# Surface characteristics of wood pre-impregnated with borates before varnish coating

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**Abstract**

Some surface characteristics of Calabrian pine (*Pinus brutia* Ten) pre-impregnated with borates before varnish coating were studied. Boric acid, borax, and sodium perborate were used as borates. An alkyd-based synthetic varnish and polyurethane varnish were used as coating materials. Before varnish coating, wood specimens were impregnated with aqueous solutions of borates (1%, 3%, and 5%) according to ASTM D1413-76. Then, adhesion, surface hardness, and gloss of wood surface were tested. Results showed that while borate preimpregnation before varnish coating increased surface hardness and gloss of wood surface, it decreased coating adhesion. Higher borate concentrations resulted in lower adhesion, higher surface hardness, and higher gloss of wood surface. Polyurethane varnish coated wood surfaces yielded higher surface hardness and gloss than the synthetic varnish coated wood surfaces.

Wood surfaces exposed outdoors are rapidly degraded because lignin readily absorbs UV light, which leads to radical-induced depolymerization of lignin and cellulose, the major structural constituents of wood (Evans et al. 2002). Changes in the chemical, physical, and optical properties of wood lead to discoloration, loss of gloss, and roughening of surface, which is accompanied by changes in the mechanical properties of the three main components of wood (cellulose, hemicelluloses, and lignin) which also appear to be rapidly oxidized and degraded by UV light (Denes and Young 1999). Many materials have been suggested as suitable coatings for wood surfaces (Yalinkilic et al. 1999a). But, the evaluation techniques leading to these recommendations were inadequate since most materials fail, some relatively quickly, when exposed to accelerated weathering or applied to field test fences (Ashton 1980). Coating alone imparts to wood only superficial protection against some deteriorating agents for a limited time, often less than 2 years (Williams et al. 1996). Therefore, impregnation of wood with an appropriate water repellent or applying a varnish compatible preservative chemical prior to hazardous service conditions has been undertaken to make wood more stable against photochemical degradation, dimensional changes, biological decomposition, and fire (Yalinkilic et al. 1999b, Williams et al. 1996, Wilkinson 1979).

Wood is much more easily degraded by environmental agents, including fire, biological organisms, water, and light, than many man-made materials (Kiguchi and Evans 1998). Although, not generally classified as a wood finish, preservatives protect against weathering (in addition to decay), and a large quantity of preservative-treated wood is exposed outdoors without any additional finish (Feist 1987). Many of the effective poisonous chemicals, however, are also questionable. Increased public concern about the environmental effect of many wood preservatives has rendered a special importance to borates as an environmentally friendly agent. Borates have several advantages when used as a wood preservative including imparting flame retardancy, providing sufficient protection against many forms of wood-destroying organisms, low mammalian toxicity, low volatility, and being generally colorless and odorless (Murphy 1990, Drysdale 1994,

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Hafizoglu et al. 1994, Chen et al. 1997, Yalinkilic et al. 1999b).

## Materials and methods

In this study, before synthetic and polyurethane varnish coating were applied, the wood was impregnated with aqueous borate solutions of boric acid (BA), borax (BX), and sodium perborate (SP). Then, some surface characteristics of wood including surface hardness, adhesion, and gloss were evaluated.

### Preparation of test specimens and chemicals

Wood specimens measuring 10 by 100 by 150 mm (radial by tangential by longitudinal) were prepared from air-dried sapwood of Calabrian pine (*Pinus brutia* Ten). Aqueous solutions of SP, BA, and BX were dissolved in distilled water to concentrations of 1 percent, 3 percent, and 5 percent, respectively. Wood specimens were ovendried at 103° ± 2°C before and after treatment.

### Impregnation method

Wood specimens were impregnated with aqueous solutions of borates according to ASTM D1413-76 (ASTM 1976). Retention of boron was calculated from the equation:

$$\text{Retention (kg/m}^3) = \frac{G \times C}{V} \times 10$$

where:

$G$ = amount of solution absorbed by wood that is calculated by $T_2 - T_1$,
$T_2$ = weight of wood after impregnation,
$T_1$ = weight of wood before impregnation,
$C$ = solution concentration as percentage, and
$V$ = volume of the specimen as $cm^3$.

### Coating

An alkyd-based synthetic varnish and a polyurethane varnish of a two-component type consisting of an aliphatic isocyanate-terminated component and an active hydrogen-bearing monomer, which when blended cures at room temperature with 4 to 5 hours pot life of the blend, were used. The alkyd-based synthetic and polyurethane varnishes were applied over untreated and borate-impregnated wood. To avoid potential interference in the surface characteristics of wood, filler was not used. Instead, varnish was applied as a primer coating for filling the voids and as a topcoat. Sufficient time for coat setting was allowed between successive applications. Specimens remained at ambient conditions for 24 hours before the top coat was applied according to the instructions given by the varnish manufacturer. Surfaces were gently sanded with abrasive paper to obtain a smooth surface prior to applying the topcoat.

### Adhesion test

The adhesion test was conducted according to ASTM D4541 (ASTM 1995a) with a special testing set up (Budakci 2003). The adhesion tester operates using pneumatic (air) pressure. Twenty-mm-diameter dollies were used for the adhesion test. Load was increasingly applied to the surface until the dolly was pulled off.

### Surface hardness test

The surface hardness test was performed according to ASTM D4366-95 (ASTM 1995b) with a measuring device (Erichsen, model 507-M). Wood specimens were placed on the panel table, and a pendulum was placed on the panel surface. Then, the pendulum was deflected through 6° and released; at the same time, a stopwatch was started. The time for the amplitude to decrease from 6° to 3° was measured as König hardness.

### Gloss test

The gloss of wood specimens was determined according to ASTM D523 (1970) with a measuring device (Erichsen, model 299/300). The chosen geometry was an incidence angle of 60°. Results were based on a specular gloss value of 100, which relates to the perfect condition under identical illuminating and viewing conditions of a highly polished, plane, black glass surface.

## Results and discussion

Adhesion of polyurethane and synthetic varnish coating pretreated with borates is given in **Table 1**. Borate pretreatment resulted in a remarkable decrease in the adhesion levels of wood surfaces. Higher concentration levels of borates resulted in lower adhesion levels of wood surfaces. The highest adhesion value obtained was 4.0 MPa and 4.1 MPa for the polyurethane and synthetic varnish coated wood surfaces, respectively. The lowest adhesion value obtained was 2.4 MPa and 2.3 MPa for surfaces pre-impregnated with

*Table 1. — Adhesion values of Calabrian pine pretreated with borates before polyurethane and synthetic varnish coating.*

| Chemicals and varnish[a] | Concentrations | Retention | Mean[b] | SD[c] | Change |
|---|---|---|---|---|---|
| | (%) | (kg/m$^3$) | | | (%) |
| PV + untreated | – | – | 4.0 | 0.4 | – |
| PV + SP | 1 | 4.18 | 3.1 | 0.4 | −22.3 |
| | 3 | 14.5 | 2.9 | 0.4 | −27.3 |
| | 5 | 16.42 | 2.7 | 0.3 | −32.3 |
| PV + BA | 1 | 3.2 | 3.6 | 0.4 | −9.3 |
| | 3 | 11.4 | 3.1 | 0.5 | −23.3 |
| | 5 | 22.9 | 2.5 | 0.4 | −38.4 |
| PV + BX | 1 | 4.3 | 3.3 | 0.4 | −18.1 |
| | 3 | 14.8 | 3.0 | 0.5 | −25.2 |
| | 5 | 23.1 | 2.4 | 0.4 | −38.5 |
| SV + untreated | – | – | 4.1 | 0.3 | – |
| SV + SP | 1 | 4.2 | 3.9 | 0.6 | −4.4 |
| | 3 | 14.5 | 3.1 | 0.4 | −24.6 |
| | 5 | 16.4 | 2.3 | 0.8 | −42.3 |
| SV + BA | 1 | 3.2 | 3.3 | 0.4 | −18.0 |
| | 3 | 11.4 | 2.6 | 0.4 | −36.0 |
| | 5 | 22.9 | 2.6 | 0.8 | −37.3 |
| SV + BX | 1 | 4.3 | 3.5 | 0.5 | −13.3 |
| | 3 | 14.8 | 3.1 | 0.3 | −22.8 |
| | 5 | 23.1 | 2.4 | 0.7 | −41.2 |

[a] SP = sodium perborate; BA = boric acid; BX = borax; PV = polyurethane varnish; and SV = synthetic varnish.
[b] Results reflect observations of five wood specimens.
[c] SD = standard deviation.

5 percent BX and 5 percent SP before polyurethane and synthetic varnish coating, respectively. **Table 2** shows surface hardness of wood surfaces pre-impregnated with borates before polyurethane and synthetic varnish coating. Higher concentration levels of borates resulted in higher surface hardness levels of the wood surface. The highest surface hardness value for the wood surface obtained was 59.4 and 13.2 for surfaces pre-impregnated with 5 percent BX and 5 percent SP before polyurethane and synthetic varnish coating, respectively. Gloss of polyurethane and synthetic varnish coating wood pre-impregnated with borates is given in **Table 3**. Gloss was lowest at 89.1 and 57.8 for polyurethane and synthetic varnish coated wood surfaces, respectively. Borate preimpregnation increased the gloss of the coating. The highest gloss obtained was 97.0 and 74.8 for surfaces pre-impregnated with 5 percent BX before polyurethane and synthetic varnish coating, respectively. A higher concentration level of borates resulted in a higher gloss of the coating.

In this study, borate pre-impregnation decreased the adhesion of the wood surface to some extent. This may be due to the weakening of the treated wood. The polyurethane varnish coated wood surface yielded higher gloss than the synthetic varnish coated wood surface. Borate pre-impregnation before the varnish coating increased the gloss of wood specimens to some extent. This suggests that proper impregnation of wood, which has naturally bright surfaces, and cleaning excess chemical from the surface prior to coating are necessary to improve gloss, as is required for producing a good coating base (Bobalek 1967). Polyurethane varnish coated wood surfaces became harder than synthetic varnish coated wood surfaces. The hardness of alkyd coatings is a function of their formulations and can be improved by additives, as they are compatible with many other resins. Variations in formulations are also possible to obtain with alkyd coatings over a wide range of properties (Kraft et al. 1967, Seymour and Mark 1990, Yalinkilic et al. 1999a).

Transparent film-forming finishes are not generally recommended for exterior use on wood (Williams et al. 1996, Yalinkilic et al. 1999a) because they allow transmission of sunlight, and surface degradation can take place underneath the coatings (Evans et al. 1992, Maclead et al. 1995, Yalinkilic et al. 1999b). To date, the most effective method of preventing the photodegradation of wood involves treatment with aqueous solution of inorganic salts (Kiguchi and Evans 1998). As an inorganic salt, boron compounds are well-known preservative chemicals for timber protection. They are recognized as being inexpensive, easily applicable, biologically active, flame retardant and, more importantly, environmentally safe preservatives and have been used for timber preservation since the early 20th century (Williams 1990, Lloyd 1993, Laks and Manning 1994). Traditionally, boron preservatives have been applied by dipping or spraying concentrated borax/boric acid onto freshly sawn timber. Most wood finishes are not designed for application on wood with a high moisture content, and it may be necessary for manufacturers to formulate coatings specifically designed for these applications (Palmere and Galyon 1991).

*Table 2. — Surface hardness values of Calabrian pine pretreated with borates before polyurethane and synthetic varnish coating.*

| Chemicals and varnish[a] | Concentrations | Retention | Mean[b] | SD[c] | Change |
|---|---|---|---|---|---|
| | (%) | (kg/m$^3$) | | | (%) |
| PV + untreated | – | – | 49.2 | 1.3 | – |
| PV + SP | 1 | 4.2 | 51.4 | 0.5 | +4.5 |
| | 3 | 14.5 | 56.2 | 1.8 | +14.2 |
| | 5 | 16.4 | 58.0 | 0.7 | +17.9 |
| PV + BA | 1 | 3.2 | 49.4 | 0.9 | +0.4 |
| | 3 | 11.4 | 53.0 | 1.0 | +7.7 |
| | 5 | 22.9 | 56.4 | 0.5 | +14.6 |
| PV + BX | 1 | 4.3 | 52.6 | 4.3 | +6.9 |
| | 3 | 14.8 | 57.6 | 0.5 | +17.1 |
| | 5 | 23.1 | 59.4 | 0.5 | +20.7 |
| SV + untreated | – | – | 8.4 | 1.1 | – |
| SV + SP | 1 | 4.2 | 11.0 | 0.1 | +30.9 |
| | 3 | 14.5 | 12.4 | 0.5 | +47.6 |
| | 5 | 16.4 | 13.2 | 0.1 | +66.7 |
| SV + BA | 1 | 3.2 | 9.6 | 1.5 | +14.3 |
| | 3 | 11.4 | 11.6 | 0.5 | +38.1 |
| | 5 | 22.9 | 12.2 | 0.4 | +45.2 |
| SV + BX | 1 | 4.3 | 9.4 | 0.9 | +11.9 |
| | 3 | 14.8 | 11.4 | 0.5 | +35.7 |
| | 5 | 23.1 | 13.0 | 0.6 | +54.8 |

[a] SP = sodium perborate; BA = boric acid; BX = borax; PV = polyurethane varnish; and SV = synthetic varnish.
[b] Results reflect observations of five wood specimens.
[c] SD = standard deviation.

*Table 3. — Gloss values of Calabrian pine pretreated with borates before polyurethane and synthetic varnish coating.*

| Chemicals and varnish[a] | Concentrations | Retention | Mean[b] | SD[c] | Change |
|---|---|---|---|---|---|
| | (%) | (kg/m$^3$) | | | (%) |
| PV + untreated | – | – | 89.1 | 1.7 | – |
| PV + SP | 1 | 4.2 | 94.0 | 0.4 | +5.5 |
| | 3 | 14.5 | 95.5 | 0.2 | +7.2 |
| | 5 | 16.4 | 96.6 | 0.1 | +8.4 |
| PV + BA | 1 | 3.2 | 92.1 | 1.2 | +3.4 |
| | 3 | 11.4 | 94.9 | 0.4 | +6.4 |
| | 5 | 22.9 | 96.8 | 0.6 | +8.7 |
| PV + BX | 1 | 4.3 | 91.4 | 1.0 | +2.6 |
| | 3 | 14.8 | 94.4 | 0.4 | +5.9 |
| | 5 | 23.1 | 97.0 | 0.3 | +8.9 |
| SV + untreated | – | – | 57.8 | 2.1 | – |
| SV + SP | 1 | 4.2 | 64.7 | 0.7 | +11.9 |
| | 3 | 14.5 | 70.5 | 0.9 | +22.0 |
| | 5 | 16.4 | 73.4 | 0.8 | +27.0 |
| SV + BA | 1 | 3.2 | 62.8 | 1.8 | +8.6 |
| | 3 | 11.4 | 67.4 | 0.4 | +16.7 |
| | 5 | 22.3 | 71.8 | 1.2 | +24.3 |
| SV + BX | 1 | 4.3 | 61.1 | 4.5 | +5.7 |
| | 3 | 14.8 | 69.9 | 1.0 | +20.9 |
| | 5 | 23.1 | 74.8 | 0.4 | +29.5 |

[a] SP = sodium perborate; BA = boric acid; BX = borax; PV = polyurethane varnish; and SV = synthetic varnish.
[b] Results reflect observations of five wood specimens.
[c] SD = standard deviation.

## Conclusion

The results of this study indicated that borate preimpregnation enhanced surface hardness and gloss of the wood surface. But, adhesion values of wood pre-impregnated with borates before varnish coating were lower than only varnish coated wood. Higher concentration levels of borates resulted in lower adhesion, higher surface hardness, and higher gloss of the wood surface.

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