On the Physical and Mechanical Properties of Gas Phase Ammonia Treated Wood

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ABSTRACT

Gaseous ammonia treatment of solid wood is commonly applied in order to gain significant colour change. Ammonia treatment is accompanied by various chemical changes leading to variation in physical and mechanical properties. This article gives an overview on the most important effects caused by gaseous ammonia treatment. It is shown that ammoniation leads to increased equilibrium moisture content, has no effect on density, a strong effect on swelling and shrinkage and little or negligible effects on mechanical properties. In general an increase of anisotropy of the modified wood was observed. The results show that ammoniation is a modification method which leads for many wood species to strong colour changes and decorative effects without significant loss of further desired properties. Some of the obtained effects can even improve performance of engineered products composed of ammoniated wood.

INTRODUCTION

Ammonia treatment is industrially applied for interior applications of solid wood such as floorings and furniture. The intensive colour change due to this modification was actually shown in Weigl *et al.* (2007, 2009a) for several wood species. Figure 1 shows this effect for oak wood, being the most commonly ammoniated species.

Figure 1: Colour change of oak wood due to ammoniation (left: reference, right: ammoniated)

This colour change is due to various possible chemical reactions of functional units of wood extractives (especially tannins) and structural polymers with gaseous ammonia. The intensive colour change due to the treatment also increases colour stability against UV-radiation (Weigl *et al.* 2007). Beside the desired colour change, even altered physical and mechanical properties appear finding their reason in chemically and even structural rearrangements.

This study deals with altered physical and mechanical wood properties due to gaseous ammonia treatment. Special attention is paid on equilibrium moisture content at standard climate (EMC), density, swelling and shrinkage in and from water, as well as bending- impact bending- compression and hardness properties. Parts of the results presented in this work were actually presented in earlier publications by Weigl *et al.* (2007)

MATERIAL AND METHODS

Most of the results presented here refer to oak, spruce and pine, whereas in specific cases even further species were selected for analyses. All analyses were carried out on flawless paired samples. This means that one sample was modified whereas a second one was used as a reference. The reference specimen always originated from an accurately longitudinal arranged position next to the specimen selected for ammoniation.

Ammoniation of selected samples was carried out within a closed barrel. Samples were stored in an elevated position above the open surface of 30% aqueous ammonia solution. Relation of introduced wood mass and ammonia equalled approximately a tenfold stochiometric overspill of ammonia according to Besold and Fengel (1983). In order to guarantee complete modification throughout the whole specimen, minimum duration time was at least two weeks or longer.

Physical and mechanical tests were carried out according to standard (DIN) procedures.

RESULTS AND DISCUSSIONS

Results for several tests on oak, spruce, pine and a pool of further species (for details see Weigl *et al.* 2007, 2009a, and b and Weigl and Müller 2009) are presented in Table 1. Given values represent the percentile change of the corresponding physical or mechanical property due to the treatment. Just in the case of colour change (ΔE^*_{ab}) absolute values are given.

Alteration of wood properties due to gaseous ammoniation is specific to species. Oak (*Quercus sp.*), Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) partly follow the common trend and partly even show the opposite. However, most commonly a general trend can be seen.

The over all colour change (ΔE^*_{ab}) reaches values up to 42, which corresponds to very distinct colour change. Colour changes are mainly based on intensive darkening. While oak is the most commonly ammoniated species, other species such as Black locust, prune, Douglas fir, movingue, mulberry, cherry and pine show even stronger colour changes due to ammoniation.

Table 1: Percentile changes (Δ) of physical and mechanical properties due to ammoniation presented for oak, spruce and pine as well as for wood in general (based on 19 to 38 species). Just ΔE^*_{ab} is given in original unites. Only significant trends are given (n.s. = non significant).

	Oak	**Spruce**	**Pine**	**Wood in general**
ΔE^*_{ab} [unites]	24	19	27	8 – 42
Δ EMC [%]	+4	-1	+2	-8 – +35
Δ density [%]	n.s.	n.s.	n.s.	n.s.
Δ swelling $_{rad}$ [%]	n.s.	+33		mostly negative
Δ swelling $_{tang}$ [%]	+25	-9		mostly positive
Δ shrinkage $_{rad}$ [%]	+30	+40		mostly negative
Δ shrinkage $_{tang}$ [%]	+13	-6		mostly positive
Δ swelling anisotropy [%]	n.s.	-20		mostly positive
Δ swelling anisotropy [%]	n.s.	n.s.		mostly positive
Δ MOE $_{bend}$ [%]	-8	n.s.	n.s.	
Δ MOR $_{bend}$ [%]	-16	-5	n.s.	
Δ strength $_{impact\ bend}$ [%]	n.s.	n.s.	-8	
Δ MOE $_{comp\ rad}$ [%]	-12	n.s.	n.s.	
Δ MOE $_{comp\ tang}$ [%]	n.s.	n.s.	n.s.	
Δ MOR $_{comp\ rad}$ [%]	-6	n.s.	n.s.	
Δ MOR $_{comp\ tang}$ [%]	-6	n.s.	n.s.	
Δ MOE $_{comp}$ anisotropy [%]	+13	n.s.	+20	
Δ MOR $_{comp}$ anisotropy [%]	n.s.	n.s.	n.s.	
Δ hardness $_{Brinell\ rad}$ [%]	n.s.	n.s.	n.s.	
Δ hardness $_{Brinell\ tang}$ [%]	n.s.	n.s.	-9	
Δ hardness $_{Brinell}$ anisotropy [%]	n.s.	n.s.	-12	

In general EMC at standard climate increases due to ammoniation and varies less between species compared to references. The increased moisture content should be considered while processing.

Wood density is not affected by the treatment. This is a mayor difference to earlier applications of ammonia treated wood from the 1960's and 70's where wood was plasticized and compressed thereafter. In the opposite, thermally treated wood which is partly used for similar applications such as ammoniated wood often shows a significant reduction of wood density leading to reduced mechanical properties. Thermally treated wood is further often characterized by a typically odour which delimits indoor application. In comparison, the intense smell of ammonium after the treatment presented here is temporary and fades away during storage. Hence, no undesired loss in wood density and no bad smell are the major advantages of ammoniated wood compared to thermally treated wood.

Swelling and shrinkage mostly decrease in the radial direction whereas they increase in the tangential one after ammonium treatment. Hence, anisotropy of swelling and shrinkage most commonly increases. Partly a loss of mechanical properties in the range of 5 to 16% compared to none treated wood can be seen. However, in several cases, even no significant reduction of mechanical properties can be found. In general, mechanical properties of spruce are less affected by the treatment compared to oak and pine. A certain alteration of anisotropic mechanical properties can also be found. For example, pine shows an increase of MOE in compression perpendicular to grain anisotropy of 20%, and a decrease of Brinell hardness anisotropy of 12%.

Although reduction of mechanical and some alterations of further physical properties of ammoniated wood can be found, observed changes are most commonly technologically irrelevant. Ammoniated wood can be used and processed similar to native wood. Further more, altered anisotropic properties such as in the case of swelling and shrinkage can even improve products performance if anatomical orientations of lamella are considered during assembly.

CONCLUSIONS

It is concluded that ammoniation is an advanced wood modification method as it highly increases woods decorative value while undesired secondary effects are mostly technologically irrelevant. Ammoniation therefore can definitely compete with other modification methods or imported high value wood species being selected for similar applications.

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