# Exploring Methods for Prevention of Oxidative Stain in Soft Maple

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# Abstract

Interior gray enzymatic oxidative stain for white woods such as maple has plagued the wood industry for many years because methods that have been found to reduce stain are hard to scale up to industrial levels. We examined possible alternative treatments to eliminate stain in soft maple (*Acer rubrum* L.), and found that exposure to sulfur dioxide gas eliminates interior gray stain and that staining might occur at different temperatures depending on the age of the logs. Comparing sawn and split boards showed that both eliminated surface stain, but sawing eliminated it to a greater depth. A mild kiln schedule also seems to reduce staining, and this solution may be easier and more economical to implement on an industrial scale, both domestically and internationally, because no other processing is required.

Keywords: soft maple, enzymatic stain, gray stain, interior stain, oxidative stain, sulfur dioxide

# Acknowledgments

# Contents

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## Introduction

A previous research note (Wiemann and others 2007) reported on possible methods to reduce the severity of non-microbial, enzymatic, oxidative stain in the sapwood of Bolivian ochoó (*Hura crepitans* L.) (Fig. 1), as stain is one of the most important utilization problems encountered among Bolivian timber species. A similar, but less severe, oxidative stain is common in the wood of soft maple (*Acer rubrum* L.) (Fig. 2). The basic specific gravity of soft maple (0.49) is only slightly greater than that of ochoó (0.41), and both species are diffuse-porous, so we decided that soft maple would be a good species to study for insights into the origin and control of oxidative stain as it occurs in the Bolivian species. This research paper reports on treatments used on soft maple and the effects of those treatments.

Non-microbial stains are caused by granules in living parenchyma that become pigmented when exposed to heat. In some tests on sapwood species in the United States, treatments using fumigants, strong reducing agents, microwaves, ultrasonic probes, vibration, and mechanical compression caused by rollers or hammers resulted in unstained areas (Forsyth and Amburgey 1992a,b). Schmidt and Amburgey (1994) found a gray-blue stain in untreated sapwood, but stain-free sapwood when parenchyma had been killed by fumigation with methyl bromide, and Amburgey and Kitchens (1997a,b, 1999) received patents for control of non-microbial sapwood stains using methods (compression and vibration) that killed parenchyma prior to drying. Denig and others (2000) recommend using the same techniques that

are effective in preventing sticker stain; these include drying rapidly, avoiding high kiln temperatures, and maintaining good airflow. In Denig and others (2000), the recommended drying schedules for ochoó and white soft maple call for temperatures of 43 to 54 °C in the early stages of drying. Yeo and Smith (2004) compared sapwood color changes in hard maple (*Acer saccharum* Marsh.) dried using a series of temperature and moisture content combinations; they found that if the drying temperature were kept below 43 °C while the wood moisture content was above fiber saturation, they could eliminate oxidative stain. Rappold and Smith (2004) compared a conventional schedule for hard maple (temperature range 54 to 82 °C) with a low temperature schedule (temperature range 43 to 71 °C); they produced stain-free wood at low temperatures but not at high. Following a low temperature kiln schedule may be difficult when the ambient temperature is high, such as in the tropical lowlands where ochoó is prevalent, and it may be necessary to use dehumidification kilns to dry the wood stain-free.

In the ochoó study (Wiemann and others 2007) 5-cm-thick, random-width boards, each containing a significant amount of sapwood, were subjected to the following treatments:

1. Control boards were left untreated.
2. Boards were submerged in a 5% sodium metabisulfite ($Na_2S_2O_5$) bath for 5 min then stacked on a plastic sheet. After submergence of all the samples, the remaining sulfite solution was poured over the dead-piled boards and they were wrapped with the plastic sheet to keep them wet for 18 h.



**Figure 1—Ochoo boards severely affected by oxidative stain (left) and unaffected by stain (right).**
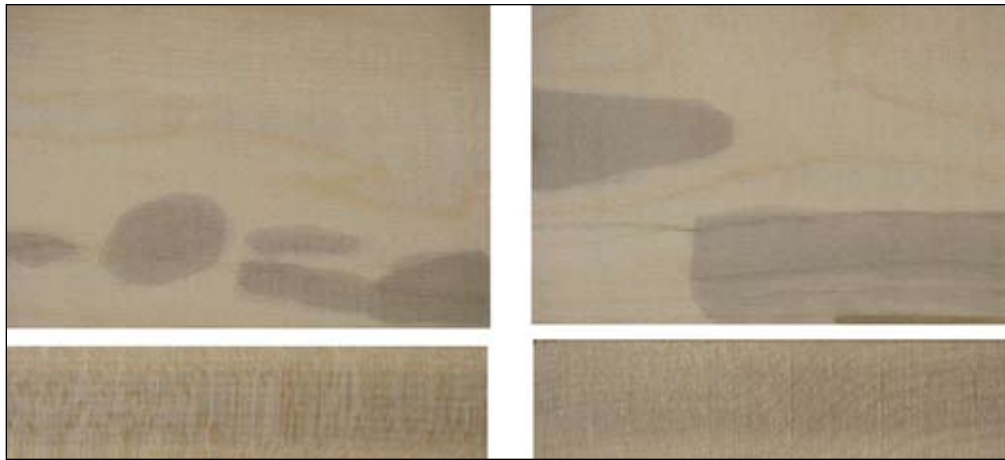
**Figure 2—Soft maple boards (surface, end, edge) showing patches of oxidative stain.**



**Figure 3—Surface of ochoó board hit with hammer, then cut open to expose extent of discoloration.**



**Figure 4—Cross sections of boards that were treated in sulfite solution. Note that some boards have discolored centers, others have little or no discoloration.**

3. Boards were hit on the end (cross section) 10 times with a sledge hammer (3-kg head, 22-cm handle).
4. Boards were hit on one surface with the 3-kg sledge hammer.
5. Boards were held for 15 s against a Peavey PV-1.3K speaker (Peavey Electronics Corporation, Meridian, Mississippi) blaring loud music.
6. Boards were dropped from a height of 4 m onto a concrete sidewalk.

Following treatment, the boards were kiln dried, stored in a workshop for three weeks, then evaluated for color. Each board was cross-cut, and the cross sections were evaluated for degree of staining. The staining was rated from 1 (slight or none) to 4 (completely discolored), and the thickness of non-discolored wood was measured. Many boards were completely discolored across their entire cross sections, but it was common for a board surface to be white to a depth of a few millimeters yet have severe staining in the center. We proposed two explanations for stain-free surfaces: rapid surface drying and mechanical action of the saw blade.

In ochoó, surface hammering produced a localized absence of discolored wood (Fig. 3), but other shock treatments (end hammering, dropping boards onto a hard surface, and exposing them to the vibration of loud music) were not effective. Eighteen-hour treatment with a 5% solution of sodium metabisulfite reduced stain, although the penetration was limited in many samples (Fig. 4). The effects of all the treatments compared with an untreated control are shown in Figure 5.

## Research on Soft Maple

The purpose of this research project was to determine if treatments applied prior to kiln drying could eliminate or reduce oxidative stain in maple. Treatments included sawing compared with splitting (to compare surfaces exposed with and without saw blade impact), exposure to sulfur dioxide gas for various lengths of time (to compare with the sulfite solution treatments of ochoó), pounding board surfaces with

**Figure 5—Cross sections of dried ochoó sample boards.**

a hammer (to compare with the markings that this treatment caused in ochoó), exposure to air horn vibration, freezing samples in dry ice or microwaving them, and exposing surfaces to electrical shocks using a Tesla coil. The objective of these treatments was to determine if they might disrupt the wood parenchyma and affect the amount of staining. Furthermore, consideration of split rather than sawn surfaces is of practical value because most veneer is produced using a splitting process.

# Methods

Possible explanations for the lack of surface staining are rapid surface drying and surface trauma from sawing. To test the trauma explanation, some boards were rip-sawn and immediately spring-clamped together, and others were split to half their length using a froe (and thus not subjected to saw blade trauma), then spring-clamped. The reason for clamping was to keep the two halves air-tight so they would not be subject to rapid surface drying. After kiln drying, the boards that were split halfway were split for the rest of their

length and the split surfaces were examined for presence of stain. Figure 6 shows a board that had been split to half its length, spring-clamped (note holes for the clamp rods), split for the rest of its length after drying, then planed to determine if stain was present below the exposed surface.

The treatment and drying of mill-run, 4/4 (2.5 cm) soft maple was carried in two phases. Two 3-m logs from the same tree, log 1 and log 2, were cut and delivered on October 5, 2007. Log 1 was sawn on October 11, and log 2 was wrapped in stretchable packaging plastic and stored indoors until it was sawn on December 11. In addition to the planned treatments, several unplanned treatments (listed below) were tried on log 2. The processing of the logs was as follows.

### Log 1

- Log 1 was sawn into 4/4 lumber on October 11.
- Nine 90-cm-long samples, end-coated with impermeable roofing cement, were prepared from the sapwood lumber produced.
  - $F_{11}$, $F_{12}$, and $F_{13}$ (froe) were split in width for half their length down the center of each board.
  - $R_{11}$, $R_{12}$, and $R_{13}$ (rip) were ripped in width end-to-end down the center of each board.
  - $C_{11}$, $C_{12}$, and $C_{13}$ (controls) were untreated.

The halves of the froe and rip samples were immediately clamped tightly together using threaded rods with spring mechanisms to prevent the split/sawn edges from air exposure. The treatment and control boards, as well as a complement of 4/4 hard maple boards, were loaded into a dry kiln on October 12 in such a manner that two of the control boards ($C_{11}$ and $C_{13}$) could be removed daily. The maple charge was kiln-dried between October 12 and 24 using a proprietary schedule for soft and hard maple. The initial moisture content of sample $C_{13}$ was determined from two 3-cm moisture content samples, its ovendry weight was calculated, and it was used to track moisture content. Each day



**Figure 6—Board split with froe prior to clamping, storage, and drying, then edge-planed after drying to reveal depth at which discoloration begins. Note that the split surface at the right end is unstained, but that planing exposes interior stain.**

**Table 1—Summary of treatments and results [a]**

| Treatment | Split or ripped surface | Comments |
|---|---|---|
| Log 1—Processed immediately | | |
| Split "before" | No stain | Planing split surface exposed stain |
| Split "after" | Stain | |
| Ripped | No stain | Planing ripped surface exposed stain |
| Control $C_{11}$ | n/a | Internal stain began when temperature rose above critical temperature |
| Log 2—Stored | | |
| Split "before" | No stain | Planing split surface exposed stain |
| Split "after" | Stain | |
| Ripped | No stain | Planing ripped surface exposed stain |
| Control $C_{21}$ | n/a | Stain began when temperature rose above critical temperature |
| Sulfur dioxide | n/a | No stain; wood significantly whiter |
| Freeze | n/a | Planing exposed stain |
| Microwave | n/a | Planing exposed stain |
| Horn | n/a | Planing exposed stain |
| Tesla | n/a | Planing exposed stain |

[a] The board surfaces of all treatments were unstained.

a 2.5-cm segment was removed from $C_{11}$ (12 segments) to monitor the progress of stain development, and the exposed board end was recoated with roofing cement each time to prevent end effects.

## Log 2

Log 2 was wrapped in stretchable packaging plastic and stored at 20 °C, 36% RH for 18 days, then at 21 to 23 °C, 23% RH for 42 days, until it was sawn into 4/4 lumber on December 11.

Nine 75-cm-long sapwood lumber samples, end-coated with impermeable roofing cement, were prepared as follows:

- $F_{21}$, $F_{22}$, and $F_{23}$ (froe) were split for half their length down the center of each board.
- $R_{21}$, $R_{22}$, and $R_{23}$ (rip) were ripped end-to-end down the center of each board.

The split and ripped samples were immediately clamped tightly together (to exclude air) using threaded rods with spring mechanisms.

- $C_{21}$ and $C_{22}$ (controls) were untreated.
- $H_{21}$ (hammer) was struck five times with blows 6 cm apart using a hammer with a 450-g head.

Ten 30-cm-long sapwood samples were cut, end-coated, and treated as follows:

- $S_{21}$, $S_{22}$, and $S_{23}$ (sulfur dioxide) were placed in plastic bags, which were then filled with anhydrous sulfur dioxide gas and sealed. $S_{21}$ was exposed for 30 min, and $S_{22}$ and $S_{23}$ were exposed for 16 h.

- $Fr_{21}$ and $Fr_{22}$ (freeze) were placed in a plastic cooler, covered with dry ice, and the cooler was sealed for two days.
- $M_{21}$, $M_{22}$, and $M_{23}$ (microwave) were microwaved for 15, 30, and 240 s, respectively.
- $Hrn_{21}$ (horn) was held against an air horn that was sounded for 30 s.

One 50-cm-long sapwood board, $T_{21}$ (Tesla), was marked at 2.5-cm intervals and was exposed at each mark to the electrical discharge of a Tesla coil as follows:

- 1 cm from board surface for 10 s (4 passes along line)
- 1 cm from board surface for 30 s (3 replicas, 9-11 passes along lines)
- 2 cm from board surface for 10 s (3 passes along line)
- 2 cm from board surface for 30 s (3 replicas, 12 passes along lines)
- Contact with board surface for 10 s (2 replicas, 3 passes along lines)
- Contact with board surface for 20 s (3 replicas, 5-6 passes along lines)
- Contact with board surface for 30 s (3 replicas, 9-11 passes along lines)

These treatment and control boards, as well as a complement of 4/4 hard maple boards, were loaded into a dry kiln on December 13 in such a manner that the control boards ($C_{21}$ and $C_{22}$) could be removed daily. The maple charge was dried between December 13 and 26 using the same schedule used for log 1. The initial moisture content of sample $C_{22}$ was determined from two 3-cm moisture content samples, its ovendry weight was calculated, and it was used to track moisture content. Each day one 2.5-cm section was

removed from $C_{21}$ (14 sections) to monitor the progress of drying and stain development, and the exposed board end was recoated with roofing cement before its re-insertion into the kiln charge.

## Results

The controls $C_{11}$ and $C_{21}$ from logs 1 and 2 showed interior gray staining after kiln temperatures were raised. During kiln drying, the staining became progressively worse with time and temperature increase. The interior gray staining began sooner in boards from log 2 (the stored log) than in boards from log 1, although the initial staining was less severe.

For both logs, the samples that were ripped, split with the froe, subjected to the air horn, frozen using dry ice, microwaved, and exposed to the electrical discharge all showed interior stain. Table 1 shows the summary of the treatments and results. The samples from log 2 (the stored log) showed more stain than those of log 1. Stain was interrupted at the interior split and sawn surfaces, with sawing producing stain-free wood to a greater depth than splitting. The samples that were exposed to the sulfur dioxide gas were all whiter in color than the controls or the samples subjected to other treatments (Fig. 7). The samples that were struck with a hammer showed the outlines of the hammer head very clearly as dark-stained areas (Fig. 8). The stain was 2.5 cm in diameter (the diameter of the hammer head) and reached a depth of 0.5 cm (Fig. 9).

## Discussion

No boards showed surface staining, but removing the unstained surfaces exposed stained wood. Because stain was interrupted by split and sawn surfaces that were not exposed to air during drying, trauma probably plays some role.

Staining was initiated in the soft maple lumber when the threshold temperature was exceeded. At the beginning of drying, the kiln temperature was insufficient to induce staining anywhere. Although drying was slow, the surfaces dried below the moisture content necessary to induce staining, but the inner wood still had a high moisture content. When the threshold temperature is reached, staining begins in the high-moisture content wood. At some depth beneath the board surfaces (approximately 2 mm in our samples), the temperature and the moisture content are high and staining begins. Staining also occurs in the center of the board. Figure 10 shows the resultant pattern, which occurred in both logs. The zones of unstained and stained wood have the following approximate thicknesses measured across the 25-mm thicknesses of the boards:

- Unstained    2 mm
- Stained    5 mm
- Unstained    4 mm
- Stained    3 mm (center of board)
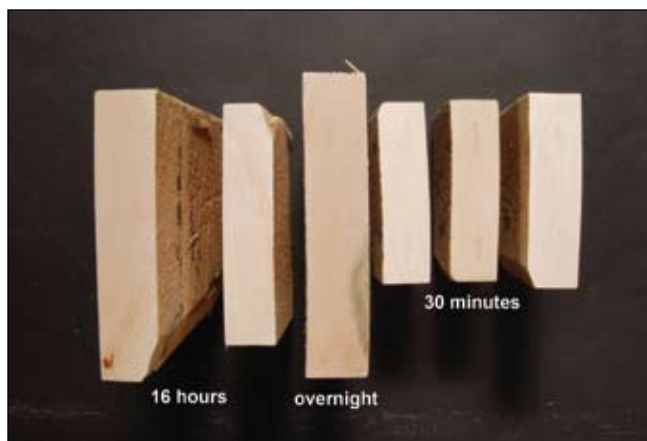- Unstained    4 mm



**Figure 7—Boards treated with sulfur dioxide.**



**Figure 8—Surface of maple board hit with hammer, then cut open to expose extent of discoloration.**

- Stained    5 mm
- Unstained    2 mm

By the following day, the 4-mm wide unstained ring also became stained (Fig. 11.) Why staining occurs in the center of the boards, surrounded by a ring of unstained wood, is puzzling. Study of the staining pattern will be an objective of future research.

Treatment with sulfur dioxide gas produced wood free of stain, even with a treatment time of only 30 min. Sulfite treatment also produced a high percentage of white wood in ochoó, although the soak treatment in ochoó was not as effective as gas treatment in maple.

The dark-stained areas marking the hammer impacts in maple (Figs. 8 and 9) are especially interesting, inasmuch as the effect is opposite that produced by striking the ochoó (Fig. 3), in which the impact caused an unstained region surrounded by stained wood. This is difficult to explain, but below we present a hypothesis.

Possibly staining involves oxidation of starch. Starch can be produced from cellulose through enzymatic action with a process that is a function of both temperature and time. A long period at low temperature may have the same effect as a short period at high temperature. Furthermore, the molecular weight of the starch polymers (and thus, their activity) may also be a function of the time and temperature of exposure to enzymes. A hammer blow early (in a fresh log, as

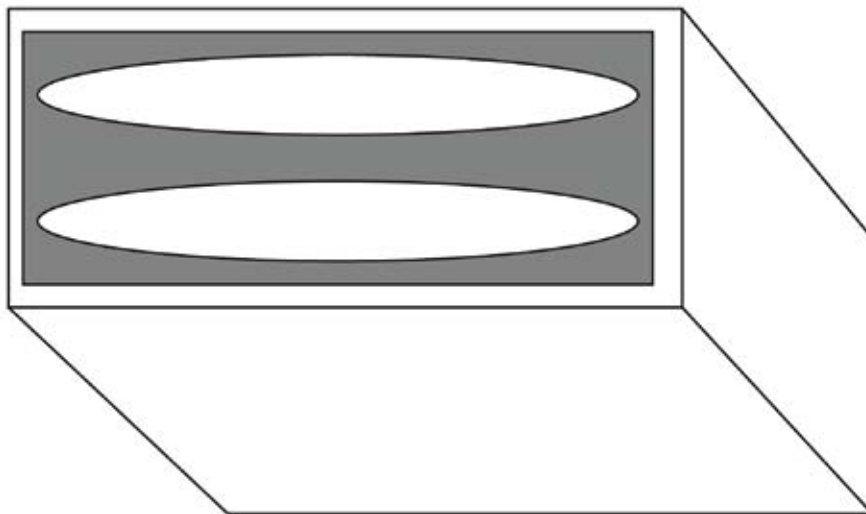**Figure 9—Hammered maple board cut open to expose extent of discoloration.**



**Figure 10—End-grain view showing ring of stained wood in log 2, specimen 4; photo and schematic.**



**Figure 11—End-grain view showing center of board completely stained in log 2, day 5.**

6

in our experiment with ochoó) might open the parenchyma cells, quenching the developing metabolite (enzyme). In the areas not affected by hammer impact (untraumatized areas), the enzyme continues to form, digests some cellulose to form starch globules, and these starches can further react to form chromophores that produce the pigmentation when a threshold temperature is reached, resulting in stained wood. A hammer blow late (in an aged log, as in our experiment with soft maple) would also open the parenchyma cells. In this case, however, the parenchyma has been forming enzymes and starch during the period of storage. All the wood might stain when it reaches the threshold temperature, but the impacted areas might release more chromophores because of bruising, resulting in deeper pigmentation.

## Conclusions and Recommendations for Drying Soft Maple and Ochoó

Use of sulfur dioxide gas was effective in eliminating stain, but an air-tight chamber is needed for effective treatment. The gas is very noxious, and a long period of out-gassing is necessary before personnel can safely handle the boards. Therefore, it would probably not be an economical solution.

Stain did not occur when the kiln temperature was below a critical value. Low-temperature drying might be an acceptable drying technique if other forms of degradation (such as fungal attack) can be controlled. The most reasonable solution will probably be prompt handling and the use of a low-temperature kiln schedule that allows the wood to dry below the fiber saturation point prior to increasing temperatures above the critical value.

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