# The Effect of Liquid Nitrogen on Retention in Uludağ Fir Wood Treated with Boric Acid and Borax

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**Abstract**

In this study, the effect of liquid nitrogen on retention of Uludağ Fir wood after exposure to boric acid and borax was determined. Before treating with liquid nitrogen, specimens were conditioned to 4 different moisture contents (oven dry, 12%, 28%, and green). Liquid nitrogen treated specimens for 1 hour, 4 hours and 10 hours. Then, all specimens were conditioned to 12% moisture content (MC). Test specimens were exposed to chemicals such as borax and boric acid for three times: short (2 min), normal (1 hour) and long (1 week). Dipping method was used for the impregnation process. For control, specimens were treated with borax and boric acid without treating with liquid nitrogen. Consequently, there is a linear relationship between moisture content and retention. Since moisture content increases the amount of retention increases as well.

**Key words**: Retention, liquid nitrogen, impregnate chemicals, Uludağ Fir

## Introduction

Throughout history, the unique characteristics and comparative abundance of wood have made it a natural material for homes and other structures, furniture, tools, vehicles, and decorative objects. Today, for the same reasons, wood is prized for a multitude of uses (Wood Handbook, 1999).

Dry wood undergoes small changes in dimension with normal changes in relative humidity. More humid air will cause slight swelling, and drier air will cause slight shrinkage. These changes are considerably smaller than those involved with shrinkage from the green condition (Wood Handbook, 1999).

All wood is composed of cellulose, lignin, hemicelluloses, and minor amounts (5 to 10%) of extraneous materials contained in its cellular structure. Variations in the characteristics and volume of these components and differences in cellular structure make woods heavy or light, stiff or flexible, and hard or soft. The properties of a single species are relatively constant within limits; therefore, selection of wood by species alone may sometimes be adequate. However, to use wood to its best advantage and most effectively in engineering applications, specific characteristics or physical properties must be considered (Wood Handbook, 1999).

Borates have several great advantages as wood preservatives as well as imparting flame retardancy, providing sufficient protection against all forms of wood destroying organisms, have low mammalian toxicity and low volatility, they are moreover colorless and odorless (Murphy, 1990; Yalinkilic et al., 1999; Drysdale, 1994, Chen et al., 1997).

Borax tends to reduce flame spread but can promote smoldering or glowing. On the other hand, boric acid suppresses smoldering but has little effect on flame spread. Therefore, these compounds are normally used together (Baysal, 1994; Hafizoglu et al., 1994).

Boric acid and borax are the most common boron compounds that have found many application areas in the wood preservation industry. Both can be used to obtain Uludağ Fir retardant characteristics (Hafizoglu et al., 1994).

The hygroscopic nature of boron salts may have an adverse effect on dimensional stability of wood under humid service conditions and can cause strength losses at elevated temperatures at high retention levels (Yalinkilic et al., 1995a).

There is no study on applying liquid nitrogen (LN) to wood materials in literature therefore it was the first study on its use to applied wood.

The major objective of this study was to determine the effect of liquid nitrogen on retention in Uludağ Fir wood treated with boric acid and borax.

## Material and Method

### Wood Species

Uludağ Fir (*Abies bornmülleriana* M.) was chosen randomly. A special emphasis was put on the selection of wood material. Accordingly, non-deficient, proper, knotless, normally grown (without zone line, reaction wood, decay, insect and fungi damages) wood materials were selected.

**Liquid nitrogen**

Nitrogen gas composes 78% of the Earth's atmosphere. It is a colorless, odorless and non-flammable gas. It is used in the electrical industry, producing chemicals safely, the food packaging industries and in the drying and preparation of refrigeration systems. Nitrogen gas is also used in; at temperatures below - 196 $^{o}$C, nitrogen is a liquid. When liquid nitrogen comes into contact with objects at room temperature it boils rapidly from the heat energy emitted by the objects.

**Preparation of experimental samples**

Before treating to liquid nitrogen, specimens (2×2×2 mm) were conditioned to 4 different moisture contents (oven dry, 12%, 28% and green). Liquid nitrogen had treated the specimens for 1 hour and 1 week. After treating liquid nitrogen, the samples were conditioned to 12%MC at 20±2 °C and at 65±3% relative humidity until their weights became stable in the conditional room. Impregnation processes stated at ASTM D 1413-76, TS 344 and TS 345 was applied to the prepared test samples. For this aim, the samples were dipped into impregnation solution such as boric acid and borax at 5% concentration for three times: short term (2 min), normal term (1 hour) and long term (1 week), respectively. Peculiarities of impregnation were determined before and after the processes. All processes were carried out at 20±2 °C. The samples, oven-dried before and after impregnation, were calculated by using the formula (3).

$$R = \frac{GC}{V} \times 10^3 \text{ kg}/\text{m}^3,$$

Where $R$ is the retention of impregnation material, $G = T_2 - T_1$, $T_1$ is the sample weight before impregnation (g), $T_2$ is the sample weight after impregnation (g), $C$ is the concentration (%) and $V$ is the volume of samples ($cm^3$).

Impregnated test samples were kept at 20±2 °C and at 65±3% relative humidity until their weights became stable.

They have been used two different exposing liquid nitrogen times, four different MCs, three different exposing impregnate chemicals and 5 repetitions for each factor. For the control samples, five repetitions with a total of 135 samples (2×4×3x5+5x3) were prepared for the steam test. Multiple variance analysis (Table 2) was used to determine the differences among the test groups. The Duncan tests were conducted to determine the importance of differences between the groups (Table 3 and 4).

**Results and Discussion**

The average air-dry density of Uludağ Fir samples is 0.408 g/cm3.

The quantities of retention due to liquid nitrogen time and impregnation period are shown in Table 1.

Table 1. Retention amount of Uludağ Fir (kg/m$^3$)

| Liquid Nitrogen Time | Moisture Content | Borax | | | Boric acid | | |
|---|---|---|---|---|---|---|---|
| | | 2 min. | 1 hour | 1 week | 2 min. | 1 hour | 1 week |
| 1 Hour | 0% | 10.45 | 11.32 | 13.32 | 10.92 | 11.69 | 14.52 |
| | 12% | 11.30 | 12.09 | 13.00 | 11.69 | 12.64 | 13.25 |
| | 28% | 10.11 | 11.68 | 12.58 | 11.57 | 11.84 | 13.25 |
| | Green | 11.84 | 12.58 | 12.46 | 10.80 | 11.32 | 13.31 |
| 16 Hours | 0% | 11.62 | 12.84 | 13.31 | 10.83 | 11.05 | 14.66 |
| | 12% | 10.75 | 11.33 | 12.09 | 10.45 | 11.43 | 13.70 |
| | 28% | 10.77 | 11.33 | 13.25 | 10.45 | 11.43 | 13.71 |
| | Green | 10.83 | 12.05 | 13.31 | 10.92 | 11.62 | 14.53 |
| Control | | 7.99 | 8.86 | 10.73 | 7.67 | 8.12 | 10.80 |

The lowest retention (10.11 kg/m$^3$) in samples exposed to borax was obtained in those with 1-hour LN exposure time, 28 %MC and 2 min short-term dipping with borax; the highest retention (13.32 kg/m$^3$) was in samples with 1 hour LN exposure time, 0%MC and 1 week long-term dipping with borax.

The lowest retention (10.45 kg/m$^3$) in samples exposed to boric acid was obtained in samples with 16 hour LN exposure time, 12 %MC and 2 min short-term dipping with boric acid; the highest retention (14.53 and 14.52 kg/m$^3$) was in samples with 16 hours LN exposure time, green MC and 1 week long-term dipping with boric acid.

The multiple variances analyze applied on the data obtained from the LN time, moisture content, impregnation chemicals, and impregnation time is shown in Table 2.

Table 2. The multiple variance analyze values

| Source | Type II Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Factor A | 704.392 | 2 | 352.196 | 20396.78 | 0.000 |
| Factor B | 3.212 | 3 | 1.071 | 62.002 | 0.000 |
| Factor C | 0.218 | 1 | 0.218 | 12.6 | 0.000 |
| Factor D | 438.037 | 2 | 219.018 | 12684.05 | 0.000 |
| A*B | 10.151 | 6 | 1.692 | 97.979 | 0.000 |
| A*C | 6.842 | 2 | 3.421 | 198.11 | 0.000 |
| B*C | 1.958 | 3 | 0.653 | 37.793 | 0.000 |
| A*B*C | 10.348 | 6 | 1.725 | 99.886 | 0.000 |
| A*D | 11.794 | 4 | 2.948 | 170.755 | 0.000 |
| B*D | 6.113 | 6 | 1.019 | 59.007 | 0.000 |
| A*B*D | 10.562 | 12 | 0.88 | 50.975 | 0.000 |
| C*D | 18.003 | 2 | 9.002 | 521.309 | 0.000 |
| A*C*D | 4.032 | 4 | 1.008 | 58.376 | 0.000 |
| B*C*D | 4.435 | 6 | 0.739 | 42.804 | 0.000 |
| A*B*C*D | 9.267 | 12 | 0.772 | 44.724 | 0.000 |

Factor A = LN Time, Factor B = Moisture Content, Factor C = Impregnation chemicals, Factor D = Impregnation Time

According to the variance analysis, the effects of LN time, moisture content, impregnation chemicals, and impregnation time were statistically significant. The interaction between factors was statistically identical ($p \leq 0.05$).

The results of Duncan tests were conducted to determine the importance of the differences between groups (Tables 3 and 4).

Table 3. Duncan test results for liquid nitrogen (kg/m$^3$)

| Factors | Mean | HG |
|---|---|---|
| Control | 9.03 | a |
| 16 Hours-%12 MC | 11.62 | b |
| 16 Hours-%28 MC | 11.79 | bc |
| 1 Hours-%28 MC | 11.84 | bc |
| 16 Hour-Green | 11.94 | bc |
| 1 hours-Green | 12.01 | bc |
| 1 Hour-%0 MC | 12.04 | bc |
| 1Hour-%12 MC | 12.33 | c |
| 16 Hours-%0 MC | 12.38 | c |

The lowest value was obtained for the control samples (9.03 kg/m$^3$); and the highest value (12.38 kg/m$^3$) was obtained from group of samples 16 hours exposed to LN with 0% MC.

Table 4. Duncan test results for impregnation (kg/m$^3$)

| Factors | Mean | HG |
|---|---|---|
| Boric acid- 2 min. | 9.86 | a |
| Borax - 2 min. | 9.97 | a |
| Boric acid- 1 Hour | 10.39 | ab |
| Borax - 1 Hour | 10.79 | b |
| Borax - 1 Week | 12.19 | c |
| Boric acid- 1 Week | 12.85 | d |

The highest value (12.85 kg/m$^3$) for impregnation chemicals was obtained in the group of samples treated 1 week with boric acid; the lowest value (9.86 kg/m$^3$) was obtained in the group of samples treated 2 min. with boric acid.

## Conclusion

The highest value for impregnation chemicals was obtained in the group of samples exposed to boric acid after long-term exposure to LN. The lowest value was found in the group of samples treated with boric acid after short-time exposure to LN. The lowest value was obtained from the control samples (9.03 kg/m$^3$); and the highest value (12.38 kg/m$^3$) was obtained in the group of samples exposed for 16 hours to LN with 0% MC.

The retention amounts were enhanced while increasing the LN time and dipping time period.

Generally, the retention amount in the group of samples treated with borax was 30.62%; in the group of samples treated with boric acid the mean retention was 38.13%, being much bigger than in the control group samples. For 1 hour exposure to LN, the average value of all treated with borax was 30.30% and treated with boric acid was 39.53%, being also bigger than the control samples.

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