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Effect of surface conditions related to machining and air exposure on wettability of different Mediterranean wood species

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ABSTRACT

Wettability of 6 different wood species commonly used in the woodworking industry in the Mediterranean region was evaluated in this study. The species were Norway spruce (*Picea abies* Karst.), umbrella pine (*Pinus pinea* L.), oak (*Quercus* sp.p.), chestnut (*Castanea sativa* Mill.) beech (*Fagus sylvatica* L.) and poplar (*Populus* sp.p.), and their surfaces were machined according to 3 different processes: planing, sanding and disc-sawing. Measurement of dynamic contact angle and extractives (evaluated by means of GC–MS analysis) were carried out on freshly cut and 24 h air exposed surfaces, in order to also evaluate the effect of ageing on wettability. The parameterisation of the contact angle vs. time curves allowed for the systematic statistical elaboration of data, in order to find the relationships existing between the four parameters characterising the dynamic curves and the considered factors (species, machining, ageing). The evaluations evidenced a different influence of these factors on the chosen parameters and hence some of them could be used to reliably assess both wood wettability and the effects of the factors here considered. In general softwoods showed higher contact angles than hardwoods due to the different anatomy and to the presence of resins and terpenes in addition to fatty acids and phenolic compounds, also present in hardwoods. After 24 h air exposure a shifting upwards of dynamic contact angle curves was observed but, despite the variation in surface composition, this shifting was imputable to other inactivation factors. Also machining appreciably influenced wettability, and the sanded surfaces were the most wettable as compared to both the planed and the disc-sawn ones. On the other hand, these observed differences diminished after ageing due to the levelling effect of inactivation that overcame surface inhomogeneities.

1. Introduction

In the market of paints and varnishes the *Decopaint* regulation, issued by the European Parliament in 2004 and valid since 2007 [1], which amended Directive 1999/13/EC [2], requires the progressive replacement of solvent-based lacquers by waterborne systems, which have very limited emission of Volatile Organic Compounds (VOCs). However, wettability of these products on wood surfaces still represents a problem to be overcome, mainly if compared to that one of solvent-carried products. As a consequence, the analysis of the various factors that control wettability is a very important issue in order to develop new and more specific products.

The wood substrate is constituted by cellulose, lignin, hemicelluloses and extractives; hence the combination of the chemical properties of these components characterises the surface.

Cellulose and hemicelluloses correspond to the hydrophilic component while the hydrophobic component is represented by lignin and the majority of extractives. Considering that the sum of the hydrophilic components is approximately 70% of its anhydrous weight, wood can be considered to have a high affinity to water. Several attempts of correlating wetting parameters with coating and adhesion have been made previously [3–6]. Most of studies on wettability have been carried out on softwoods from North America, mainly pine and fir [7], or tropical species [8,9]. On the contrary, very few studies were carried out on Mediterranean species [9–11], and even no studies at all were found on sweet chestnut (*Castanea sativa*) and umbrella pine (*Pinus pinea*).

In addition to wood species, also the surface morphology, more specifically roughness and anatomical aspects, plays an important role in the surface–liquid interaction. While in laboratory tests the microtome can be used to obtain a wood surface that can be considered as "ideal" [12], in the case of industrial wood products the influence of cutting tools on the morphology and also the chemistry of the surface have to be considered [3,13–16]. In fact, during machining some undesired side effects can arise. They include: (a) breaking and deformation of cells with variation in roughness and porosity; (b) instantaneous increase in temperature for the friction of instruments; (c) occlusion of cell lumens by wood particles.

Some chemical effects, imputable to the presence of extractives, have also been considered to appreciably affect wood wettability. Extractives are a few percent of wood mass, although they vary

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greatly in quantity and composition among wood species and within them [17]. It has been reported that the presence of extractives decreases the wettability of wood surface [18–20] and also reduces bond quality [21,22]. Most importantly, extractives are considered the principal responsible for the inactivation of wood surface. In fact, besides the environmental pollution (such as dust), wood surface is also subject to a sort of "self-contamination" and inactivation [19,23–25]. Back [26] reviewed five inactivation mechanisms, occurring within a few hours or days. Among them, the migration and the concentration of low molecular weight substances at the external surface appear particularly important for wettability, together with the chemical modification of these compounds upon oxidation.

When a liquid wets a porous material three effects can be observed [27]

– the formation of a contact angle between the surface and the drop;
– the spreading of the drop on the support;
– the penetration inside the porous solid if the contact angle is less than 90°.

Those effects are not instantaneous and they make the contact angle change during time. The sessile drop technique is one of the most common ways to evaluate contact angle. Considering the inconveniences evidenced before, several methods of contact angle evaluation have been proposed. Shupe et al. [8] measured the angle after 5 s, whereas Maldas and Kamdem [28] used both the initial contact angle (i.e., the intercept of the regression line of contact angle values over time) and the rate of decrease in the contact angle in the first moments to represent the curves. Liptáková and Kúdela [29] determined the value corresponding to the ideal smooth wood surface on the basis of the contact angle at the beginning of the wetting process and of the equilibrium contact angle. Instead, Nussbaum [19] considered the 'constant wetting rate angle' (cwra) as the value reached by the contact angle vs. time curve when the corresponding variation of contact angle ($d\theta/dt$) vs. time reached its plateau.

However, because of the complexity of analysing wettability on wood surfaces, most Authors prefer to refer to the experimentally measured (or 'apparent') instead of 'ideal' contact angle, as normally considered in Young's equations (see for instance [15]). More specifically, an increasing interest in measuring the contact angle as a function of time (dynamic contact angle) can be observed in literature. Liptáková and Kúdela [29] observed three different stages for the droplet shape on a wood surface: an initial stage with a rapid decrease in the apparent contact angle; a second stage where the drop diameter value is constant and the liquid spreads on the irregular surface and fills voids; a final stage where the drop diameter decreases due to liquid gradual penetration into the support. Other researchers tried to describe through a mathematical model the whole curve of contact angle versus time. Boheme and Hora [9] observed that contact angle decreased with the square root of time while Shi and Gardner [30] proposed another model to describe this change basing on the intrinsic relative contact angle decrease rate, defined through the parameter K. This value measured how fast the liquid spread and penetrated into the wood surface at the initial stage. High K corresponded to a contact angle fast decreasing in the first seconds.

All the models proposed so far suffer of two kinds of limits:

(1) Authors usually strove for finding a single parameter able to characterize the wettability of wood surface. This is hard to accomplish because of the strong time-dependence of the contact angle values, mainly when machining effects are also considered;
(2) a systematic statistical analysis has never been carried out so far, according to our knowledge, to study the effects of the considered factors on the parameters obtained from the model.

On the other hand, only a rigorous statistical treatment of data allows to correctly take into account the elevated scattering of data that usually affects this kind of measurements.

Aim of this study was to investigate the effects of selected machining process, namely planing, disc-sawing and sanding, on the wettability of six different wood species among the most commonly used in the wood industry in the Mediterranean basin. Contact angle measurements were carried out to evaluate wettability on surfaces both freshly cut and 24 h air exposed in laboratory conditions. GC analysis of extractives on the planed just-cut and aged surfaces was also carried out to relate their effects to wettability. A parametric model able to quantify the dynamic contact angle curves was proposed. The model allowed analysing the obtained data systematically in a statistical way. Moreover an analysis of variance allowed establishing the influence of the considered factors on the contact angle parameters, and thus having a precise evaluation of which factors most affected wettability.

2. Material and methods

Contact angle measurements were carried out on various wood species and on surfaces subjected to different machining processes. More specifically, six wood species were selected, two softwoods and four hardwoods, within those commonly used in the woodworking industry in the Mediterranean basin. In details, the species were: Norway spruce (*P. abies* Karst.), umbrella pine (*P. pinea* L.), sweet chestnut (*C. sativa* Mill.), oak (*Quercus* sp.p.), beech (*F. sylvatica* L.) and poplar (*Populus* sp.p.).

Samples were taken from boards stored under controlled conditions of temperature and humidity (20 °C/65% RH) and had final dimensions of $60 \times 15 \times 5$ mm^3, cut parallel to the grain direction. The different machined surfaces were compared on the radial surface. For each species, three different machining processes were considered:

– Planing: samples were obtained from a single board planed just before the achievement of the final dimension of the blocks;
– Disc-sawing: samples were obtained starting from blocks with dimensions approximately double respect to the final ones ($60 \times 15 \times 13$ mm^3) and then reduced to size by cutting the radial face with a disc saw blade with 108 teeth and 350 mm diameter;
– Sanding: samples were initially prepared in the same way as for the planed ones. Then, each sample was sanded (grit 500), firstly 10 times perpendicular to the grain and then 10 times parallel to it.

Measurements were carried out on specimens taken from heartwood, taking care to discard those with defects like resin pockets and knots.

2.1. Contact angle measurements

The sessile drop method was adopted and a Rame–Hart 200-00 instrument with an automated dispensing system was used. Drops of 8 μl of deionised water were deposited on the longitudinal–radial surface by an automated dispensing system. The right and left angles of the drop on the surface were collected and the average of the two angles calculated, at intervals of 0.3 s for a total duration of 150 s.