Influence of accelerated aging on bending strength of particleboards

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Abstract. Particleboards are used in the manufacture of furniture, as well as the furnishing of structures and prefabricated homes. Their quality dictates where they can be used and how long they can last. The boards’ characteristics deteriorate as they are used. To examine the change - degradation of the properties of the boards are exposed to the effects of the external climate (rain, snow, wind, sun) or regimes of accelerated aging. For this purpose, a degradation test of the properties of wood-based panels was performed, which aims to create a model that will describe the change in bending strength of the mentioned panels. The paper presents the results of bending strength and thickness swelling tests of 16 mm thick particleboards that were exposed to accelerated aging regimes, and the basic model of property degradation.

1. Introduction

For years, the most used wood-based panels are particleboards. There are many reasons for this such as large raw materials base, raw material price, low-cost adhesive, for example, urea formaldehyde adhesive, favorable properties for the inside usage as well for the construction. All these qualities make the particleboards cost less which makes them more favorable compared to other wood-based panels.

Particleboards are defined as boards made of lignocellulosic materials (mostly wood) in the shape of small pieces – wood particles combined with synthetic or other types of adhesives made into a compact panel under high temperatures and pressure. There are many criteria for particleboard classification. They can be classified according to the type of raw material, based on the position of particles in the panel, according to the dimensions of particles, according to look of the cut and its structure, according to the panel processing and structure, according to the volume, according to the type of usage, according conditions of usage, according to the type of adhesive used and formaldehyde emission [1]. Although, they have somewhat different qualities to other types of panels (particleboard and fibrous boards) particleboards have found wide range of usage, primarily in furniture manufacture as well as, interior design as wall coating, etc. (Figure 1.). Place of usage determines which type of panel to use (based on the standard BAS EN 312: 2012). There are following classes of panels: P1 – particleboards of general purpose in dry conditions, P2 –boards for interior space design and furniture and usage in dry conditions, P3 –non-bearing boards for humid conditions, P4 – bearing particleboards for dry conditions, P5 – bearing particleboards for humid conditions P6 –bearing particleboards for heavy load conditions in dry conditions, P7 – bearing particleboards for heavy load conditions in humid conditions.
Figure 1. Raw particleboard and examples of usage for furniture and wall coating [6].

Every construction type has specific conditions that a material, in this case particleboard needs to comply with. Particleboard can be used raw but, in most cases, it is coated with materials made for this purpose such as veneer, melamine foil, sieve coating, paint and varnish, impregnated paper, textile and different composite materials. All the wood-based plates used in construction throughout Europe should comply with standard BAS EN 13 986 (Wood-based panels for use in construction – Characteristics, evaluation of conformity and marking). This standard determines properties of wood-based panels for construction purposes and methods of determination and testing of properties of mentioned panels. Based on place of usage, chosen panels are tested for some or all of the properties, i.e. weather they are used in dry or humid conditions, or in the external weather conditions.

2. Testing of particleboard qualities
Panel qualities play a great role when deciding which type of panel is best suitable for a specific area of usage. Every space has specific conditions that panels should be compatible with in order to be used. As time goes by the panel qualities change based on the conditions of the space where the panel is used. This is why, aside from basic quality controls, we need to estimate conditions that will affect panel properties while in use and test the panel in such conditions to see its behaviour under the influence of the environment (change of humidity, temperature, etc.) To see the results faster, panels undergo tests in different conditions in a laboratory. This way panel properties deteriorate faster. These conditions are then compared to real conditions where the panel will be applied so that lasting period and resistance of panels in given conditions can be determined.

2.1. Theoretical study of testing of particleboards
There are many studies done on the influence of climate and wood usage conditions and wood-based materials. The aim of these studies is to show how much climate and usage conditions affect wood materials over time as well as estimating influence of external factors on wood materials and level of change of those materials after years of exposure. Another aim is to understand difference between simulated and real external conditions. The ultimate goal being building a model that shows different influence of weather conditions on wood material. That being said, it is crucial to know the climate of the area where the material will be used. I. Teodorescu, D. Tapusia, R. Erbasu (2016), did a study of this matter, e. i. how the change in temperature and humidity change wood and wood material properties [11]. An analysis of temperature and humidity results recorded over a course of a few years in different parts of the day was done. These studies were based on different variables of wood such as loss of mass, resistance, influence of humidity, the lifespan of a tree and its shape. This study was done in France where they studied the influence of weather changes on wood materials. For temperature estimate minimum and maximum temperatures are recorded which gives insight in the daily temperature trend. Mechanical and physical properties of wood elements in wood construction are changed under the influence of humidity, temperature and bioactivities so the goal is building a model to estimate deterioration of wood for elements exposed to weather conditions. According to this the lifespan of the material depends on relative air humidity combined with different temperatures and time of exposure.
Aside from the aforementioned researchers, Y. Kojima and S. Suzuki (2010) made great contribution in this field [8]. Great deal of their research was focused on wood and wood materials deterioration under the influence of external weather conditions and comparison of lab induced aging with real aging of wood after years of exposure. Wood panels are used in construction more than ever. That is why we need durable wood i.e. we need to calculate how long could wood panels could be used in real life conditions, while keeping necessary properties given by law. Sekino and Suzuki (2010) presented the findings of their ten years long study of different types of panels (particleboard, OSB plate, MDF – fibrous plate, plywood plate etc). There are studies from Europe and USA that compared results with those gotten in Japan with regards to influence of climate properties on exposure conditions.

Methods used in studies of wood durability can be long term and short term. Long term studies examine exposure in outside conditions in long time frame including conditions from the past. These tests have many flaws such as long term and heavy damages and their results differ depending on the testing location. Short term studies analyse change of mechanical properties under lab conditions using dipping in water, boiling, steaming, freezing and drying methods. Sekino and Suzuki (2010) tested link between accelerated aging and exposure in the city of Shizuoka using bending properties. Eight different wood-based plates underwent five different accelerated aging treatments as well as five-year long test of external exposure. For every accelerated aging treatment bending strength decreased as cycles number increased. Bending strength after six cycles of treatments for JIS-B, APA D-1 and ASTM almost completely matched [9]. Five-year long test of exposure in open air showed that the bending strength of all the plates decreased with time. Bending strength of particleboard and OSB plate were less than 30 % and 10 % after five-year long exposure. Change of strength after five years of external exposure was equal to the change after six cycles of ASTM treatments [8][10].

3. Experimental studies of particleboards
The aim of this paper is to find out how will a raw particleboard be affected i.e. how will its properties change and deteriorate under the influence of different climate and load. Influence of climate on panels properties is shown through sample treatments. The treatments applied were exposing samples to different changes in temperatures and humidity in specific time intervals. These treatments were done in three cycles. Changes in sample panels were noticeable after every cycle visually as well after measurements of parameters (humidity, thickness, density and fracture force).

3.1. Standards and other resources for experimental studies
Resources can be material (samples, tools, instruments, etc) as well as immaterial. Knowledge, as part of resources of experimental studies, means skills and experience of a person who conducts the experiment and relies on standards and guidelines for a given experiment. The experiment presented in this paper applied the following standards: BAS EN 326 – Sampling, cutting and inspection – Part 1: Sampling and cutting of test pieces and expression of test results, BAS EN 321 – Cyclic tests in humid conditions, BAS EN 322 – Determination of moisture content, BAS EN 325 – Determination of dimensions of test pieces, BAS EN 310 – Determination of modulus of elasticity in bending and of bending strength.

Due to variability in and between panels it is inevitable to test a number of panels [n], and a number of samples [m], cut out of one panel, to get reliable results. Minimum number of samples for testing [m] is: sample for density testing [6], for bending test [6], for humidity testing [4], treatment depending on test method requirements. When cutting minimum distance between two samples in the same test has to be 100mm, except for test of quality of glued joints. All samples cut from one panel have to have the identification number of the panel and serial number of the sample. They must have straight edges; no damage and they should be perpendicular on the panel. Every other panel property of a sample should be tested according to the in-effect standards, for samples cut from a whole panel. This testing requires
two types of samples: BAS EN 310 for bending test; sample had following dimensions: sample length \( L = 20 \ t + 50 \) mm, sample width \( b = 50 \) mm and sample thickness \( t = 16 \) mm (Figure 2.a.). Humidity and density testing samples have following dimensions 50 mm x 50 mm x panel thickness (16) mm, and they are shown in (Figure 2.b) [2].

![Figure 2. Samples of particleboards.](image)

16 mm particleboard used here is a three-layer non-bearing panel suitable for indoor spaces and dry conditions. It has great dimensional stability and rigidity. It is used for furniture, partition walls, floor bases, sandwich panels etc. Basic properties of this panel are shown in the table below (Table 1).

| PARAMETAR                        | Classes of panels |
|----------------------------------|-------------------|
| Panel type (standard BAS EN 312) | P2                |
| Fire resistance                  | D-s1, d0          |
| Formaldehyde emission (EN ISO 12460-5) | Class E1       |

Classes of panel shown in the table are gotten from the supplier (Babilon doo, Tuzla) i.e. panel manufacturer (Kronospan). Aside from mentioned standards and particleboard samples other equipment was used in this study, such as digital scale, dryer, tensimeter - SHIMADZU, movable scale, micrometre, hygrometer, freezer, computer with suitable software and other lab equipment.

### 3.2. Particleboard testing

It is necessary to identify process parameters that will be included in the experiment. It is possible to identify them through an experiment where a certain number of parameters is chosen from the total and defined as independent variables. The rest is viewed as constants (although these parameters can be independent variables). Maximum fracture force of wood-based panel (particleboard) depends on many factors such as: plate density \([\rho_p]\), plate thickness \([d_p]\), plate type, glue type, humidity \([w_p]\), modulus of elasticity \([E_p]\), plate structure- based on plate type (type of wood, thickness/size of veneer/chips, raw material quality, etc.), manufacturing technology (pressure and temperature of pressing, and other properties of manufacturing equipment). In this study, considering the aim of this research independent variables were plate type and conditions of exposure.

Testing of change in humidity is based on standard BAS EN 322. Humidity values change shows as change in mass of samples scaling of which occurs in precisely determined intervals. Samples are dried in a dryer on temperature 103 ± 2°C until constant mass. Data acquired in this way is used to calculate panel humidity. Mass measurement is accurate up to 0,01 g. Number and method of sample cutting is based on standard BAS EN 326-1. One panel gives four samples provided that none of the samples is lighter than 20,0 g. As needed clean the samples of dust and wood particles in order to get results as accurate as possible [14]. Calculating density value of tested wood-based panels is done on panels of
following measurements 50 mm x 50 mm x panel thickness in mm. Panel density is the arithmetic mean value of densities of all samples cut from one panel. Sample needs to be tempered until constant mass in the following conditions: air humidity 65 ± 5% and temperature 20 ± 2°C. If the results in two consecutive tests do not differ more than 0.1 % from the test tube mass, constant mass is achieved. When measuring e. i. scaling accuracy has to be 0,01 g. Panel density \( \rho \) is calculated as arithmetic mean value of densities of all the sample panels made from one panel and it is expressed in \( \text{kg/m}^3 \) [5].

Sample treatment is done according to standard BAS EN 321. This experiment has three cycles. Every cycle consists of the following: immersing sample into the water, freezing and drying samples in high temperatures. Sample immersion in water was done in controlled conditions. Water temperature was 20±1°C, pH value 7 ± 1. Samples were put in plastic containers, separated from each other, in depth of 25±5 mm. Duration of the immersion in water was 70±1 hours. Samples are then taken out of the water, dried and put to freeze at temperature -12°C to -25°C. It is important to have the distance between the samples be at least 15 mm and that upside/downside are the same i freeze as they were in the water. Freezing duration was 24±1 hours. Next step is drying of frozen samples in a dryer at a temperature of 70°C. Samples are positioned properly with defined distance and in accordance with dryer capacity. Downside/upside are the same as in the freezer. Drying duration was 70±1 hours. This concludes the first cycle (immersion, freezing, drying) Second and third cycle are identical to the first one.

Testing samples were cut and processed according to standard BAS EN 326. Those samples were put in tensimeter - SHIMADZU where the force is increased until sample destruction (fracture) in 90 ± 30 seconds interval. Sample is put on lower supporters properly spaced apart (20 values of sample thickness). Properly positioned sample should be in the middle of the supporters with 25 mm of distance from the edges on each side. Control unit (computer) had Trapezium software where all the parameters were adjusted before the test start. While testing all the study-relevant data is being recorded such as fraction force, time, elastic deformation, etc. Sample thickness was measured before and after the testing. They were measure before testing and after each cycle which is why we can calculate the level of swelling after each treatment.

### 3.3. Results of experimental properties testing

Density calculations are done according to standard BAS EN 323. Eight samples were measured and scaled and then mean density values were calculated. Sample humidity was measured three times and the values are shown in the table below. Swelling values was calculated in this experiment by measuring thickness before and after treatment. Based on this data results comparison was made and swelling value for specific samples was determined (Table 2).

| Table 2. Parameters of measurement while testing (density, humidity, thickness of sample). |
|---------------------------------------------------------------|
| Raw particleboard panel– thickness 16 mm                      |
| Testing                                                      |
| Panel density (mean value \( \rho \)) [kg/m\(^3\)]             |
| Untreated          | 1. cycle | 3. cycle |
| 657,682            | 409,820  | 370,010  |
| Sample humidity [%]                                          |
| 8 ± 2             | 7 ± 2    | 6 ± 2    |
| Sample thickness [mm]                                         |
| 16,17             | 24,01    | 26,56    |

Fracture force testing was done on tensimeter (SHIMADZU), where maximum fracture force was determined in three points. As in previous tests it was measured on untreated samples, and then after first and third cycle.
Table 3. Maximum value of fracture force – mean values.

| Panel type      | Sample No. | Untreated | 1. cycle | 3. cycle |
|-----------------|------------|-----------|----------|----------|
| Particleboard   | 6          | 282,013   | 30,341   | 11,521   |

Based on maximum fracture force values mean values were calculated for every type of panel. They were compared with mean values after treatment e. i. after first and third cycle (Table 3).

4. Model of changes in properties of particleboards

Optimal choice of particleboard for a specific area of use is determined by the algorithm for material choice, that defines mechanical, physical, rheological, functional, technical, economic, ecological, social and other requirements. When used (furniture, partition walls, ceiling and roof construction) particleboards are exposed to different weather conditions and load, that changes over time. Choice algorithm can be understood through three units: input data, request verification and output data. Input data includes the choice of wood-based material and defining basic requirements determined by structure type. It, the structure type: bearing or non-bearing defines stability of shapes and dimensions, strength, heath, sound and humidity protection requirements, resistance to climate changes e. i. minimum and maximum values predetermined and many other properties specific to a certain type of structure. Request verification means that any suggested material will be checked for each and every requirement. If it passes all the checks it will proceed to the further controls. If it does not comply with all the specifications, it will be discarded. We will be at the beginning checking different material. This procedure will be repeated until the required conditions and properties are met [2].

Analysing results gotten in the experiment on the 16mm thick particleboard, we can notice change of values of some parameters after 3 cycles of treatment e. i. change of mean value of density of particleboard depending on testing cycle as well as humidity value of the panel before every cycle. (Figure 3). Change of panel density is notable after every cycle, that is after first and third cycle compared to untreated panel. Change is much greater after first cycle compared to the other two cycles. Decrease in density is cca. 38% after first cycle compared to the untreated panel while the difference between first and third cycle is cca. 10%, which practically means that the biggest change in density value happens in the first cycle while the other cycle cause much less of a change.

![Figure 3. Mean values of density and humidity of particleboard (sample).](image)
Thickness swelling of particleboard is one of the parameters noted after first and third cycle that showed similar tendencies as change in density. After first cycle, panel thickness increased by cca. 32% but after the second and third cycle it increased by only 7%. Relation between density and thickness swelling is shown in the figure below (Figure 4).

Figure 4. Mean values of panel thickness by cycles expressed in percentage.

Change of value in modulus of rupture is shown in (Figure 5), where we can see change after first and third cycle. Aside from that we can see minimum, maximum and mean values of fracture force for untreated and treated (1st and 3rd cycle) particleboards. Important finding is that the particleboard, after just first, cycle lost strength almost completely. The value of force decreased to cca. 10 %. After additional two cycles it decreased even more, lost its stability and strength. As such it was practically useless.

Figure 5. Values of force of fracture on a particleboard in different treatments.

Hook’s law is used in most cases to calculate strength. It is a linear correlation between straining and deformation. A classical approach to the problem of strength says that the fracture occurs when a combination of factors such as staining, deformation, temperature and other parameters (that describe condition of the material and its specific properties) reaches critical value which can be expressed through the following equation:

$$\sigma = f(\sigma_0, \varepsilon, T, W, C_n)$$  \hspace{1cm} (1)
where \( C_n \) represents parameters of macro real volume of the body, determined through an experiment. Change of the environmental conditions (change of temperature and relative humidity as well as duration of influence of climate parameters and how fast these influence change) influences the changes in temperature and humidity of the panel; the value of strength which is different from the maximum strength value that material can have in ideal conditions.

That is why to describe this model phenomenological equation for material conditions is more suitable and can be generally expressed as follows:

\[
\sigma = f (\sigma_0, T, W, t)
\]

Studies of influence of temperature on strength and strength [14], kinetic measurements of strength of particleboards in a long-term period [15], studies of influence of temperature and humidity on values of model of elasticity and module of rigidity [16], as well as our own experimental studies have shown that change of strength is not in fact linear and can be shown as Arrhenius equation:

\[
\sigma_{W,T} = \sigma_0 e^{\alpha T_e} e^{\beta W_e} e^{\gamma W_e/T_e} e^{\delta N}
\]

Where:
- \( \sigma_{W,T} \) – real (life) strength of wood in real humidity and temperature,
- \( \sigma_0 \) – wood strength when humidity value is 0 % and temperature is 0°C
- \( T_e \) – effective temperature,
- \( W_e \) – effective humidity,
- \( \alpha, \beta, \gamma, \delta, \) - constant values:
  - \( \alpha \) - influence of temperature on value of the material strength
  - \( \beta \) – influence of humidity on the value of the material strength
  - \( \gamma \) - change of material strength properties in combined influence of humidity and temperature
  - \( \delta \) – changes of strength caused by cyclical changes of humidity and temperature
- \( N \) – number of cyclical changes of humidity and temperature.

\( e^{\delta N} \) can exist as part of the \( \gamma \) value when the change happens in the real life (external) conditions or as a separate value in accelerated aging treatments depending on the number of cycles.

This model can present influence of humidity and temperature on values of panel strength, that is change in strength due to influence of climate where the boars is exposed. Coefficients (\( \alpha, \beta, \gamma, \delta \)) differ for different types of wood and its properties such as density, humidity, wood quality (wood fallacy). Influence of these factors manifests differently during temperature and humidity change in testing conditions and as such gives different results.

5. Conclusion
It is necessary to know the properties of material so that we can predict its changes over the course of time so that the material would meet necessary construction requirements. Particleboard is widely used as it has good qualities. This paper presented experimental testing of raw particleboards to study the influence of weather conditions in which the panel is used on the panel qualities. This is show through simulated conditions of aging of panels in three cycles. panels were measured before any treatments and then after first and third cycle. Based on these measures results were compared (density, humidity, thickness swelling, and maximum fracture force while bending) where we can see (degree of) changes after every testing cycle. panel evidently deteriorates after first cycle, although, it continues to do so in the next two cycles to a much lesser degree.
After analysing results of particleboard testing, we can see changes of variables of certain parameters during treatment:

- Change of panel density occurs after every cycle,
- Change is greater after the first cycle (cca. 38%) compared to the change in the next two treatment cycles (cca. 10%),
- Change of thickness swelling is similar to the change of density. After the first cycle the swelling increased approximately 32%. After the following two cycle it increased by approximately 7%,
- Modulus of rapture significantly decreased after first treatment cycle. The panel lost its strength almost completely (value of the force decreased to approximately 10% of the original value). After the other two treatment cycles strength and stability of the panel additionally decreased and as such the panel became unusable.

A model was made based on this data: Function of dependency of parameters such as temperature, humidity, testing duration and number of testing cycles. This shows the influence of climate conditions of the area on the qualities of panel. Thus, we need to consider it when choosing a panel. There is an (aforementioned) algorithm that helps choose panels and includes all the material and environment parameters and then suggest a panel suitable for any given requirements.

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