made with a urea-based glue with low formaldehyde emission.

In order to assess any influence on the mechanical behavior of the MLW of the orientation of the veneers (with respect to the direction in which the stress occurs), several sawn boards were cut from each block of obeche (blocks W and Z), with a nominal thickness of 25 mm and with different cutting angles; Figure 5 shows the sampling scheme followed and the identification details. The choice of the various cutting angles was strongly influenced by technical problems concerning the cutting of the boards from the blocks, which made it impossible to obtain sawn boards with all of the cutting angles desired (at equal intervals between 0 and 90 degrees).

- “T” and “R” boards were cut perpendicular to each other and with a cutting angle of the original block of 0 and 90 degrees, respectively.
- “I” boards were cut at an angle of 14.4 degrees; the pattern of the corresponding sliced veneers having thirty-five 2.9-mm-wide differently colored stripes in the 10-cm width of the surface.
- “J” boards were cut at an angle of 10 degrees; the sliced veneers had twenty-four 4.1-mm-wide stripes visible over 10 cm of the surface.
- “K” boards were cut at an angle of 4.3 degrees and contained ten 9.8-mm stripes in 10 cm of surface.

The boards labeled T reproduce the grain that would be shown by cutting the
trunk tangentially to the growth rings. Boards labeled R show on the surface the thickness of each single block. In contrast, boards labeled I, J, and K reproduce the same pattern that would be obtained by cutting the trunk radially. The resulting pattern is regular and composed of straight equidistant parallel lines. From the poplar block (block P), we obtained only burr boards of type T, i.e., sawn parallel to the surface. These boards, while still belonging to type T, have an irregular pattern caused by the particular type of pressing. This sampling plan was worked out with the aim of obtaining representative results of the natural variability of the features of the material used and so that test pieces were from both the central and the edge portions of the board.

For each angle type (i.e., T, K, J, I, and R), three boards were cut from each block: one was kept whole for future testing, and the other two were used to prepare specimens for the scheduled tests. Each board therefore provided the following:

- 15 test pieces, 50 by 50 by 24 mm (B, G, and N), to determine the density under normal moisture conditions (according to the standard ISO 3131) and the surface hardness (ISO 3350, Janka method), and 15 test pieces (again 50 by 50 by 24 mm and identified as B, G, and N) to determine the resistance to footprints in compliance with UNI 4712 (UNI 1961), following conditioning carried out as indicated in the standard UNI 3253 (UNI 1952);
- 30 longitudinal test pieces, with respect to the longitudinal axis of the board, 530 by 50 by 24 mm (marked A, F, and M), to determine the bending strength (f m,0) and the (apparent) modulus of elasticity (E m,0) in compliance with the standard EN 310 (CEN 1994a);
- 6 transversal test pieces (C, H, and O), to determine the f m,90 and E m,90 on specimens of the same size as above, in compliance with EN 310 (CEN 1994a);
- 24 test pieces, 75 by 75 by 24 mm (D, I, and P), to determine the screw-withdrawal resistance in compliance with standard EN 320 (CEN 1994b);
- 6 test pieces (E, L, and Q) as spare material.

Figure 6 shows the scheme used for cutting the test pieces.

The test pieces used for physical-mechanical characterization were pre-conditioned (until constant mass was reached) in a climatic cell at the temperature of 20 ± 2°C in an atmosphere with 65 ± 5 percent relative humidity. All mechanical testing was done using a general-purpose testing machine with a maximum capacity of 50 kN. The influence of the various angles and the bleaching process on the performance of the two blocks of obeche was assessed by means of the Student’s t-test for statistically significant differences between the means of the data obtained.

Results and discussion

The results of our testing are shown in Table 1. In the remaining sections, we discuss the results of the different tests individually.

Density

The mean values of density are remarkably homogeneous within the block, with the coefficients of variation (COVs) always below 3.5 percent. It can be seen that the experimental data do not show any relation between the density of the test pieces and the cutting angle used for obtaining the sawn pieces from the block. The Student’s t-test did not reveal significant differences between the two blocks of bleached (W) and unbleached (Z) MLW of obeche.

The mean values were well above those reported in literature for solid poplar and obeche; for the poplar, in addition, the values were also higher than those of laminated veneer lumbertest pieces (Castro and Zanuttini 1991, Castro et al. 1994, Baldassino et al. 1996). This increase in density is partly due to the effect of the adhesive, which accounts for between 6 and 15 percent of the weight of the whole MLW, and partly to the pressure to which the wood is subjected during re-composition of the blocks, which induces densification.

Hardness

The mean values of hardness are homogeneous, but rather low; to give an order of comparison, they are about half those that can be obtained with solid wood of beech or oak (Negri et al. 1995). The variability of the data was always low, with a 6 percent COV for poplar and between 4.2 and 9.3 percent for obeche. The Student’s t-test highlighted a statistically significant difference in the data found for the two blocks W and Z. The bleaching seems to have slightly reduced the resistance to penetration of the steel punch, and therefore the hardness of the test pieces. The treatment also seems to have made the material more uniform, with a consequent evident reduction in the variability of its performance. The test pieces cut from type R boards of obeche proved to be more resistant due to the effect of the orientation between the direction of the stress and that of the layers of the block. Taking into consideration all of the test pieces, with a hardness of 4085 N for the bleached block and 4295 N for the natural one, R angle test pieces were about 10 percent above the mean values of the same blocks.

The surface hardness and density data were statistically analyzed: the coefficient r indicated that there was no correlation between the two parameters.

Footprints

The data of resistance to footprints showed a clear increase in the uniformity of the MLW as compared to solid wood of the same species. In the case of poplar, in fact, while solid wood generally records mean penetrations of about 1.1 mm, with an extremely high COV (Castro and Paganini 1994), in the pop-
lar MLW, the mean penetration was 0.47 mm, with a COV of about 15 percent. For the ML W of obeche, little difference was found between the various types of board, with the exception of type R, which showed slightly greater resistance and a COV generally lower than poplar ML W. In addition, for this angle the prints left by the steel punch, 0.23 mm for the bleached block and 0.25 mm for the natural one, were, respectively, 41 and 38 percent lower than the mean of all the test pieces examined. Still concerning the two blocks of obeche, the Student’s t-test did not show any significant differences that would support the conclusion that the bleaching process affects this mechanical property.

### Bending strength and apparent modulus of elasticity

As regards strength, the data of unbleached block Z of the ML W of obeche were higher both in the case of longitudinal and transversal test pieces, but the Student’s t-test did not show any statistically significant differences. For both the W and Z blocks, higher strength was seen for the longitudinal test pieces from the I boards and lower strength in those from the R boards. Of the transversal test pieces, those from the T boards gave strength data about double those of the R boards (in particular for the block Z). The test pieces derived from boards with intermediate pitches recorded slightly contrasting results in the two blocks W and Z, even though they were homogeneous within the same block, and in any case between the two extremes T and R. In practice, there was no proportionality between bending strength and cutting angle in either of the blocks. As concerns the modulus of elasticity, as already seen for strength, it was stronger in the longitudinal test pieces from the I boards and weaker in the transversal test pieces from the R boards for both blocks W and Z. The test pieces from bleached block W, both longitudinal and transversal, gave the highest values. In this case, also the Student’s t-test showed a statistically significant difference between the two blocks of obeche. The comparison between the mean values of block Z (not bleached) and those of block W (bleached) shows how the bleaching treatment tends to increase the stiffness of the material (block W having a higher modulus of elasticity) and to reduce the bending strength. In other words, bleaching seems to have made the material more rigid and at the same time more fragile. The variability and the COV were, however, very low, confirming the remarkable homogeneity of the material. In the case of angle R, the bending strength and modulus of elasticity for the transversal test pieces cut from both the bleached and unbleached blocks were lower than for the other four cutting angles.

In the MLW of poplar, the strength of the longitudinal test pieces was markedly lower than in specimens made from the MLW of obeche, with greater variability of the material (COV = 10 ), but higher than the strength given in the literature for solid wood of the same species (Castro and Zanuttini 1991). The strength of transversal test pieces was

### Table 1.

Mean data values for the physical-mechanical properties (density, hardness, footprint, bending strength and stiffness, screw withdrawal resistance) of MLW with different cutting angles.

<table>
<thead>
<tr>
<th>Board type</th>
<th>Cutting angle</th>
<th>Density (g/cm³)</th>
<th>Hardness (N)</th>
<th>Footprint (mm)</th>
<th>Bending strength f₀₀,₀ f₀₀,₀</th>
<th>Bending stiffness E₀₀,₀ E₀₀,₀</th>
<th>Screw withdrawal (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block P (poplar)</td>
<td>T 0</td>
<td>0.588</td>
<td>3743</td>
<td>0.47</td>
<td>64.7</td>
<td>11.4</td>
<td>9684</td>
</tr>
<tr>
<td></td>
<td>(2.2)³</td>
<td>(6.0)</td>
<td>(15.0)</td>
<td>(10.0)</td>
<td>(10.0)</td>
<td>(4.8)</td>
<td>(7.0)</td>
</tr>
</tbody>
</table>

| Block W (obeche) Bleached | T 0           | 0.588          | 3739         | 0.43           | 75.9                        | 8.9                        | 8557                 |
|                          | (2.1)         | (5.5)          | (12.6)       | (5.3)          | (3.2)                       | (5.1)                      | (9.5)                |

| K 4.3                      | 0.555         | 3754          | 0.45         | 77.4           | 8.9                        | 8593                      | 885                  |
| J 10                       | 0.551         | 3484          | 0.45         | 75.2           | 8.3                        | 8292                      | 780                  |

| Block Z (obeche) Not bleached | T 0           | 0.551          | 3757         | 0.44           | 78.8                        | 9.2                        | 8215                 |
|                              | (1.8)         | (9.3)          | (20.1)       | (7.4)          | (3.5)                       | (2.7)                      | (3.7)                |

| K 4.3                      | 0.545         | 3788          | 0.46         | 78.4           | 9.0                        | 8181                      | 817                  |
| J 10                       | 0.550         | 3640          | 0.43         | 81.7           | 9.0                        | 8459                      | 798                  |

| I 14.4                     | 0.562         | 3561          | 0.43         | 82.7           | 8.9                        | 8538                      | 752                  |
| R 90                       | 0.548         | 4295          | 0.24         | 80.4           | 4.8                        | 8450                      | 579                  |

| (2.1)                      | (7.5)         | (7.2)         | (4.2)         | (2.8)           | (2.9)                      | (9.7)                     |

³Values in parentheses are coefficients of variation.
Screw withdrawal resistance

The mean resistance to screw withdrawal was quite high for both types of wood, being highest in block Z. There was a difference of between 3 and 10 percent for the two blocks of obeche, depending on the cutting angle of the boards, with a slight increase in variability recorded in block Z; although, according to the Student’s t-test, these differences did not achieve statistical significance. The highest resistance values were found in the board R: 1863 N for the bleached block and 1930 N for the untreated one. They exceed the overall mean values of the corresponding blocks (i.e., considering all the angles studied) by 11 and 9 percent, respectively. They were, however, lower than those found for poplar MLW.

Variability within the block

The very limited variability observed for all of the performance examined indicates considerable homogeneity of the material within the block, apart from the test pieces from the R boards, for which the effect of the direction of the stress with respect to the orientation of the layers seems predominant. This emerged also by the analysis of the variance, which confirmed that the position of the test pieces in the block had no effect on their mechanical properties.

Conclusions

This study showed modest performance of MLW, which for obvious reasons is connected to the types of wood used. However, the product showed remarkable homogeneity in its behaviour. Regarding MLW made from poplar rotary-cut veneers, the tests recorded better mechanical properties than those reported in the literature for solid poplar wood and even higher homogeneity for all of the technological features that were investigated. A similar tendency was seen for the MLW of obeche. In this case, only the boards corresponding to a 90-degree cutting angle with respect to the base plane of the block were significantly different in their mechanical properties from the others. Bleaching of the obeche blocks, however, did, in fact, lead to significant performance differences, particularly in relation to hardness and modulus of elasticity.

The enhancement of the mechanical properties of the underlying wood probably relates to the fact that during the manufacturing process of MLW any defects in the wood, such as knots, are eliminated. Moreover, the presence of adhesive, and the densification induced by pressing the block results in higher density, with a positive impact on the related mechanical properties. The same factors (as well as the use of logs from a single clone in the case of poplar) are responsible for MLW’s highly homogenous behavior. Within the limits due to the relatively low number of samples used and the inclinations of the cutting plane studied, the study reported here makes a useful preliminary contribution to a better knowledge of the mechanical properties of a still innovative wood-based material, recognized and appreciated on the international market. It should also help to fill the gaps that at present risk jeopardizing the future use of MLW in fields of application where the aesthetic appearance has to be coupled with well-known performance requirements.

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