Effect of laboratory-accelerated aging treatment on the ultimate strength of a 4-sided MDF kitchen cabinet

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Abstract: In this study, 4-sided rectangular full-size cabinets from 2 types of medium-density fiberboard (MDF; melamine-coated MDF with edge band and uncoated MDF without edge band) were manufactured and tested. Screws with nominal size of 4 × 40 mm were used for joint fabrication. Cabinets were kept in a conditioned climate chamber for accelerated aging treatment and their maximum load-bearing capacity was measured. Results revealed that approximately one-third of the load-carrying capacity of both types of cabinets (when compared to control samples) was lost after aging cycles. The ultimate strength of cabinets (in both control samples and after aging cycles) constructed of melamine-coated MDF with edge band was 1.8 times greater than that of cabinets made of uncoated MDF without edge band. Therefore, using edge banding and coated MDF in cabinet construction is strongly suggested, as this can improve the maximum load-bearing capacity and service life of cabinets while having little effect on aging prevention of cabinets.

Key words: Accelerated aging, edge band, melamine coating, medium-density fiberboard kitchen cabinet, ultimate strength

1. Introduction
Medium-density fiberboard (MDF) panels are extensively used in the manufacturing of modern furniture because their physical and mechanical properties as well as their surface qualities are relatively standardized and uniform within and between similar panels. These characteristics make the panels a suitable alternative to solid wood for industrial manufacturing of furniture. Engineered composites such as MDF or particleboard have been frequently used in kitchen-cabinet manufacturing, especially for middle-class end users. Kitchen-cabinet structure can be manufactured by at least 3 different methods: by wood composite panels, by wood frame, or by a combination of these 2 methods (Kasal et al. 2008). Kitchen cabinets have been constructed and used for thousands of years as storage systems, but the manufacturing of current forms, and especially of wall-mounted forms, is only less than 100 years old, probably starting in 1920 (Luppold and Bumgardner 2009). Published documents show that the first scientific study of the structural characteristics of cases was started by Kotas about half a century ago (Kotas 1957).

Panel-made square or rectangular shapes with L-type corner joints, such as closets or cabinets, are the basic structures for case-type furniture manufacturing. Many researchers have studied the moment capacity of L-type joints as the main joint in cabinet-making by considering the effect of the types of fasteners used, distance between the fasteners, material types, loading types, etc. (Rabiej et al. 1993; Zhang and Eckelman 1993; Rajak and Eckelman 1996; Liu and Eckelman 1998; Tankut 2006; Kasal 2008; Atar and Ayhan 2008; Barboutis and Vassiliou 2009; Simek et al. 2010). Limited other studies focused on the maximum load-bearing capacity of a single box-type cabinet (Eckelman and Rabiej 1985; Kasal et al. 2008, 2011) and some others explored the rigidity of L-type joints, their relation to the rigidity of the box (Lin and Eckelman 1987), and the effects of adding shelves, frames, and other factors on the rigidity of case furniture (Eckelman and Resheidat 1984; Eckelman and Munz 1987; Tankut et al 2003; Tankut 2009).

Many different types of fasteners are available in the market for manufacturing of furniture cases. Wood and sometimes plastic dowels and screws with or without glue are the most popular. Modern types of fasteners including Minifix and Rafix are also used widely for industrial production of knock-down and ready-to-assemble case furniture. Small- and medium-size enterprises widely use screws because they are cheap and can be fastened on site quickly by simple tools. Screws are also strong enough to
produce a structure such as a kitchen cabinet for middle-class end users; therefore, some researchers have focused on this faster as the main connector. Kasal et al. (2008) studied the effects of screw size on load-bearing capacity and stiffness of 5-sided furniture cases constructed of MDF and particleboard. Results indicated that MDF cases yielded significantly higher load-bearing capacity than particleboard cases, but the significance of MDF cases stiffness over that of particleboard cases was mainly dependent on the applied screw diameter. In another study, Kasal et al. (2011) found that the application of thicker and longer screws increased the cabinet load-carrying capacity and stiffness. Eckelman (1988) calculated formulas to predict face and edge withdrawal strength of screws from commercially available MDF.

All types of cabinets, especially those that are used inside kitchens or bathrooms, absorb and desorb moisture in their lifetimes. The amount and frequency of it depends on the environmental conditions inside each place. When this natural phenomenon of absorption/desorption and thus swelling/shrinkage repeats over time, it will affect the strength and rigidity of cabinet joints. This hidden cumulative destruction continues until joint failure suddenly happens due to an overloading of the structure. Researchers have devised methods to simulate this long-term process in the laboratory in a short period of time, known as “accelerated aging” tests.

Kajima and Suzuki (2011) studied the effects of accelerated aging treatments on the durability of 4 types of wood-based panels (MDF, particleboard, oriented strandboard, and plywood) bonded with methylene diphenyl diisocyanate and phenol formaldehyde after bending tests. Zhou et al. (2001) studied the bending creep behavior of MDF and particleboard during cyclic moisture changes. Tests were run at 20 °C with 3 cyclic relative humidity changes of between 65% and 95% and less than 10%. The results indicated that relative deflection and total compliance of the samples increased over the history of cyclic moisture changes, and magnitudes varied with board types and the used adhesive. Ozarska and Harris (2007) undertook a study to determine creep characteristics of furniture panels, both laminated (melamine and hardwood veneer) and un laminated, in cyclic humidity conditions. Relative humidity changes were set to between 35% and 85% with a constant temperature of 23 °C. Results revealed that the creep behavior of MDF panels subjected to cyclic humidity can be reduced by using surface laminations. The greatest reductions in relative creep values in bending of MDF panels were observed at up to 3.3 times in the panels laminated with melamine surface overlays and at up to 2 times for those with hardwood veneer as compared with uncoated panels. River (1994) explored the correlation between outdoor aging of wood-based panels with laboratory aging. He found that this relation existed, but it was different for various tests (modulus of rupture [MOR], modulus of elasticity [MOE], internal bond strength, and thickness swelling). The strongest correlation between outdoor aging and laboratory aging was found in the modulus of rupture test.

Natural moisture fluctuation of a kitchen or bath cabinet during its daily life will affect its mechanical strength. Technical and precise knowledge in this area can help designers and manufacturers of cabinets to better understand the reaction of their products in a service location as well as predict their service time. No published research was found, however, studying the effects of cyclic relative humidity changes on the load-bearing capacity of a full box-type structure. The main objective of this new study is to give insight into this issue by answering the following 2 questions:

1) What is the effect of laboratory-accelerated aging on maximum load-bearing capacity of cabinets?

2) What is the effect of using melamine-coated MDF with edge band in cabinet construction on maximum load-bearing capacity of the structure?

2. Materials and methods

2.1. Materials

MDF sheets were obtained from a manufacturer (2.07 × 2.8 m) in 1 shipment and in 2 forms: uncoated MDF and melamine-coated MDF. The melamine cover on the surface of MDF panels was a paper layer impregnated with melamine formaldehyde. Panels were immediately cut into 4 identical smaller sheets for easier handling and storage. Afterwards, final box members were cut from these smaller panels in 2 different dimensions as wall (side) members (600 × 320 mm) and top and bottom members (568 × 320 mm).

2.2. Sample preparation

Suction pads of computer numerical control (CNC) machines are only capable of fixing sealed-surface (such as melamine-coated) panels on their position; therefore, in cases of processing uncoated panels, their surface must either be sealed or cut by a normal circular table saw. In this study, secondary cut processing of melamine-coated MDF was done by CNC machine, while secondary processing of uncoated MDF was done by circular table saw with a cutting precision of <1 mm due to penetration of air through the thickness of the panel and the neutralizing of the efficacy of suction pads. Table 1 presents basic technical information of the used panels. Self-tapping screws (without glue) from a recognized company were the only connectors used in the cabinet manufacturing. The screw nominal size utilized in box construction was 4 × 40 mm with a root diameter of 2.57 mm and a threaded area of 56%. Two screws were installed in each corner joint at a 64-
mm distance from the edge of the panel (192 mm of space in between) so each rectangular box was erected with only 8 screws. The depth of embedment of each screw was 24 mm in the edge member and 16 mm in the face member of the box. Pilot holes were drilled 1 mm longer than the real depth of embedment. Drilling pilot holes before screw placement in wood-based panels, especially when driving the screw on the edge of a panel, is essential. It is suggested that pilot hole diameter should be around 80% to 85% of the root diameter of the screw. Pilot holes not only help to locate screws, but also facilitate their insertion in a desired direction (Rajak and Eckelman 1993). Others suggested that it is better to adjust the pilot hole between 85% to 95% of the root diameter to obtain maximum screw holding power as well as the fewest cracks around the hole after driving the screw (http://www.norbord.com). Hence, the best pilot hole diameter to obtain maximum screw holding power should be found by individual testing based on the used screw and the panel type (Eckelman 1988). In this study, after several tests, the optimum pilot hole diameter was found to be 2.3 mm, which is equal to 90% of the screw root diameter. Pilot hole drilling in all samples was done by CNC machine.

2.3. Manufacturing and assembly
The cabinets were manufactured very carefully considering joining members and were lined up straight and square. Each box dimension was 600 × 568 × 320 mm (L × W × D). Two types of MDF were used separately for cabinet construction. Uncoated MDF cabinets had no edge band, while melamine-coated MDF was covered by 2-mm-thick acrylonitrile butadiene styrene (ABS) edge band. A fully automated edging machine was used for edge-banding the cabinet members. The melamine coating of panels was in the form of a very thin, impregnated paper.

2.4. Laboratory aging
Accelerated laboratory aging tests were invented by researchers to fulfill the need to assess the durability of wood and wood-based panels in their natural usage environments in a short time. Five types of invented accelerated aging treatments that are used in different countries are cyclic JIS - B treatment, cyclic APA D - 1 treatment, V313 procedure, ASTM cyclic procedure, and VPSD procedure (Kojima et al 2009). Other methods may also be used.

The laboratory-accelerated aging plan (hereafter called “treatment”) that was used in this study consisted of 16 cycles of wet and dry periods with relative humidity (RH) changes between 90% to 30% and a constant temperature of 70 °C. This treatment was optimized for indoor conditions based on ASTM 1037-1999 and the guidance of DIN 321-2002. The aging treatment started with a wet step (90% RH) for 3 h, followed by a dry step (30% RH) for 3 h, a wet step again for 3 h, and finally a dry step for 18 h. This process was repeated for 4 cycles (Table 2). This modified plan was suggested after intensive tests in the laboratory and real measurement of RH changes in the indoor kitchen and bathroom environments, and also by comprehensive study of the published articles by previous researchers (Baker and Gillespie 1978; Caster 1980; Back and Sandstrom 1982; Chow and Janowiak 1983; Dobbin McNatt and Link 1989; Kajita et al. 1991; River 1994). Separate studies in the laboratory proved that dipping samples in warm water (as required by ASTM 1037) is very harsh for panels made of urea formaldehyde glue. Samples were destroyed completely after the second cycle of dipping, and so this step was removed. The most often reported problem with the original laboratory-accelerated aging mentioned in ASTM D1037 is that it is much too strong.

### Table 1. Technical specifications of used MDF panels in box construction.

<table>
<thead>
<tr>
<th>Panel Type</th>
<th>Density (kg/m³)</th>
<th>Panel thickness (mm)</th>
<th>MOE (MPa)</th>
<th>MOR (MPa)</th>
<th>Internal bond strength (MPa)</th>
<th>G modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control samples (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncoated MDF</td>
<td>708</td>
<td>16.27</td>
<td>2993 (1.9)*</td>
<td>25.75 (3.4)</td>
<td>0.32 (6.25)</td>
<td>1545 (5.7)</td>
</tr>
<tr>
<td>Melamine-coated MDF</td>
<td>725</td>
<td>16.22</td>
<td>3863 (2.5)</td>
<td>24.9 (5.3)</td>
<td>0.22 (9.1)</td>
<td>2052 (3.4)</td>
</tr>
<tr>
<td>Treated samples (T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncoated MDF</td>
<td>686</td>
<td>17.19</td>
<td>2187 (3.55)</td>
<td>16.9 (4)</td>
<td>0.31 (3.2)</td>
<td>1283 (4.5)</td>
</tr>
<tr>
<td>Melamine-coated MDF</td>
<td>724</td>
<td>16.43</td>
<td>3469 (4.1)</td>
<td>21.5 (4.3)</td>
<td>0.19 (15.8)</td>
<td>1730 (4)</td>
</tr>
</tbody>
</table>

*Numbers in parentheses are coefficients of variation.
Replication number for each measurement was 5. Densities are based on standard climate (20 °C, 65% RH).
long to be used as an in-plant quality control check. A prior study proved that application of shorter cycles (4 instead of 6 cycles in the original standard) of laboratory-accelerated aging had essentially the same effect on panel bending strength and stiffness (Dobbin McNatt and Link 1989). Therefore, 4 cycles of aging were selected based on this study. Some other researchers have also made similar studies and finally modified or removed some steps from this laboratory aging (West Coast Adhesive Manufacturers’ Association 1966; Caster 1980; Back and Sandstrom 1982). Modifications of the used accelerated aging cycles were done after studying these resources.

In this study, “T” represents samples that were exposed to aging cycles in a climate chamber. Treatment (T) length of time was 5 days and 20 h, similar to the suggestions in modified ASTM 1037. “N” represents control samples (untreated). All treated as well as control samples were tested only after conditioning in a normal climate chamber (20 ± 1 °C, 65 ± 3% RH) in order to reach the same level of equilibrium moisture content. Cabinets manufactured with uncoated MDF were kept in a normal climate chamber for at least 3 days, while cabinets manufactured with melamine-coated MDF with edge band were stored in a normal climate chamber for at least 3 weeks.

### 2.5. Tests

After manufacturing cabinets and before the static load testing, all samples were fixed in a metal fixture that was made before the experiments. As is illustrated in Figure 1, each cabinet is supported at 3 points by 3 steel columns, which are screwed and fixed into a stiff panel beneath it. On the top of each support there is a steel lubricated ball in a small bowl, which makes a pin joint and gives the cabinet free rotation during loading. The fourth corner is unsupported and is the place where the vertical load is applied from above. On the opposite corner of the loading head there is another support, called “top support”, which keeps the whole box fixed during loading. In order to properly indicate screw position, a naming system was used as shown in Figure 1. The rotation direction for screw naming is counter-clockwise and the position of front or back screws is shown by A or B. For instance, joint 41A is the front joint (A) in the top panel (4) where it abuts the left panel (1), while screw 12B is the joint near support 3, screw 23A is the joint near support 1, and so on. Load was constantly increased until cabinets were broken. Replication number for each test was 5. Altogether, 20 cabinets were built and tested. Loading speed was 9 mm/min as the speed of MOE and MOR tests. Material testing machine 1485 testXpert II was used for tests with the maximum 200-kN capacity.

### 3. Results

After each test, maximum load-bearing capacity, maximum deflection, and the total time of the test as well as modes of failure for each box were recorded. Results...
revealed that load-bearing capacity in treated cabinets (T) made of uncoated MDF without edge band was 70% as compared to the control samples. This cabinet type could tolerate 387 kg of load after aging cycles. In cabinets made of melamine MDF with edge band, this strength after aging cycles was recorded as 71% compared to the control samples showed 690 kg of load-carrying capacity (Figure 2). Results expressed that aging has nearly the same amount of destruction on the ultimate strength of both types of cabinets, and so it seems that edging and coating of cabinets’ panels cannot prevent aging. This is probably because of the high treatment temperature that accelerates relative humidity penetration into the panel’s texture, which destroys the bonding between fibers in MDF. Separate tests proved that normal edge-banding practice of cabinets can never make a completely sealed edge and moisture can still move into the texture of the panel from the borders of the edge band and the surface coating. The amount of penetration depends on coating thickness, type of moisture (air humidity or liquid water), and temperature, which itself speeds up the movement of molecules and thus inevitably the destruction. According to described cabinet structural integrity standards and test methods by the Kitchen Cabinet Manufacturers Association, both types of cabinets after aging can pass the minimum requirements for mechanical strength. As Figure 2 shows, using melamine-coated MDF with edge band in the manufacturing of cabinets has a very strong influence on the maximum load-bearing capacity of the cabinet’s structure. This superior cabinet strength is recorded as 1.8 times over that of the cabinets made of uncoated MDF, which is remarkable.

Generally, 2 typical locations of failure were mostly observed in cases after testing (Figure 3). As expected, the main type of failure was delamination of the panel at the screw joint located near the loading head in the top panel (namely joint 41A) and in the same direction in the bottom panel (namely joint 12A). To understand the naming system of fasteners based on their positions, please refer to Figure 1. Delamination of the panel near each screw joint caused the screw to pull out of its place; this was the main reason for case rupture (Figure 3). Sometimes screw failure happened without panel delamination. In these cases, fibers were brought out of the pilot hole and joint failure happened. After treating samples, the location of screw failure changed when compared with the location of screw failure in the control samples. Failure in control sample cabinets was mostly observed in screws near the loading head of the machine in the top panel and at the same location in the bottom panel. The same procedure can be tracked in treated samples, but the location and tendency of screw failure spreads to other joints, as well. A complete list of box failure for melamine-coated MDF with edge band in both control and treated samples is given in Table 3. None of the screws were broken, but some of them, especially in the joint failure location, were bent. Failure happened either by delamination of the panel in the joint area or by the screw getting pulled out of the panel. No edge band was broken after the test.

Failure location of cabinets made of uncoated MDF under load often started with the delamination of the joint near the loading head of the machine in the top panel. In general, joint failure mostly occurred in a time span of 60 to 90 s and was seen in joints 12A, 12B, 41A, and 41B, as well as in lower frequency in some other joints. Failure happened along with the screws being pulled out of the panel. Box samples after treatment were roughly broken 20% sooner in time as compared to the control samples.

4. Discussion

An advantage of using melamine-coated MDF with edge band in manufacturing cabinets is the higher ultimate strength of the final product (Figure 2). This higher strength of the structure can also give a longer service time by showing more resistance against repeated load over a cabinet’s lifetime. The findings of this research express that decline in mechanical strength of both types of cabinets after laboratory-accelerated aging are nearly the same, and so the main role of coating and edging is to add to the total strength of the cabinet, not necessarily to prevent aging. A part of this higher strength in melamine-coated MDF is also because of the higher density of melamine-coated board (Albin et al. 1987) (Table 1) and due to the melamine coating itself (Ozarska and Harris 2007), but the main difference can be related to the ABS edge banding. Edge banding with 2 mm of thickness not only adds to the strength of the whole cabinet’s structure but also protects the panel’s edge from developing cracks in the core layer.
The form of joint failure in this research was compared with a similar test by Kasal et al. (2008). They reported that frequency of screw joint failure in cabinets manufactured of uncoated particleboard and MDF was 80% in the joints in the top panel and 20% in the joints in the bottom panel. In this study (in melamine-coated MDF with edge band), in control samples 46% of screw failure happened in the top panel and 54% in the bottom panel. After box treatment, this proportion changed to 61% of the joint failure in the top panel and 39% in the bottom panel. In cabinets manufactured from uncoated MDF, most of the time the failure started from the top panel and the failure mode was closer to the findings of Kasal et al. (2008), and this frequency increased in treated cabinets. Generally, if joint breakage in cabinet testing always occurs from the same location, the researcher should be suspicious of the reliability of the gained results (Ho and Eckelman 1994).

Application of coated and edge-banded panels in kitchen-cabinet manufacturing adds to the strength of the whole structure as well as to the beauty of the cabinet. There are also other benefits associated with this practice, as it makes cabinets more durable against deteriorating biological agents.

**Figure 3.** Typical locations and modes of screw failure.
Cabinets, like other types of furniture, encounter many different forms of load in their lifetimes. This load can be a static long-term dead load or a dynamic short-term impact load that can repeat over time. It should be noted that the result generated by this study is only practical when the cabinet itself stands alone and no static or dynamic load that itself accelerates the destruction applies to it. The findings of this research are helpful for designers and manufacturers of furniture to better understand the behavior of their products in real conditions.

**Table 3. Location and frequency of joint failures in boxes made of melamine MDF with ABS edge band.**

<table>
<thead>
<tr>
<th>Screw position in box*</th>
<th>Joints between top and left panels</th>
<th>Joints between left and bottom panels</th>
<th>Joints between bottom and right panels</th>
<th>Joints between right and top panels</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>41 A</td>
<td>12 A</td>
<td>23 A</td>
<td>34 A</td>
<td>100%</td>
</tr>
<tr>
<td>N (Control)</td>
<td>31%</td>
<td>23%</td>
<td>7%</td>
<td>9%</td>
<td>100%</td>
</tr>
<tr>
<td>T</td>
<td>15%</td>
<td>27%</td>
<td>4%</td>
<td>7%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Please refer to screw joint numbering map in Figure 1.

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