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# The strength- and dimensional changes of wood based composites along the sorption isotherm

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# 1 Inroduction

Wood based composites are used more and more in construction and cabinet making. They are hygroscopic as all lignocelluloses. The increase of moisture content effects a reduction of bending strength and modulus of elasticity (MOE). The effect of the climate changes of industrial produced three layer urea-formaldehyde particleboards (UF) and middle density fibreboards (MDF) on their bending strength, MOE and thickness swelling were determined in this study. The water vapour sorption measurements and the sorption analysis were carried out to clear up the effect of sorbent/sorbate interaction on material properties investigated in this study. All these properties are very important for estimating the load carrying capacity and dimensional stability of these products under different climate conditions.

Studies on moisture sorption properties of particleboards have been carried out in the past by GRESSEL (1968), SCHNEIDER (1973) and SELL (1978). The equilibrium moisture content measurements of MDF have been investigated by NIEMZ and POBLETE (1995). NIEMZ and POBLETE (1996) described the swelling and shrinking behaviour of particleboards and MDF. The strength properties of particleboards and MDF were determined by NIEMZ (1992) and NIEMZ, DIENER AND POEHLER (1997). In none of the studies mentioned above conclusions about the sorbent/sorbate interaction have been made.

# 2 Materials

Materials used in the present study included industrial three layer urea-formaldehyde particleboards (UF-boards) from two manufacturers (A and B) and commercially made MDF. The specimens used (30 per board type) were cut to 300 mm in length, 50 mm in width and 16 mm in thickness.

# 3 Methods

Sorption tests were carried out at relative humidity (RH) of 0, 11, 44, 65, 75 and 93% and temperature of 20 °C. The temperature and relative humidity were kept constant to ±1 °C and ±1% respectively. The specimens (30 per board type) were placed in a special conditioning container and the relative humidity was activated by saturated salt solutions. Climate room according to DIN 50 014 controlled the temperature. The air circulation inside of the container was maintained by ventilator, which was switched on and out in an interval of 15 minutes to avoid temperature rises. The relative humidity was measured by electrolytic resistance sensor and the temperature by NTC-resistance. The specimens were exposed to the ambient relative humidity till the mass remains constant for 24 hours (weight difference <0.1%). The equilibrium moisture content of each relative humidity step was related to the oven dry condition.

The bending strength and MOE (three point test) was determined according to the EN 310 (1993).

# 4 Results and Diskussion

## 4.1 Testing of the elastomechanical properties

The strength properties of the UFA-, UFB- and MDF-boards along the sorption isotherm are documented in table 4-1, 4-2 and 4-3. Figure 4-1 and 4-2 shows the dependence of bending strength and MOE on moisture content of the test pieces.

**Tabelle 4-1 The dependence of strength properties of UFA-boards on ambient relative humidity**

| RH % | n | $\sigma$ bB N/mm$^2$ | s N/mm$^2$ | v % | MEOb N/mm$^2$ | s N/mm$^2$ | v % | $\sigma$ P N/mm$^2$ | s N/mm$^2$ | v % | $F_{MAX}$ N | s N | v N/s | $v_\beta$ N/s | $u_\Phi$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 30 | 10.72 | 0.87 | 8.12 | 2242 | 150 | 6.69 | 6.19 | 0.45 | 7.28 | 362 | 29 | 8.12 | 9.8 | 0 |
| 11 | 30 | 11.82 | 1.46 | 12.39 | 2311 | 212 | 9.16 | 6.21 | 1.05 | 16.84 | 406 | 50 | 12.37 | 10.4 | 4.25 |
| 44 | 30 | 13.03 | 1.83 | 14.07 | 2372 | 295 | 12.43 | 6.49 | 1.11 | 17.16 | 460 | 67 | 14.66 | 11.0 | 7.51 |
| 55 | 30 | 13.02 | 2.02 | 15.50 | 2291 | 272 | 11.88 | 5.60 | 0.82 | 15.04 | 461 | 72 | 15.54 | 10.2 | 10.03 |
| 75 | 30 | 12.52 | 1.76 | 14.04 | 2192 | 244 | 11.15 | 5.51 | 0.70 | 12.71 | 460 | 65 | 14.22 | 7.7 | 11.76 |
| 93 | 30 | 8.22 | 1.10 | 13.41 | 1386 | 160 | 11.56 | 3.37 | 0.38 | 11.18 | 332 | 45 | 13.65 | 5.2 | 16.78 |

**Tabelle 4-2 The dependence of strength properties of UFB-boards on ambient relative humidity**

| RH % | n | $\sigma$ bB N/mm$^2$ | s N/mm$^2$ | v % | MEOb N/mm$^2$ | s N/mm$^2$ | v % | $\sigma$ P N/mm$^2$ | s N/mm$^2$ | v % | $F_{MAX}$ N | s N | v N/s | $v_\beta$ N/s | $u_\Phi$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 30 | 9.30 | 1.28 | 13.77 | 1798 | 168 | 9.33 | 5.47 | 0.43 | 7.90 | 314 | 44 | 13.85 | 8.1 | 0 |
| 11 | 30 | 11.66 | 1.22 | 10.78 | 2031 | 85 | 4.18 | 5.18 | 0.39 | 7.43 | 404 | 44 | 10.78 | 9.0 | 4.22 |
| 44 | 30 | 11.50 | 1.11 | 9.61 | 1901 | 99 | 5.21 | 5.12 | 0.33 | 6.52 | 410 | 40 | 9.70 | 8.7 | 7.52 |
| 55 | 30 | 12.04 | 1.25 | 10.35 | 1976 | 133 | 6.73 | 5.19 | 0.36 | 7.02 | 430 | 44 | 10.35 | 9.0 | 10.15 |
| 75 | 30 | 10.52 | 1.27 | 12.11 | 1689 | 124 | 7.34 | 4.53 | 0.26 | 5.72 | 390 | 46 | 11.88 | 5.9 | 1201 |
| 93 | 30 | 7.02 | 0.68 | 9.67 | 1037 | 70 | 6.71 | 2.62 | 0.13 | 4.85 | 297 | 29 | 9.63 | 4.1 | 17.57 |

**Tabelle 4-3 The dependence of strength properties of MDF-boards on ambient relative humidity**

| RH % | n | σ bB $N/mm^2$ | s $N/mm^2$ | v % | MEOb $N/mm^2$ | s $N/mm^2$ | v % | σ P $N/mm^2$ | s $N/mm^2$ | v % | $F_{MAX}$ N | s N | v N/s | $v_\beta$ N/s | $u_\Phi$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 30 | 34.17 | 1.46 | 4.26 | 3309 | 85.63 | 2.59 | 12.73 | 5.56 | 43.67 | 1126 | 48 | 4.24 | 21.2 | 0 |
| 11 | 30 | 40.09 | 2.15 | 5.35 | 3886 | 131.16 | 3.37 | 18.20 | 3.98 | 21.86 | 1371 | 73 | 5.34 | 25.4 | 4.38 |
| 44 | 30 | 39.46 | 1.32 | 3.35 | 3699 | 71.50 | 1.93 | 17.39 | 2.52 | 14.50 | 1397 | 47 | 3.35 | 23.7 | 7.61 |
| 55 | 30 | 39.35 | 0.96 | 2.43 | 3669 | 31.30 | 0.85 | 12.64 | 0.80 | 3.74 | 1396 | 34 | 2.44 | 24.0 | 10.03 |
| 75 | 30 | 34.72 | 1.25 | 3.59 | 3220 | 164.77 | 5.12 | 12.30 | 3.61 | 28.53 | 1266 | 45 | 3.52 | 17.6 | 11.66 |
| 93 | 30 | 21.10 | 0.83 | 3.95 | 1878 | 62.70 | 3.34 | 10.04 | 0.06 | 0.64 | 854 | 34 | 4.01 | 9.2 | 16.24 |

Legend: n … number of specimens

RH .. relative humidity in %

σ bB .. bending strength in $N/mm^2$

MEOb ...bending MOE in $N/mm^2$

σ P … proportionality limit in $N/mm^2$

$F_{MAX}$... maximum force in N

$v_b$ ..... load velocity in N/s

s ...... standard deviation

v ..... variation coefficient in %

$u_\Phi$ ..... equilibrium moisture content of the sorbent in %

From table 4-1, 4-2 and 4-3 results a reduction of the bending strength and MOE in the range of capillary condensation. All tested boards shows for bending strength and MOE the same characteristic shape of the RH-dependence plot (Fig. 4-1 and 4-2):

- An property increase in the chemisorptions range,
- Practically constant property values in the physisorptions range
- And a strong property reduction in the range of capillary condensation.

The relatively low property value at RH 0% refer to weakening of the material due to humidification and subsequent oven drying (perhaps because of a hydrolysis of polyoses). In the whole hygroscopic range there is no difference in strength properties between UFA- and UFB-boards. As expected the bending strength and MOE of the MDF-boards was higher than these one of UF-boards, not only because of differences in the bulk specific gravity (MDF 0.78 $g/cm^3$, UFA 0.70 $g/cm^3$ and UFB 0.68 $g/cm^3$), but also in regard to the fineness ratio of the fibres. The higher bending strength of the MDF compare to these of the particleboard is well known (NIEMZ, 1993; DEPPE and ERNST, 1996).

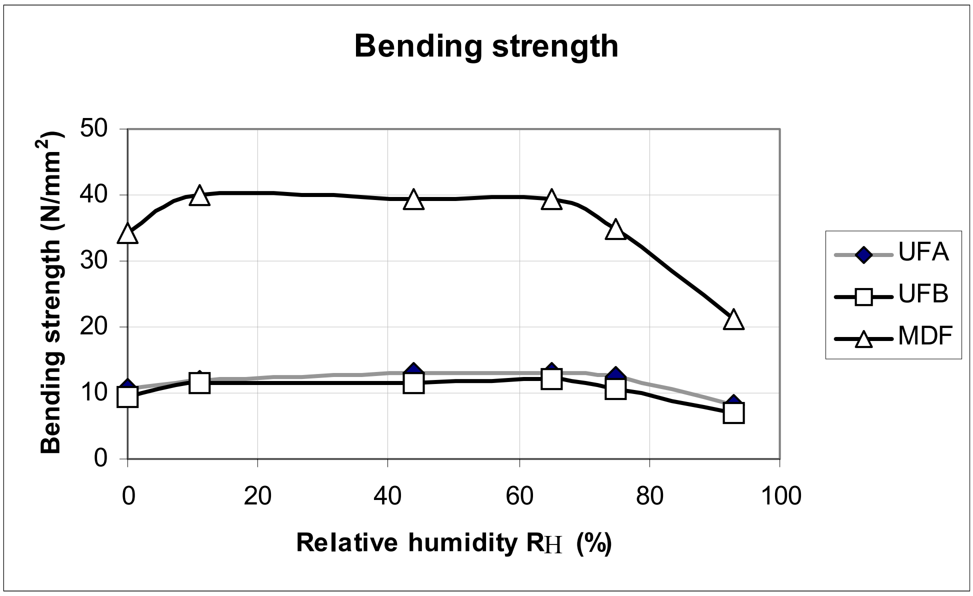


**Figure 4-1 The dependence of bending strength on relative humidity**

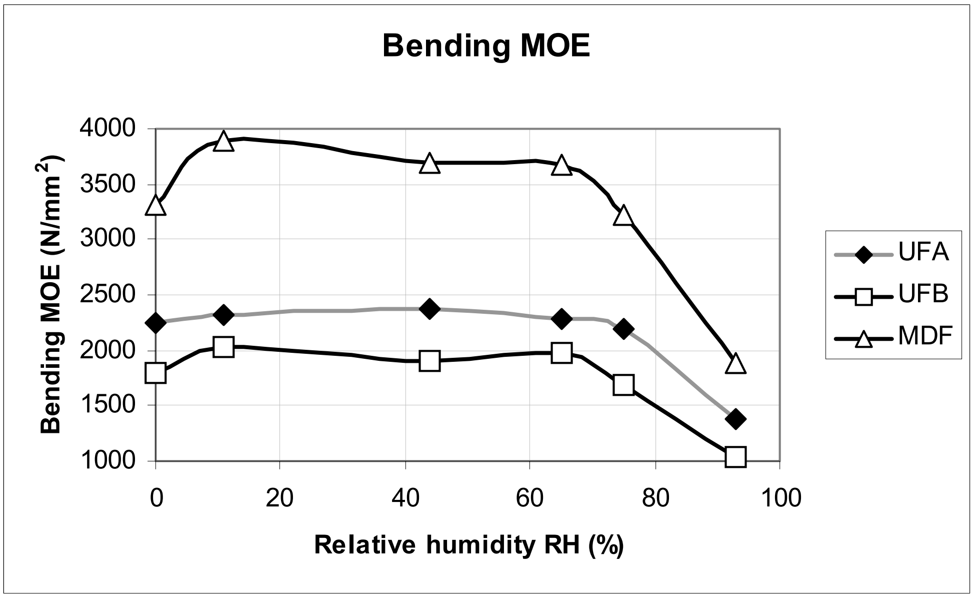


**Figure 4-2 The dependence of MOE on relative humidity**

The small strength differences between UFA- and UFB-boards are due to differences in bulk specific gravity and structure (particle length).
If the proportionality limit along the sorption isotherm will be taken in consideration (Figure 4-3), so it will be evident that the increase in embedment of water molecules causes an increase in plasticity of the material. MDF-boards were plastic already at RH 50% the particleboards at RH 75%.

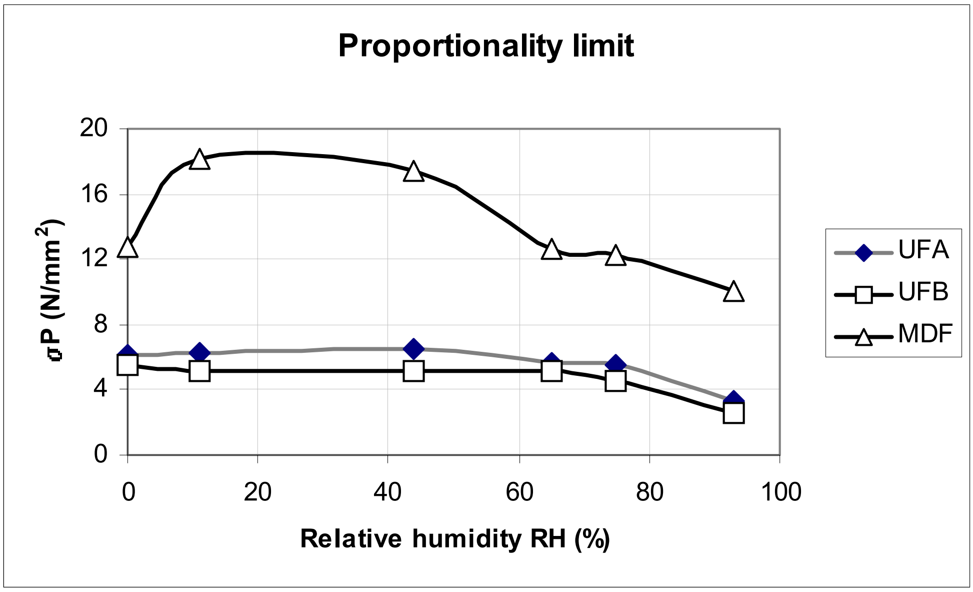


**Figure 4-3 The dependence of proportionality limit on relative humidity**

## 4.2 Sorption properties

The Hailwood-Horrobin sorption model (1964) was used in this study to clear the effect of sorbent / sorbate interaction on the material properties. This sorption model is based on the assumption that the water adsorbed by the lignocelluloses exists as a simple solution and as a lignocelluloses hydrate. It will be further assumed that the adsorbed layer, which consists of a non hydrated and hydrated lignocelluloses and free liquid water builds an ideal solid solution. In addition to the determination of monomolecular- ($U_m$) and polymolekular- ($U_P$) water vapour sorption at the fibre saturation point the Hailwood –Horrobin model allows estimating following variables of state:

- Inaccessibility of the sorptive active sites of the sorbent to the sorbate ($Z$),
- The hypothetical molecular weight of the sorbent ($M_P$),
- Specific surface area ($A$)
- And the fibre saturation point ($U_{FS}$).

All these variables were determined with the use of computer program (POPPER, 1982) and are shown in table 4-4.

**Tabelle 4-4 Charakterisation of test material useing of Hailwood-Horrobin sorption model**

| Material | *A* $m^2/g$ | *Z* % | *Mp* | *Um* % | *Up* % | $U_{FS}$ % |
|---|---|---|---|---|---|---|
| UFB-the upper variation limit | 184 | 50.93 | 337 | 5.20 | 16.36 | 21.56 |
| UFB-the mean value | 182 | 51.42 | 333 | 5.15 | 16.19 | 21.34 |
| UFB- the under variation limit | 180 | 51.94 | 330 | 5.09 | 16.02 | 21.11 |
| UFA-the upper variation limit | 187 | 5017 | 332 | 5.28 | 14.97 | 20.25 |
| UFA-the mean value | 185 | 50.72 | 329 | 5.22 | 14.80 | 20.02 |
| UFA- the under variation limit | 183 | 51.25 | 325 | 5.16 | 14.64 | 19.80 |
| MDF-the upper variation limit | 193 | 48.67 | 328 | 5.44 | 13.87 | 19.31 |
| MDF-the mean value | 189 | 49.66 | 322 | 5.34 | 13.84 | 19.18 |
| MDF-the under variation limit | 186 | 50.68 | 316 | 5.23 | 13.83 | 19.06 |

Legend:

UFA urea formaldehyde particleboards (manufacturer A),

UFB urea formaldehyde particleboards (manufacturer B),

MDF middle density fibreboards (MDF),

*A* specific surface of the sorbent ( $m^2/g$),

*Z* inaccessibility of the sorbent to the sorbate molecules (%),

*Mp* hypothetical molecular weight of the sorbent,

*Um* monomolecular water content at fibre saturation point (%),

*Up* polymolecular water content at fibre saturation point (%),

$U_{FS}$ water content at fibre saturation point (%).

The following figures 4-4, 4-5 and 4-6 are documenting an extraordinary good agreement of measuring ($U_{mes}$) and analytically obtained values ($U_m$, $U_P$ and $U_{tot}$) by Hailwood-Horrobin sorption model.

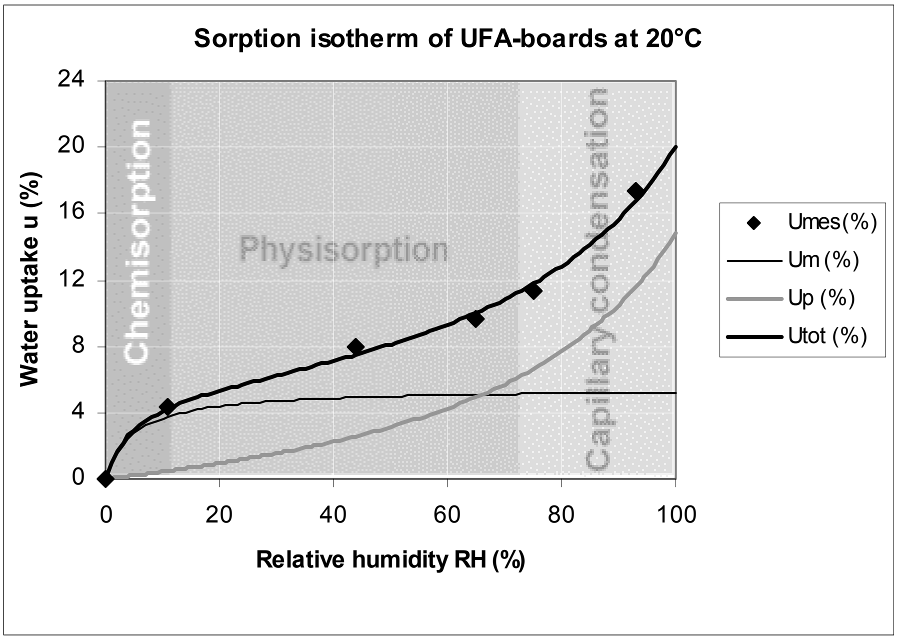


**Figure 4-4 Sorption isotherm of UFA-boards at 20°C**

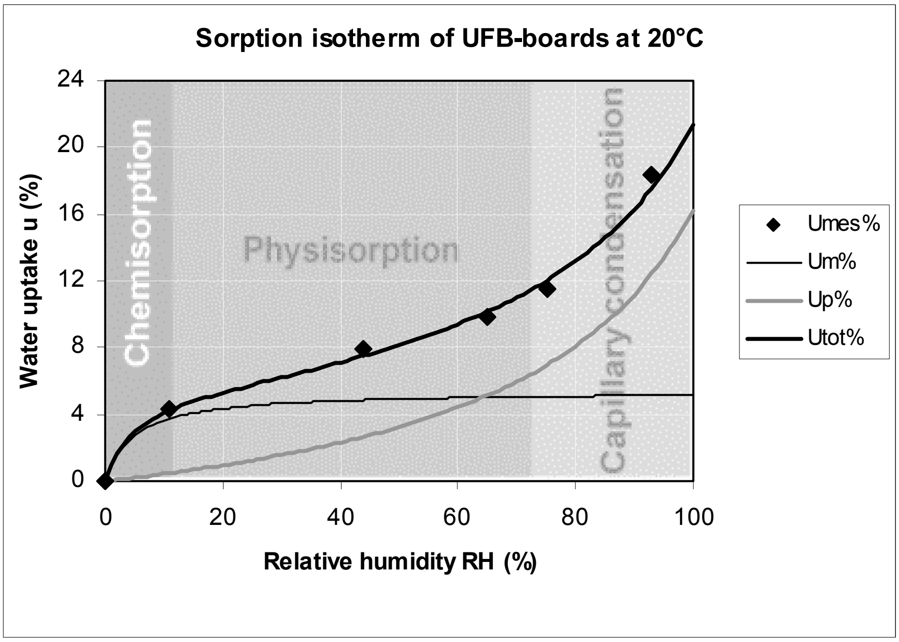


**Figure 4-5 Sorption isotherm of UFB-boards at 20°C**

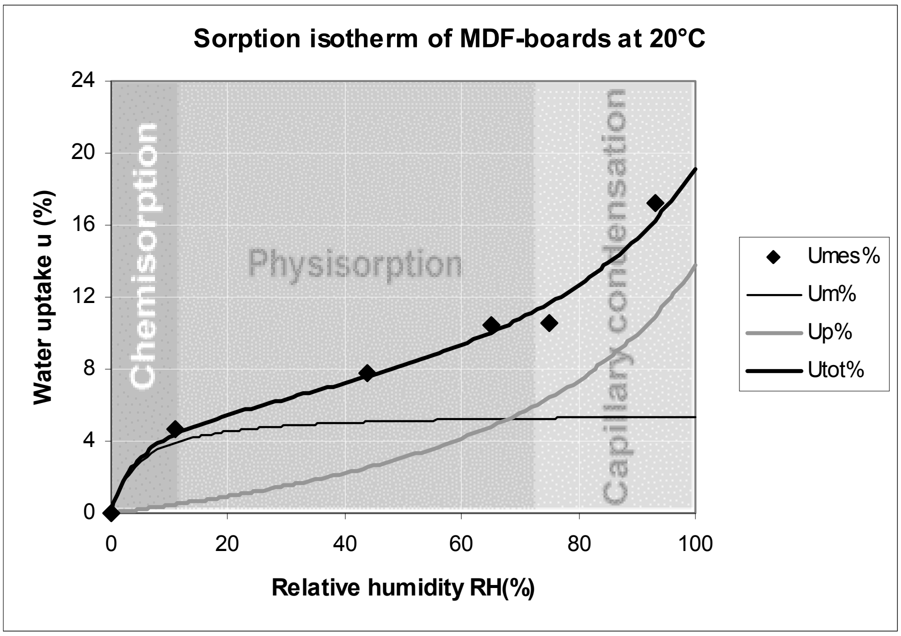


**Figure 4-6 Sorption isotherm of MDF-boards at 20°C**

Each point in these plots refers to the mean value of 30 measurements.

There is no significant difference in monomolecular bound water between UFA- and UFB-boards. In contrary the water is stronger adsorbed by MDF than by UFA- and UFB-boards. This is probably due to the hydrothermal treatment of the particles in the technological process and subsequent to hydrolysis of rather hygroscopic polyoses, which are washed out of the board.

In another way behaves the boards by the polymolecular sorption. The water is strongest adsorbed by UFB-, less by UFB- and more less by MDF-boards. The sorption model used in this study make no difference between polymolecular sorption and capillary condensation but the plotted curves differ practically only in the higher hygroscopic range where the capillary condensation take place. The low water uptake of the MDF-boards in this water-vapour pressure range is due to the bulking effect. Through this effect the internal structure of the material is cloaked, so that the water is prevent to be adsorbed. The fibre saturation point increases from MDF-, trough UFA- to UFB-boards. The sorbate inaccessibility (*Z*) of the boards is based on the assumption, that there are three active sorption sites in a glucose unit and each of these sites can absorb only one sorbate molecule. There is a linear dependence between sorption capacity of the monomolecular bound water ($U_m$) and the sorbate inaccessibility of the sorbent (*Z*). By extrapolation of the sorbate inaccessibility to 0% results a water uptake of 10.67%. Consequently one gram molecule of the glucose anhydride unit bounds 0.96 gram molecule water. This leads very approximately to glucose monohydrate ($C_6H_{10}O_5.H_2O$).

It is well known that the risk of a fungal attack by lignocelluloses is very high if the water content reach 20% at temperature about 20°C. All specimens used in this study were more or less attacked by fungi at the climate condition of 93% RH and temperature of 20°C.

## 4.3 Thickness swelling

The dependency of the thickness swelling ($\alpha$) of the attempt samples on the climate conditions (*RH%*) was determined. The thickness swelling was carried out with the help of a gauge (measuring accuracy 0.01mm). As a base factor for the calculation were oven dry conditions of the material.
As follows from figure 4-7, the curves of the dependence thickness swelling and relative humidity have almost the same sigmoid shape as sorption isotherms. Each point of the curve corresponds to an average value of 30 measurements.

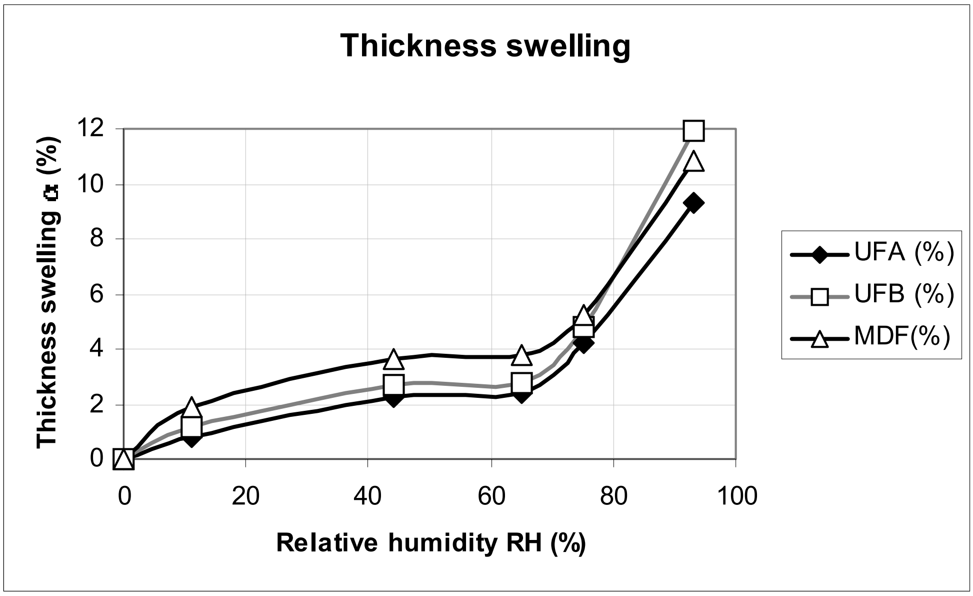


**Figure 4-7 The dependency of thickness swelling on the climate conditions**

Remarkable is the steep increase of thickness swelling in the range of capillary condensation. The UFB- as well as the MDF-boards shows in this water vapour range a significantly stronger thickness swelling compared with the UFA-boards. The difference in thickness swelling of UFA- and UFB-boards is limited practically only to this vapour pressure range. This is probably due to a more weak structure of the UFB-boards. In this water-vapour pressure range the void structure and/or the wetting angle are decisive for the humidity deformation. The stronger thickness swelling of the MDF-boards in contrary to the UFB-boards attribute to the storage of the water molecules in the entire hygroscopic range. The internal structure of the material becomes weaker by the storage of water molecules, which leads to reduction of the bending strength and bending MOE within the same vapour pressure range (see figure 4-1 and 2). There is a higher affinity to the water for the sorption active sites of the MDF-boards within the range of chemi- and physisorption and therefore also a stronger thickness swelling. This is conforming to the higher sorption capacity of the monomolecular bound water of the MDF-boards. It is to be notice that the thickness swelling discussed here is not to be compare to the thickness swelling defined in the DIN 68 763, it corresponds however much better to the conditions practically used and is therefore also more meaningful.

# 5 Conclusions

Due to the investigation carried out at industrially manufactured urea formaldehyde particleboards as well as at middle density fibreboards along the sorption isotherm the following conclusions can be drawn:

- In the entire hygroscopic range the bending strength and the bending MOE of the MDF-boards are higher, than those of the urea formaldehyde particle-boards.
- The bending strength and MOE of the specimens used in this study remain up to 65% RH, with exception of the oven dry samples, practically constant.
- Related to the normal climate the particleboards shows at 93% RH a bending strength reduction of about 39% and the MDF-boards a reduction of around 46%.
- Related to the normal climate the particleboards shows at 93% RH a MOE reduction of about 44% and the MDF-boards a reduction of around 49%.
- According to the proportionality limit the MDF becomes plastic at relative humidity around 50% and the particleboards at about 75% RH.

The sorption analysis according to Hailwood-Horrobin theory permits to meet following conclusions:

- The specific surface of the MDF-boards is larger than the one of particle-boards.
- A glucose monohydrate is estimated from the inaccessibility of the sorbent.
- The sorption properties of the particleboards and MDF differ mainly in the capillary condensation range.
- The particleboards points in relation to the MDF-boards a lower affinity to water in the capillary condensation range.
- The fibre saturation point of the particleboards exceeds that of the MDF, which is due to the difference in the blockage of the internal structure of the boards.
- The thickness swelling of the MDF is larger in the entire hygroscopic range than that of the particleboards.
- All boards shows a stronger thickness swelling in the capillary condensation range.
- It is to be assumed that the resistance against weather of all boards within the capillary condensation range is strongly impaired.
- The fungal attack becomes above 75% relative humidity by all boards favours.

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