cigre PARIS 2022

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Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10829

Mechanical strength of pressboard materials under dynamic compressive stress

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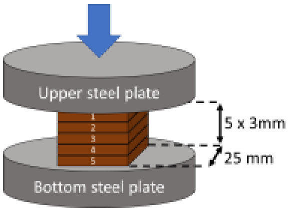
Motivation

- The present investigation studies the effects of a compressive force applied perpendicularly to the pressboard surface.
- The goal of the investigation is to understand the influence of dryness level, oil impregnation, and loading rate on the out-of-plane strength of pressboard.
- Currently, there are no methods that define the mechanical performance in terms of strength and deformation of the materials used in spacers under dynamic short-circuit loading conditions.
- The short circuit events exhibit fast rising times, resulting in the mechanical load being applied at very high rates.

Objects of investigation

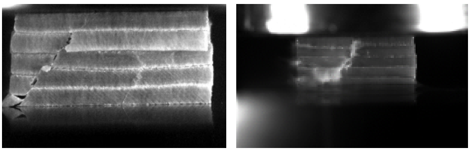
- The present investigation considers two different materials used in fluid-filled transformers: cellulose-based pressboard and aramid-based pressboard.
- The structure of pressboard is porous, allowing for full liquid impregnation.
- **Cellulosic-based test specimens** were manufactured from high density pressboard according to IEC 60641-3-1 Type B.3.1 A.
- **Aramid-based test specimens** were manufactured from high density board plates according to IEC 61629 type APB-HD (100% aramid, high density, heat compressed).
- Five pieces of pressboard pieces size 25 mm × 25 mm × 3 mm were stacked to form a specimen.



Schematic of the test set-up and specimens

Experimental details

- **Non-dried specimens**: The specimens were conditioned in a room climate (about 23°C and 50 % RH). The tests pieces were placed in the testing machine and directly tested without any drying.
- **Dry specimens**: The samples for this specific test were dried in a hot air oven at T=105 °C for 24 h. The samples were then stored in a dry environment before testing.
- **Impregnated specimens**: The samples for this specific test were dried in a hot air oven at T=105 °C for 24 h. Then the specimens were kept in the vacuum oven and impregnated at room temperature (RT) with mineral oil according to IEC 60296.
- **Compressive test :** The compressive tests were performed using am MTS tensile testing machine with maximum load capacity of 500 kN. Five pressboard pieces were stacked on top of each other and placed between two metallic plates with polished surfaces.
- **Loading rates:** The non-dried, dry, and oil-impregnated specimens were subjected to three different loading rates, 0.05 mm/s, 1 mm/s and 10 mm/s.



Failure initiation in pressboard in compression at different loading rate, 0.05 mm/s (left) and 1 mm/s (right)

Examples of failed cellulose pressboard specimens exhibiting the slant shear type of failure

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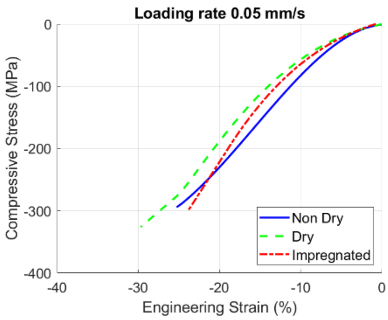
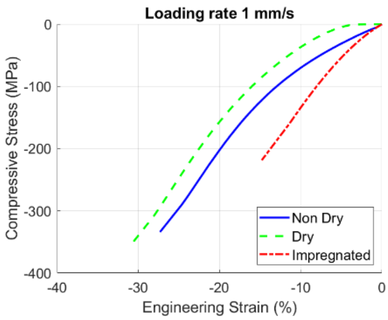
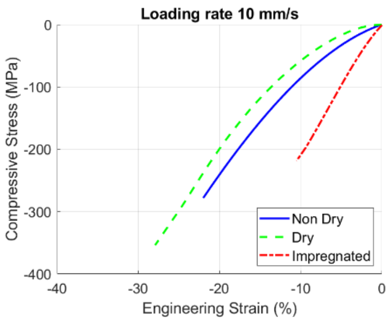
Experimental results

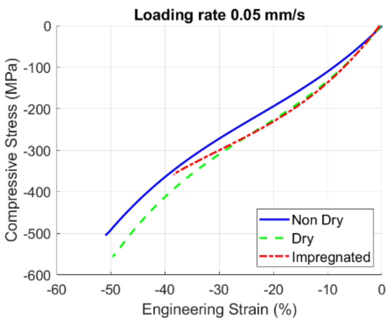
Tests on cellulose pressboard

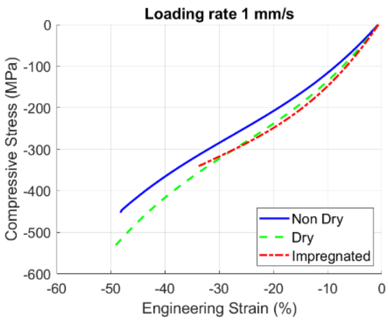


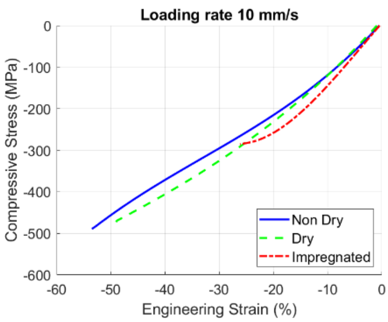




Tests on aramid pressboard







The graphs presented above show the average compressive stress-strain curves for non-dried, dry, and impregnated cellulose and aramid pressboards as functions of loading-rate (respectively 0.05 mm/s, 1 mm/s, and 10 mm/s). Each curve is the average of the number of the performed tests.

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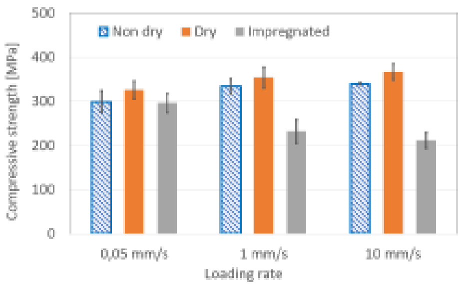
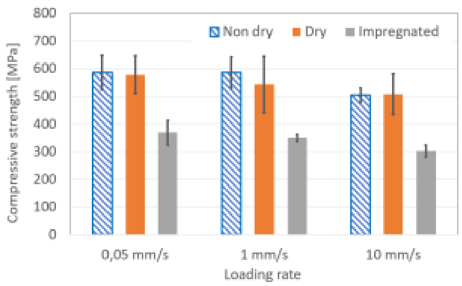
Experimental results

Strength of cellulose pressboard



Strength of aramid pressboard



The above diagrams show the strength for the tested material in the Non-dry, Dry and Impregnated conditions. It is worthwhile to point out that the average compressive strengths are calculated as the mean value of the maximum stress reached on each test piece.

Discussion

- The strength and stiffness of unimpregnated non-dried and dry pressboards (both cellulose-based and aramid-based) are not significantly affected by the loading rate.
- Loading rates become relevant for impregnated cellulose pressboard. Impregnation causes a stiffening of the cellulose pressboard at higher loading rates, probably due the incompressibility of the oil trapped in the pores of pressboard.
- Loading rate affects strength and stiffness in a less pronounced way in aramid-based pressboard. No major stiffening effect of impregnation was noticed on the aramid pressboard.
- The strength of both impregnated pressboard types is lower compared to non-dry and dry materials of each type respectively.

Conclusion

It can be pointed out that the compressive strength values obtained in the present study indicate a compressive strength far above the recommended design limits described in the standard on short circuit withstand of power transformers (IEC 60076-5). However, there are also other factors affecting the mechanical resistance of a transformer winding. For instance, in transformers, the force acting on the pressboard spacers might not be a pure compressive force due to shape of the conductor and winding type.

Further analyses are needed to investigate the above-described geometric factors, the effect of size of the test piece, the effect of macro deviations from the ideal cuboid dimension of the samples respectively the sample stack, the effect of porosity and oil viscosity, aging, and temperature.